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Quantifying Vegetation on a Rock-Ramp Fishway for Fish Run-Up and Habitat Enhancement: The Case of the Miyanaka Intake Dam in Japan

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Abstract: The Miyanaka Intake Dam fishway underwent improvements in 2012, and we established a new rock-ramp fishway called the Seseragi Fishway, cognizant of its utility as a passage and a habitat for bottom-dwelling and small fish with weak swimming ability. However, the fishway is occasionally submerged by floods, causing sediment accumulation that leads to changes in the vegetation composition. In addition, the arrival and inflow of seeds from upstream and the surrounding areas result in vegetation changes. In this study, the inside and outside of the rock-ramp fishway were divided into eight areas, and the vegetation succession after 2012 was determined. A correlation was observed between the results of fish catch surveys during the same period and the vegetation. Based on these results, we reported on the process of steadily operating the rock-ramp fishway while devising and improving specific management methods. Changes in vegetation, such as an increase in upright vegetation and a decrease in flow-obstructing vegetation, contributed to an increase in the population of bottom-dwellers, weak swimmers, and juvenile fish. The existence and management of appropriate vegetation are important for maintaining fishways inhabited by a variety of fish species.

Keywords: bottom-dwelling fish; obstruction of flow path; flow rate; riparian management; vegetation coverage; vegetation succession

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1. Introduction

River channel continuity is an essential requirement for migrating fish [1–5], but is threatened by the modification of rivers, such as the construction of dams and weirs [6–15]. A fishway is one of the solutions to these problems [3,16–23]. Fishways have been developed for various fish species globally, including salmonids, such as *Salmo salar* and *Oncorhynchus* spp., which are of commercial importance in many parts of the world [21,24–32]. These fishways are mostly made up of several concrete walls, bottoms, and deceleration plates to reduce the flow velocity inside the fishway [33].

They are sufficient for large salmonids, targeted in Europe and the United States [29,34–38]. However, their high flow rates make it difficult for many fish species, as well as invertebrates, to move upstream [39–43] or to use them as their habitats [44,45].

Fishways for large varieties of fish have been tested based on the biological, hydraulic, and other physical parameters involved [46]. Coarse bed materials, such as rocks and boulders, are important for several bottom-dwelling fish species, as well as invertebrates [29,47–52], and are suitable for the construction of rock-ramp fishways in addition to technical fishways [28].

However, in contrast to technical fishways, vegetation can colonize a rock-ramp fishway more efficiently due to the accumulation of fine sediment and dammed-up water along the fishway. It may be necessary to accommodate changing conditions in the fishway over time, not only hydrological conditions but also vegetation growth [53]. Thus, a rock-ramp fishway requires specific maintenance management that differs from that of other constructed fishways with no vegetation inside. Normal staircase-type fishways were installed in 1939 on the right bank side of the Miyanaka Intake Dam at the Shinanogawa Power Station in Tokamachi City, Niigata Prefecture, Japan. A rock-ramp fishway was newly constructed in 2012 to accompany the previous ones [54]. The rock-ramp fishway was effective at accommodating bottom-dwelling fish species such as *Cobitis biwae* and *Rhinogobius kurodai*, and small fish with weak swimming abilities, such as *Pseudorasbora parva* and *Micropterus salmoides*, both as a path of the dam or as their primary habitat [44,45,55,56].

The rock-ramp fishway was completed in March 2012 as part of structural improvements to the fishway. Subsequent surveys in the fishway and upstream and downstream of the dam confirmed a significant increase in the population of fish with weak swimming ability and bottom-dwelling fish upstream and downstream of the dam [54]. The increase was probably due not only to the gentle slopes (gradient 1/200, drop 0.50 m per step) and resting pools but also to vegetation that did not exist in large and small fishways. Despite the benefits of fishway vegetation, such as attracting aquatic insects that fish feed on, providing shade and hiding places, and improving harmony with the surrounding landscape, no plants were growing. Furthermore, the riverbed was covered with rocks, and no fine sediment had accumulated yet as a substrate for plants. However, in the summer of 2012, *Bidens frondosa* overgrew to the extent that it inhibited the flow path of the rock-ramp fishway. However, after its removal in 2013, the abnormal overgrowth of *B. frondosa* did not reoccur. Many other plants, whether native or invasive species, naturally grew in and around the rock-ramp fishway. They contributed to the spread of invasive species or the restoration of important endangered species [57–59]. These results indicate that different modes of management are required for a rock-ramp fishway [53]. Although considerable research exists on vegetation management [60–62], none has focused on plants in the fishway and on vegetation management from the perspective of fish and other aquatic organisms' habitat [63–69].

In addition to supplying a habitat for various types of fish, including small fish with low swimming ability and bottom-dwelling fish, this study also focused on the effect of vegetation colonization around the channel and not just the watered zone of the rock-ramp fishway. There are many papers on the construction of rock-ramp fishways (e.g., [70–72]), most of which are concerned with river-bed materials and flow regimes. Here, we report on the vegetation management conducted at the fishway of Miyanaka Intake Dam based on the concept of adaptive management, focusing on the formation of and secular change in vegetation, effects of external pressure on vegetation, and types of plants that influence the creation of fish habitats. Thus, our findings will have broad applicability beyond the case study that we present here and provide insights for future management of fishways globally.

2. Materials and Methods

2.1. Study Site

The Miyanaka Intake Dam (37°03′57.0″ N, 138°41′50.7″ E) is located about 134 km from the mouth of the Shinano River in Niigata City, which drains into the Sea of Japan. The water accumulated here is used for hydroelectric production for the trains in the Tokyo metropolitan area and the Joetsu Shinkansen. Since 1939, when the Miyanaka Intake Dam was installed, a large fishway (improved from a staircase-type to an ice-harbor type in March 2012) and a small fishway were installed. Then, in March 2012, a rock-ramp fishway was newly established (Figure 1) to contribute to improving biodiversity by providing habitats for and assisting the movement of weak-swimming and bottom-dwelling fish. Various types of fishways were created by changing the overflow depths and flow velocities of the three fishways (Table 1).

Figure 1. Photos of Miyanaka Intake Dam: (**a**) dam and fishway from the downstream side, (**b**) a sector gate at the upstream end of the rock-ramp fishway; the dam end of the sector gate rises by 0.5 m when flooded or when needed for maintenance, the blue arrow indicates the direction of flow, (**c**) rock-ramp fishway and the revetment on the right bank side from the upstream side of the dam, (**d**) the turn-around section of the rock-ramp fishway from the downstream side.

Table 1. Specifications of the three fishways. The ice-harbor-type fishway has a notch for *Oncorhynchus keta*. The stair-type fishway was designed for *Plecoglossus altivelis* and *Tribolodon hakonensis*.

Name		Water Depth (m)	Flow Velocity (m s^{-1})	Flow Rate (m^3 s^{-1})
Ice-harbor type	General	0.24	1.27–1.69	1.637
	Notch	0.39	1.57–2.43	
Stair-type	-	0.13	0.87–1.05	0.133
Rock-ramp type	-	0.08–0.15	0.33–0.64	0.022–0.071

Figure 1a shows the dam and fishway from the downstream side. There are three fishways on the right bank side, and the main flow downstream of the dam is on the left bank side. The large fishway has been improved to an ice-harbor type by narrowing the width from 10 m to 8 m. The small fishway moved in parallel to the vacant 2 m site with the stair-type fishway. The rock-ramp fishway was newly established on the site of the stair-type fishway. A sector gate installed upstream of the rock-ramp fishway keeps the inflow of water constant (Figure 1b). In addition, since the sector gates are closed during floods, the inflow and deposition of sediment from upstream are suppressed. Figure 1c shows the rock-ramp fishway and the revetment on the right bank side from the upstream side of the dam. The channel of the rock-ramp fishway has a meandering shape to reduce the gradient. As shown in Table 1, the underwater cross section is trapezoidal (water surface width 0.7 m, bottom width 0.25 m, slope gradient 1:1.5) to change the water depth and flow velocity in the channel. The area was flooded for the first time by the largest recorded flood in the area due to Typhoon Hagibis in 2019. Figure 1d shows the turning part of the rock-ramp fishway from the downstream side when discharge was about 60 m^3 s^{-1}. This area is flooded relatively frequently due to flooding of 1500 m^3 s^{-1} occurring once a year.

Rocks of approximately 15 cm were placed without fixing as the riverbed material in the rock-ramp fishway. These rocks were the same size as those found in the surrounding natural rivers and, given their large size, they will not flow out of the fishway when the water flow increases, so they will help support biodiversity in the fishway. To maintain the alternately meandering flow patterns, alternate resting pools were constructed by installing a concrete overflow wall diagonally toward the downstream instead of parallel.

To create a fishway similar to a natural mountain stream with repeated shallows and pools, we applied gaps around the unfixed rocks and a trapezoidal channel. As shown in Table 1, water areas with various depths and flow velocities were formed in the rock-ramp fishway. As a result, this fishway is used by bottom-dwelling fish and small fish with weak swimming ability. The fishway was carefully designed based on the balance between the overflow depth and the flow velocity, targeting the fish species indicated, and the required flow rate was measured later.

2.2. Method

2.2.1. Scope and Method of Vegetation Survey

The vegetation growing at the rock-ramp fishway was monitored to develop a management plan for the fishway. Although the fishway was designed to prevent sediment accumulation due to inflow from upstream, some degree of sediment accumulation still occurs in the lower part of the fishway during floods exceeding 3000 m^3 s^{-1}. Figure 2 shows discharge records from 2011 to 2021. Floods of 3000 m^3 s^{-1} and higher occurred six times, with four of these occurring in the last five years. Floods are mainly caused by typhoons and weather disturbances along the Baiu front. When a flood of 1500 m^3 s^{-1} or more occurs, the sediment discharged from the spillway gate accumulates at the entrance of the fishway around the downstream side of the fishway. Fish migration is greatly affected, so it is necessary to remove the earth and sand at the entrance of the fishway. Most of the deposited sediment was removed by heavy machinery each time, although some remained between the rocks.

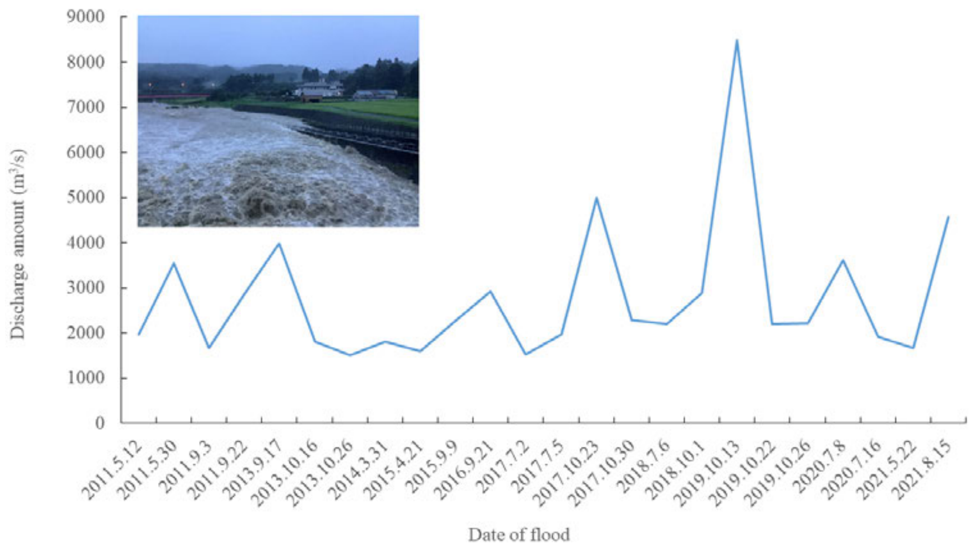


Figure 2. Records of discharges of over 1500 m^3 s^{-1} from 2011 to 2021. The photo shows the situation of approximately 4500 m^3 s^{-1} discharge at the time. The curved section of the fishway was clearly submerged.

The rock-ramp fishway areas were divided into the following four categories with respect to sediment accumulation (Figure 3). Area 1 was a reach, with a 1/200 gradient slope, where sediment did not accumulate, even during floods. Area 3 was a section where sediment was deposited during flooding of more than 5000 m^3 s^{-1}, which occurred once every few years. In these reaches, the channel bed remained covered with the original rocks, with some fine sediment accumulating between them. Area 6 was a curved zone; thus, some sediment was relatively easily deposited during floods of 3000 m^3 s^{-1} or more. In the downstream reach (Area 7), sediment was deposited every year in cases of more than 1500 m^3 s^{-1} flooding.

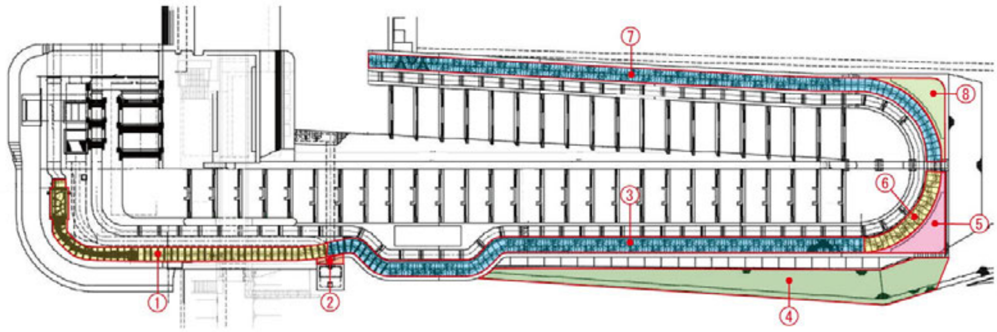


Figure 3. Scope of the vegetation survey. Area numbers were assigned from the upstream side on the left side of the Miyanaka Intake Dam. Areas 1, 3, 6, and 7 were set in the rock-ramp fishway, and Areas 2, 4, 5, and 8 were set around the rock-ramp fishway. Due to the discharge of the maintenance flow rate (40 m^3 s^{-1}), it was always flooded up to the middle of Area 7.

Some spaces were allocated in the areas surrounding the fishway: Area 2, a shaded small section behind the building, and Area 4, a section only with revetments with mortar. Area 5 is a section where stagnant water remains after flowing in from outside, and Area 8 is one where inflow sediment accumulates after more than 3000 m^3 s^{-1} floods, which occur about once every two years. Upon completion of the rock-ramp fishway in the summer of 2012, abnormal overgrowth of *B. frondosa*, an alien species [73], was confirmed at the rock-ramp fishway. Consequently, a detailed vegetation survey was conducted in early summer (6 June) and mid-summer (2 August) of 2013 to assess the vegetation status to determine the best time to remove them in the future. Then, detailed surveys were conducted in early summer (9 June) and mid-summer (8 August) in 2014, and in early summer (23 June) and autumn (28 September) in 2020.

Regarding flood history (Figure 2), a flood of about 4000 m^3 s^{-1} occurred between the 2013 and 2014 surveys. In October 2019, there was a flood of about 8400 m^3 s^{-1}, which was the largest in recorded history (the second largest was about 7400 m^3 s^{-1}, which occurred in 2008). In July 2020, between the June and September surveys, there was a relatively large flood of approximately 3600 m^3 s^{-1}.

Monitoring was conducted visually. Plants were photographed, and the locations of individuals of each species were recorded. Species were mostly identified on site, but some individuals that were difficult to identify were brought back to the laboratory for identification. Changes in plant growth that cause blockages and affect the flow of fishways and the presence or absence of large-scale plant growth were also recorded to explain the advantages and disadvantages of vegetation for fish habitats and migration in rock-ramp fishways. First, plants were classified into annual herbs, perennial herbs, and woody plants according to the revised new edition of "Japanese Wild Plants" [74]. The annual herbs germinate, bear fruit, and die within a year. Annual herbs also include winter annual herbs that germinate in autumn, overwinter, and die the following year. Annual herb stems do not grow lignified. Annual herbs include biennial herbs, which live for multiple years, but flower and fruit only once. A perennial herb survives for many years, and flowers and fruits twice or more during its lifetime. Deciduous perennial herbs overwinter act as rhizomes and regrow in the spring. Evergreen perennial herbs, on the other hand, remain green in winter and regrow in spring. Woody plants produce flowers and fruits above ground for many years and have a lignified stem that lasts for several years. Woody plants are divided into deciduous and evergreen trees.

Next, the confirmed species were classified into native species and alien species, based on the Ministry of the Environment and Niigata Prefecture, designated.

In addition, from 2012 to 2020, excluding 2016, the vegetation coverage rate, which indicates the ratio of area occupied by vegetation to the total area, was calculated using aerial photographs. Vegetation coverage was calculated for Areas 1, 3, 6, and 7 in the fishway, divided into Under Water and the Cobblestone gap beside the channel. Areas 2, 4, 5, and 8 outside the fishway were excluded from the target for calculating the vegetation cover rate, assuming that they would have little direct impact on the migration and habitat of fish.

2.2.2. Scope and Method of the Fish Survey

To evaluate the improvement of the fishway as a habitat in terms of vegetation, a fish-catching survey was conducted. The survey was conducted from 2012, when the rock-ramp type fishway was completed, to 2020. For the investigation, a temporary trap was installed at the upstream end of the rock-ramp fishway for 1 month in June. The temporary trap had an entrance of 0.2 m width, 0.2 m height, and with 2 mm mesh inside a partition net of 0.9 m width, 0.45 m height, and 2 mm mesh. A hole of 50 mm diameter was provided at the entrance to capture fish that moved upstream. This contraption was based on a trap used by local fishermen to catch bottom-dwelling fish, such as *Cottus pollux*. The trap was pulled out of the water once for 1 h during the survey from 7:00 to 19:00 every day, and the number of individuals of each fish species was confirmed. At Area 3, in the middle section of the rock-ramp type fishway, catch surveys with a net were also conducted three times a day. This net was a landing net with a depth of 0.4 m, an entrance width of 0.35 m, and a mesh of 2 mm [54].

2.2.3. Statistical Method

The survey results on fish habits and vegetation were statistically analyzed with a t-test. Prior to performing the t-test, F-tests were performed to determine whether the variances of the vegetation data and the fish data were equal. The first relationship organized in Excel was the change in the number of plant species and the change in the number of fish caught. Changes in the number of plant species, including those of erect, tufted, and partial rosette types, were recorded only for Areas 1, 3, 6, and 7 within the fishway. Changes in fish populations are shown separately for bottom-dwelling and non-bottom-dwelling fish. The relationship between each fish species and the number of plant species was organized for 2013, 2014, and 2020, when surveys on the number of plant species were conducted. Next, the relationship between the changes in the vegetation cover rate of the fishway and the change in the number of fish caught was identified in the Excel dataset. Changes in vegetation coverage are described for the period from 2012 to 2020 (excluding 2016) when aerial photography was performed. The relationship between changes in fish populations with $R^2 > 0.36$ and vegetation coverage was organized for Areas 1, 3, 6, and 7 in the fishway.

3. Results

3.1. Transition of the Different Vegetation Types

Survey results for 2013, 2014, and 2020 are shown by area in Appendix A. Three important species, *Cyperus glomeratus* (Near Threatened), *Galium gracilens* (Local Population), and *Veronica undulata* (Near Threatened), were confirmed in the 2020 survey. In 2013, 15 alien species, including *Rumex obtusifolius*, *Barbarea vulgaris*, and *B. frondosa*, and three specific alien species, *Sicyos angulatus*, *Veronica anagallis-aquatica*, and *Coreopsis lanceolata*, were confirmed. In the 2014 survey results, 18 alien species were confirmed, with three species, *S. angulatus*, *V. anagallis-aquatica*, and *C. lanceolata*, corresponding to specific alien organisms confirmed, and three alien species requiring management attention, i.e., *R. obtusifolius*, *B. vulgaris*, and *B. frondosa*. In the 2020 results, two species (*S. angulatus* and *V. anagallis-aquatica*) were confirmed as specific alien species, with 20 alien species confirmed for ecological damage prevention, including *R. obtusifolius*, *B. vulgaris*, and *B. frondosa*.

Table 2 shows the results of the vegetation characteristics. Over the survey period, the number of native species in the entire area increased from 64 to 97 species (67.4% to 66.9%) and alien species increased from 31 to 48 species (32.6% to 33.1%). The proportion of alien species was slightly higher compared with the Japanese average, which is around 20% [75]. They are shown by areas in Figure 4. Figure 5 shows the changes in vegetation in each area for three years. The vegetation situation based on the characteristics of each area is shown in Table 3.

Table 2. Composition of native, alien, and different species' characteristics of the entire area in 2013, 2014, and 2020.

	Native Species				Alien Species				
	Annual	**Perennial**	**Woody**	**Subtotal**	**Annual**	**Perennial**	**Woody**	**Subtotal**	**Total**
2013 Species	30	26	8	64	17	12	2	31	95
Ratio (%)	31.6	27.4	8.4	67.4	17.9	12.6	2.1	32.6	100
2014 Species	39	26	12	77	17	13	2	32	109
Ratio (%)	35.8	23.9	11.0	70.6	15.6	11.9	1.8	29.4	100
2020 Species	62	30	5	97	29	17	2	48	145
Ratio (%)	42.8	20.7	3.4	66.9	20.0	11.7	1.4	33.1	100

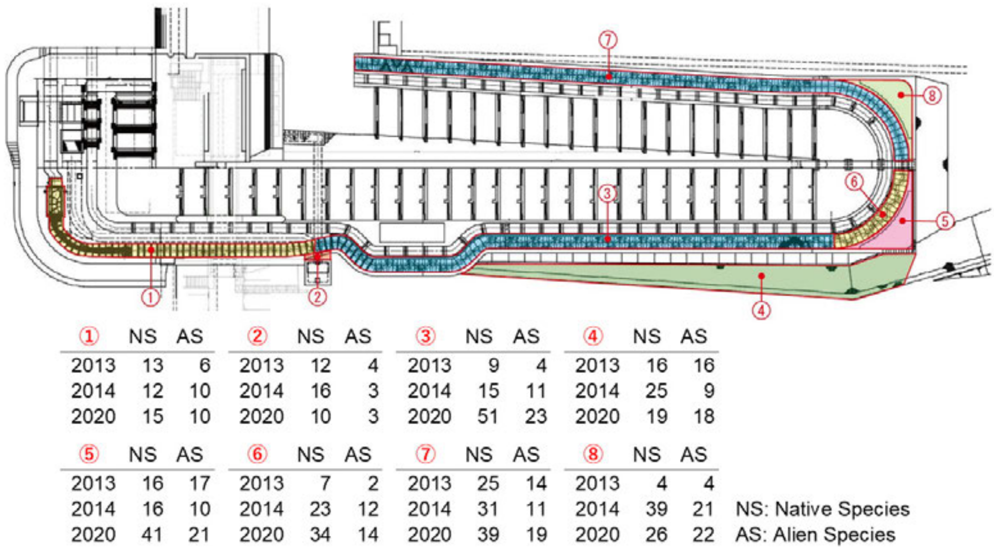


Figure 4. Number of native and alien species in each area based on the survey results of 2013, 2014, and 2020.

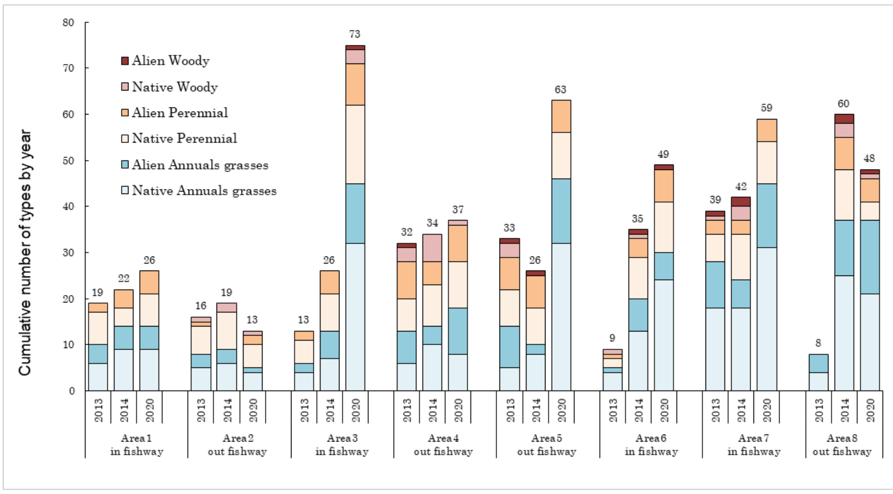


Figure 5. Variation in the cumulative number of different types of vegetation of each survey area based on their lifestyle characteristics.

Table 3. Annual changes in vegetation in each area and the main confirmed plants.

Area 1 (30 m^2): The annuals *Eclipta prostrata* and *Bidens frondosa* were sparse. On the upstream side, *B. frondosa* grew densely between rocks; however, it decreased in fall 2020. In inundated zones, an alien submerged species, *Elodea nuttallii*, colonized in 2020.	Area 2 (1 m^2): *Persicaria lapathifolia*, *Bidens. frondosa*, *Petasites japonicus*, and *Morus australis* grew sparsely, and after artificial logging in the summer of 2020 only short plants generally remained.
  Upstream side Inundated zone	  2013 summer 2020 summer
Area 3 (45 m^2): In 2020, *Sedum sarmentosum*, *Bidens frondosa*, *Elodea nuttallii*, and *Equisetum arvense* colonized this area following the new sediment deposition and seed settlement from the 2019 heavy floods. Important species and specific alien species were also confirmed.	Area 4 (30 m^2): Maintenance was applied until 2019, due to which the gaps in the masonry were filled with mortar. Many species such as *Coreopsis lanceolata*, a specific alien plant, were depleted. Then, a colony of *Galium gracilens*, which prefers sunny banks, was identified.
  2014 Summer 2020 Autumn	  2013 Summer 2020 Autumn
Area 5 (12 m^2): In 2014, woody plants, such as *Zelkova serrata* and *Salix gilgiana* disappeared due to floods. The vegetation became denser due to sedimentation from the 2019 and 2020 floods. The important species *Galium gracilens* disappeared and *Cyperus glomeratus* was confirmed.	Area 6 (20 m^2): Many plants grew, including *Equisetum arvense* and *Persicaria lapathifolia*. Owing to the sedimentation caused by the flood in the summer of 2020, large herbs and *Galium gracilens* and *Veronica undulata* disappeared and the annuals *Echinochloa crus-galli* and *Persicaria hydropiper* dominated.
  2014 Summer 2020 Autumn	  2014 Summer 2020 Summer
Area 7 (50 m^2): A large number of species were confirmed throughout the survey period. *Salix jessoensis* was identified in 2013, but it was not confirmed in 2014 and *Juglans ailantifolia* grew. Due to the flooding of 2020, *Phalaris arundinacea* decreased. Instead, *Echinochloa crus-galli* formed a community.	Area 8 (12 m^2): Annuals such as *Digitaria ciliaris* and *Conyza sumatrensis* grew in the wastelands, and *Melilotus albus* was observed. Most species emerged in 2014. *Persicaria lapathifolia* grew densely in damp places, and young trees of *Ailanthus altissima* were found. One *Cyperus glomeratus* was confirmed.
  2013 Summer 2020 Autumn	  2013 Summer 2020 Summer

When we compared the results of 2020 with those of 2014, the composition of native annual and perennial species increased, and the composition of native woody species decreased (Figure 6). The number of native annuals and perennials increased due to the loss of perennials because of flooding and the emergence of disturbance-loving annuals and perennials. As the survey was conducted in the fall after flooding, many native annual and perennial plants, such as Cyperaceae and Linderniaceae, appeared. The growth of woody species declined downstream of the turn-around section owing to sediment accumulation.

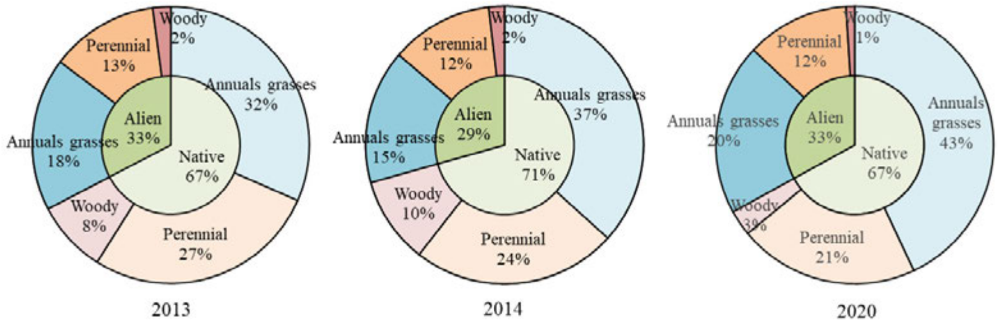


Figure 6. Confirmed species in 2013, 2014, and 2020. Confirmed plants were classified into native and alien species, which were then divided into annuals, perennials, and woody plants.

3.2. Changes in Vegetation and Fish Habitats

Table 4 highlights the number of fish individuals caught in the rock-ramp type fishway and the number of tall plant species confirmed on the cobblestone gap in the rock-ramp type fishway (Areas 1, 3, 6, and 7) in 2013, 2014, and 2020.

Table 4. Relationship between the fish captured and the number of plant species between cobblestones, particularly erect, tufted, and partial rosette types, in Areas 1, 3, 6, and 7.

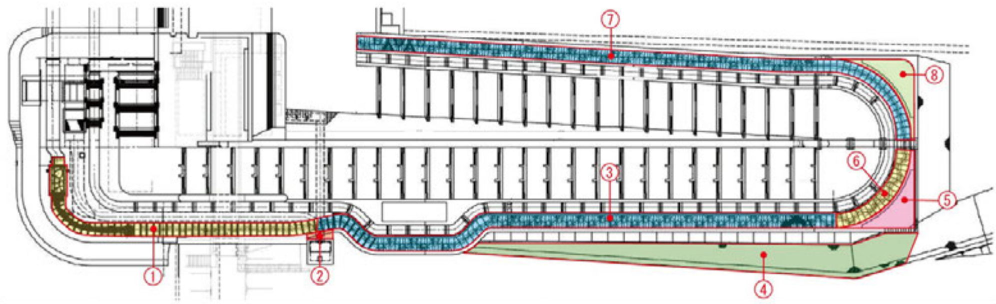
					2013	2014	2020
Number of Plant Species in Areas 1, 3, 6, and 7					17	14	18
Fish catch survey results	R^2	df	t	*p*	Individuals		
Individuals (bottom-dwelling fish)	0.907	2	4.303	0.185	130	33	237
Species (bottom-dwelling fish)	0.923	4	2.776	0.001	5	4	6
Misgurnus anguillicaudatus	0.942	4	2.776	0.000	0	1	0
Paramisgurnus dabryanus	0.923	4	2.776	0.000	1	0	2
Cobitis biwae	0.886	4	2.776	0.025	6	2	11
Pelteobagrus nudiceps	0.481	4	2.776	0.002	0	0	5
Liobagrus reini	0.516	2	4.303	0.451	1	0	25
Cottus pollux	0.585	2	4.303	0.388	65	4	38
Rhinogobius kurodai	0.705	2	4.303	0.248	57	26	156
Individuals (non-bottom-dwelling fish)	0.753	2	4.303	0.620	18	3	57
Species (non-bottom-dwelling fish)	0.612	4	2.776	0.013	4	3	10
Carassius auratus langsdorfii	0.481	4	2.776	0.000	0	0	2
Opsariichthys platypus	0.906	2	4.303	0.397	10	1	20
Nipponocypris temminckii	0.481	4	2.776	0.000	0	0	1
Rhynchocypris lagowskii	0.923	4	2.776	0.000	2	1	3
Tribolodon hakonensis	0.703	4	2.776	0.001	3	0	2
Pseudorasbora parva	0.481	4	2.776	0.021	0	0	10
Gnathopogon elongatus	0.297	4	2.776	0.002	0	1	5
Plecoglossus altivelis	0.481	4	2.776	0.015	0	0	9
Salmo trutta	0.481	4	2.776	0.015	0	0	1
Micropterus salmoides	1.000	4	2.776	0.001	3	0	4
Individuals (total)	0.878	2	4.303	0.196	148	36	294
Species (total)	0.689	4	2.776	0.130	9	7	16

The number of tall species outside the channel was 17 in 2013, 14 in 2014, and 18 in 2020. Three of the 17 plant species confirmed in 2013 were confirmed in 2013 alone, and they all occurred in Area 7. Two of the 14 species confirmed in 2014 were confirmed in 2014 alone, and they were confirmed in Areas 6 and 7, respectively. Six of the 18 species recorded in 2020 were confirmed for the first time in 2020, and they were found in each area. Five species of plants were confirmed each time during the three sampling years, and they were confirmed in each area.

Compared to 2013 and 2014, in 2020, one bottom-dwelling fish, *Pelteobagrus nudiceps*, and five non-bottom-dwelling species, *Carassius auratus langsdorfii*, *Nipponocypris temminckii*, *Pseudorasbora parva*, *Plecoglossus altivelis*, and *Salmo trutta*, were newly caught. The bottom-dwelling fish *Cobitis biwae* and *Pelteobagrus nudiceps* increased in 2020 ($R^2 = 0.886$, $p < 0.05$; $R^2 = 0.481$, $p < 0.05$, respectively). The non-bottom-dwelling fish *Pseudorasbora parva*, *Plecoglossus altivelis* and *Salmo trutta* also increased in 2020 ($R^2 = 0.481$, $p < 0.05$, respectively). *Pelteobagrus nudiceps* and *S. trutta* are large fish species with body lengths of adult specimens reaching 0.2–1 m. Therefore, *P. nudiceps* and *S. trutta* are not fish species that typically swim upstream on a rock-ramp-type fishway. However, the individual concerned was a juvenile with a body length of less than 61 mm and was caught using a rock-ramp type fishway.

As the number of these plant species increased over the course of the study, the overall number of fish increased from an average of 92 individuals (average total number caught in 2013 (148) and 2014 (36)) to 294 individuals ($R^2 = 0.878$, $p = 0.196$). Furthermore, the overall number of species increased from 8 (average total number caught in 2013 (9) and 2014 (7)) to 16 ($R^2 = 0.689$, $p = 0.130$). This was particularly apparent for the number of non-bottom-dwelling fish species ($R^2 = 0.612$, $p < 0.05$).

Figure 7 shows the calculated results of the vegetation coverage. The vegetation coverage rate is an index value, with "10 or less" indicating less than 10% coverage, "10–25" indicating 10–25% coverage, "25–50" indicating 25–50% coverage, "50–75" indicating 50–75% coverage, and "75 or more" indicating 75–100% coverage. The vegetation coverage of underwater sections did not change significantly in any area, while vegetation coverage in the Cobblestone gap in Areas 1, 3, and 6, which are relatively unaffected by flooding, showed an increasing trend. However, the vegetation coverage in the Cobblestone gap in Area 7 varied significantly because of floods.



Year[2] \ Area[1]	Area 1		Area 3		Area 6		Area 7	
	Under water	Cobblestone gap	Under water	Cobblestone gap	Under water	Cobblestone gap	Under water	Cobblestone gap
2012	less than 10	less than 10	less than 10	less than 10	less than 10	less than 10	less than 10	less than 10
2013	less than 10	less than 10	10 to 25	less than 10	less than 10	less than 10	less than 10	25 to 50
2014	less than 10	less than 10	10 to 25	less than 10	less than 10	25 to 50	less than 10	10 to 25
2015	less than 10	less than 10	10 to 25	less than 10	less than 10	25 to 50	less than 10	10 to 25
2017	less than 10	less than 10	less than 10	25 to 50	less than 10	50 to 75	less than 10	10 to 25
2018	less than 10	less than 10	less than 10	25 to 50	less than 10	50 to 75	less than 10	25 to 50
2019	less than 10	less than 10	less than 10	25 to 50	less than 10	75 or more	less than 10	25 to 50
2020	less than 10	50 to 75	less than 10	50 to 75	less than 10	75 or more	less than 10	50 to 75

1) Except for Areas 2, 4, 5, and 8 outside the rock-ramp fishway 2) Except for 2016 without aerial photography

Figure 7. Vegetation coverage divided by 25% for each area. Data were divided into underwater sections and cobblestone gaps beside the main stream. Areas outside the fishway (2, 4, 5, and 8) and in 2016 without aerial photographs are excluded.

As shown in Table 5, the correlations between vegetation coverage and fish individuals in Areas 1, 3, and 6 were high (R^2 = 0.655, $p < 0.05$; R^2 = 0.679, $p < 0.05$; R^2 = 0.481, $p < 0.05$, respectively). The correlation between vegetation coverage and fish individuals in Area 7 was relatively high (R^2 = 0.831, $p < 0.05$). In contrast, the correlations between vegetation coverage and the number of fish species were not very high in any area (R^2 = 0.453, $p > 0.05$; R^2 = 0.621, $p < 0.05$; R^2 = 0.603, $p < 0.05$; R^2 = 0.289, $p < 0.05$, respectively).

Table 5. Relationship between vegetation cover rate separated by 25% for each area and number of fish caught by rock-rump fishway from 2012 to 2020. Only the Cobblestone gap beside the main stream, where the change in vegetation cover was confirmed, and only fish that correlate with vegetation cover (R^2 > 0.4), are shown.

	R^2	df	t	p	2012	2013	2014	2015	2017	2018	2019	2020
Vegetation coverage at Area 1					10	10	10	10	25	25	25	50
Liobagrus reini	0.603	14	2.14	0.087	3	1	0	6	10	3	26	25
Rhinogobius kurodai	0.756	8	2.31	0.007	59	57	26	46	70	115	138	156
Opsariichthys platypus	0.403	14	2.14	0.088	0	10	1	5	3	27	11	20
Pseudorasbora parva	0.576	8	2.31	0.007	1	0	0	4	1	0	2	10
Plecoglossus altivelis	0.754	8	2.31	0.006	1	0	0	1	0	1	2	9
	R^2	**df**	**t**	**p**	**2012**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2020**
Vegetation coverage at Area 3					10	10	10	10	25	25	25	25
Cobitis biwae	0.736	14	2.14	0.010	1	6	2	2	36	24	26	11
Liobagrus reini	0.473	14	2.14	0.099	3	1	0	6	10	3	26	25
Rhinogobius kurodai	0.687	11	2.20	0.082	59	57	26	46	70	115	138	156
	R^2	**df**	**t**	**p**	**2012**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2020**
Vegetation coverage at Area 6					10	10	50	50	75	75	75	100
Liobagrus reini	0.481	8	2.31	0.005	3	1	0	6	10	3	26	25
Rhinogobius kurodai	0.496	14	2.14	0.190	59	57	26	46	70	115	138	156
	R^2	**df**	**t**	**p**	**2012**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2020**
Vegetation coverage at Area 7					10	50	25	25	25	50	75	75
Cobitis biwae	0.568	14	2.14	0.048	1	6	2	2	36	24	26	11
Rhinogobius kurodai	0.727	14	2.14	0.022	59	57	26	46	70	115	138	156
Opsariichthys platypus	0.512	9	2.26	0.007	0	10	1	5	3	27	11	20

In Area 1, bottom-dwelling fish had a strong correlation with *Rhinogobius kurodai* (R^2 = 0.756, $p < 0.05$) and a slight correlation with *Liobagrus reini* (R^2 = 0.603, p = 0.087). Non-bottom-dwelling fish had a strong correlation with *Plecoglossus altivelis* (R^2 = 0.754, $p < 0.05$), a correlation with *Pseudorasbora parva* (R^2 = 0.576, $p < 0.05$), and a weak correlation with *Opsariichthys platypus* (R^2 = 0.403, p = 0.088). In Area 3, the bottom-dwelling fish showed a strong correlation with *Cobitis biwae* (R^2 = 0.736, $p < 0.05$), and bottom-dwelling fish showed a slight correlation with *Rhinogobius kurodai* and *Liobacrus reini* (R^2 = 0.687, p = 0.082; R^2 = 0.473, p = 0.099, respectively). In Area 6, bottom-dwelling fish had a strong correlation with *Liobagrus reini* (R^2 = 0.481, $p < 0.05$) and a slight correlation with *Rhinogobius kurodai* (R^2 = 0.496, p = 0.190). In Area 7, bottom-dwelling fish had a strong correlation with *Rhinogobius kurodai* (R^2 = 0.727, $p < 0.05$) and a slight correlation with *Cobitis biwae* (R^2 = 0.568, $p < 0.05$), while non-bottom-dwelling fish were correlated with *Opsariichthys platypus* (R^2 = 0.512, $p < 0.05$).

4. Discussion

4.1. Change in Naturalized Plants in the Rock-Ramp Fishway

The proportion of alien species in the rock-ramp fishway exceeded 30%, which is higher than the Japanese average of about 20%. The present study, which calculated the naturalized vegetation rate (20%), was conducted at 22 sites in 10 rivers. The naturalized plant rate (20%) is the average value of 22 sites (3.4–28.0%). The survey sites with low naturalized vegetation rates were forested mountain streams where river improvements had not been implemented. Many naturalized plants grow in open, bright places. When the rock-ramp fishway was newly constructed in 2012, it contained no vegetation and was constructed with cobblestones. Therefore, such results were confirmed. *B. frondosa*, which formed a colony, also happened to grow in this place.

By 2020, 8 years after the rock-ramp fishway was built, the proportion of naturalized plants had exceeded 30%. There are two possible explanations for this. First, the environment for vegetation did not change in areas not submerged by floods. Although soil is essential for vegetation growth, vegetation did not grow because there was no supply of soil to areas not submerged by floods. Therefore, an open and bright environment where naturalized plants can easily grow was preserved. Second, perennials and woody plants could not settle in flooded areas. Floods shared the soil with these areas, but at the same time vegetation was washed away by the floods. They were clear because the proportion of annual grasses increased from 2013–2014.

4.2. Species Confirmed in Each Survey Area

The number of confirmed species increased slightly in most areas except for Area 2 (Figure 5). In the area inside the rock-ramp fishway, numerous species and growing individuals were confirmed near the turning part of Areas 6 to 7. In contrast, in Areas 1 and 3, the growth of plants was sparse. One of the factors that caused such differences in the growth conditions of each area was the presence or absence of a substrate for plants to take root. In the area near the turn of the rock-ramp fishway, the slope of the fishway was gentle, and sediment sometimes accumulated due to flooding. Therefore, sediment was deposited in the gaps between the rocks, and many plants, including the annual *P. thunbergii* and the perennial *Phalaris arundinacea*, could grow on the ground.

In contrast, because there were few foundations for plants to take root, plant growth was sparse in areas where sediment accumulation was low. *Elodea nuttallii*, an alien submerged plant, was found in Areas 1 and 3 of the rock-ramp fishway. In addition, in the cobblestone crevices, plants such as *Sedum sarmentosum* that do not require a growth base due to sedimentation, expanded their distribution area. Regarding the growth of *E. nuttallii*, this species may have been transported from sites upstream. If left unattended, its distribution may expand in the rock-ramp fishway.

Area 5 outside the rock-ramp fishway had a rocky substrate adjacent to the upstream turn-around section in 2014. However, by 2020, the accumulation of sediment facilitated the growth of plants. Previously, moist and uninhabitable dry environments were present, but after the 2019 flood the entire environment was disturbed and became moist; in this area, the number of confirmed species of plants was relatively high. In addition, on the revetment on the right bank side (Area 4), a colony of *G. gracilens* was confirmed. In Area 4, several *C. lanceolata* and *S. sarmentosum* were growing in 2013 and 2014, but in 2020 *C. lanceolata* was not confirmed and almost all of the masonry was visible. In Area 4, gaps between logging and masonry were filled with mortar as part of maintenance. These changes in the habitat made it easier for *G. gracilens*, which grows on sunny banks, to establish, which may have contributed to the disappearance of woody plants.

In this way, vegetation growth and changes in rock-ramp fishways are caused not only by species flowing through the channel from upstream but also by plant species inhabiting the surrounding areas. The plants in the upstream and slightly distant areas are out of the hands of facility managers, which indicates the difficulty of their management.

4.3. Changes in Vegetation and Fish Populations

The bottom-dwelling and weak-swimming fishes were mainly found in the rock-ramp type fishway, which also had the highest number of species among the three fishways [56]. The water depth of the rock-ramp type fishway is 0.15 m, which is the same as the stair-type fishway. However, unlike the ice-harbor type fishway and the stair-type fishway, the slope is mild and the riverbed material is not concrete but cobblestone. On both sides of the main stream, there are stagnant areas behind rocks and gaps between them.

Vegetation was not initially planted when fishway improvement was completed in 2012. Nevertheless, vegetation gradually colonized the fishway as seeds flowed in from outside sources. In addition, downstream to Area 3, sediment was deposited due to repeated floods, creating a substrate for plants to colonize. Vegetation inside the fishway Areas 1, 3, 6, and 7 grew year by year, covering more than half the area of the fishway in 2020.

The area between cobbles of the main channel was filled with fine sediment, serving as a substrate for vegetation such as *Chenopodium album* and *Amaranthus retroflexus* that was classified as erect, *Setaria viridis* and *Eragrostis multicaulis* that was classified as tufted, and *Solidago altissima* and *Erigeron sumatrensis* that was classified as partial rosette, which all contributed hiding places and shade for fish.

Rhinogobius kurodai, *Cobitis biwae*, and *Liobagrus reini* were less sensitive to vegetation conditions in the cobblestone gaps on either side of the main stream. *Plecoglossus altivelis*, *Pseudorasbora parva*, and *Opsariichthys platypus*, which are relatively small, were confirmed to increase or decrease depending on the vegetation conditions at the entrance and exit of the fishway. Such vegetation changes are considered to be important for increases in bottom-dwelling fish and fish with a weak swimming ability, as well as juveniles of other fish. In contrast, the plants that contributed to the improvement of these environments include alien species. Fortunately, no specific alien species were among them. Proper management of these plants is necessary for the conservation of important native species.

Among the main currents, Chaetophoraceae dominated in 2013 but was not identified in 2014. Furthermore, in 2014, *Oedogonium* spp. dominated. Chaetophoraceae and *Oedogonium* spp. were green algae rather than vascular plants, so they were easily swept away and were not recorded in 2020. In 2020, *Elodea nuttallii* was observed, and although a certain amount of colonization was confirmed, it was not large enough to block the flow path.

When *Elodea nuttallii* grows enough to obstruct the flow path, and the roots of plants living in crevices between cobblestones on either side of the main stream block the waterway, movement of bottom-dwelling fish and fish with low swimming ability may be impeded. Had that event occurred, then surveys at the upstream end of the rock-ramp type fishway would have confirmed fewer of these fish. From these perspectives, the existence and management of appropriate vegetation are considered important to maintain a fishway that accommodates a variety of fish species.

4.4. Vegetation Management in the Rock-Ramp Fishway

The design concept and necessity of adaptive management are demonstrated by examples of various forms and functions. It is important to recognize the interdependence of the biological, hydrological, and geomorphological components in fishways [76] to simplify the phenomena. Combined phenomena, including changes in fish community structure that because an increase in epiphytic biomass and a decrease in available light, leading to changes in vegetation [77], have resulted in shifts in various communities, from phytoplankton to larger plants. These shifts are caused by an increase in fish-eating populations and a decrease in plankton population [78], which are reflected in the differences in bottom sediment types. These factors, along with hydrological management methods, have become a considerable management issue [79]. Adaptive management is advocated for complex ecosystem management that can only be learned through experience. This requires a feedback system that repeats the processes of identifying management objectives, evaluating the environment, planning, implementing management activities, and finally evaluating results [80].

At the design stage of the rock-ramp fishway, no colonization of vegetation formation was expected. Therefore, using the results from the above-mentioned survey from 2013 to 2014, we created the *Guidelines for Efforts to Control Alien Species in a Rock-ramp Fishway*

(Draft), which aimed at vegetation dominated by native species as the maintenance method of vegetation in the fishway by referring to the measures for existing alien species [81]. In developing the *Guidelines for Efforts to Control Alien Species in a Rock-ramp Fishway* (Draft), it was also important to strengthen effective measures to prevent the infestation and spread of specific alien organisms [82]. For species designated as invasive alien species, effective measures to prevent their invasion and spread must be strengthened [83].

The vegetation around the rock-ramp fishway was maintained and managed using only the draft guidelines, based on the concept of collectively weeding specific alien organisms. However, during maintenance in 2015, the alien plant *E. alba* and native species *Mosla dianthera* were abnormally overgrown and blocked the main flow, affecting the fishway. On the upstream side of the turn-around section of the fishway, fine sediments and seeds from the nearby grassland accumulated into the gaps between the rocks in the hangout, becoming a substrate for vegetation establishment. On the upstream side of the bending zone, sediment accumulated and was stably colonized by vegetation. It is reasonably possible to stably develop vegetation composed mainly of native species by artificially removing alien species. *S. angulatus* and *V. anagallis-aquatica*, which cover the ground surface densely and form dominant communities, may inhibit the germination and establishment of native species. In addition, since *V. anagallis-aquatica* hybridizes with native species, its future distribution and expansion must be understood. Therefore, the alien species, including *C. lanceolata,* should be carefully removed to avoid facilitating seed dispersal.

In contrast, vegetation destruction and regeneration naturally occur downstream from the folded part due to the sedimentation of earth and sand containing seeds due to flooding and subsequent vegetation development and its outflow. Thus, natural vegetation development was preferred for the vegetation status of the rock-ramp fishway and its surroundings. Therefore, in daily maintenance, removing specific alien organisms, as recommended in the guidelines, was not completely implemented. This approach cannot maintain the aquatic environment of the fishway with a suitable vegetation environment conducive to fish movement and habitat.

Vegetation succession, such as changes from vegetation characterized by alien species to vegetation centered on native species, and changes in the breakdown of native species, was confirmed in the maintenance of the rock-ramp fishway in early summer 2020, eight years after its construction. A cover structure in the fishway was formed in the upstream part of the rock-ramp fishway, which was not affected by the flood due to the overgrowth of vegetation, mainly comprising the native species *Equisetum arvense* and *P. thunbergii*. Consequently, a favorable environment for aquatic organisms was confirmed. The fishway was designed to be a location for fish migration, run-up, and descent, not a place for fish to settle and inhabit. However, in the rock-ramp fishway, with an extent of about 250 m, demersal fish and fish with a weak swimming ability may inhabit or reproduce, so a settling area was provided. In recent years, abnormal overgrowth of submerged plants, such as *E. densa*, was confirmed mainly on the upstream side of the folded part that was not affected by flooding. As this situation has been confirmed in the stagnation area and the main stream, there are concerns regarding the deterioration of water quality in the habitat of fry and fish larvae, and aquatic insects on which fish feed. Therefore, we must identify the advantages of fishway vegetation, such as creating shade and hiding places and improving harmony with the surrounding landscape, and the disadvantages of maintaining vegetation that inhibit the mobile environment and negatively affect water quality. Thus, it is necessary to observe and properly maintain the vegetation environment formed by the rock-ramp fishway.

The following two viewpoints were adopted for future vegetation maintenance methods. First, the overgrowth of plants in the rock-ramp fishway should be tolerated to the extent that it does not obstruct the main flow of the fishway. However, if vegetation becomes too dense, plants must be removed to restore the habitat and allow the migration of fish. Second, the strategy for vegetation management downstream of the folded part of the rock-ramp fishway should consider the response of vegetation to flooding over 3000 m^3 s^{-1}. The environment of the folded part of the rock-ramp fishway is easily submerged by flooding and is susceptible to disturbance, so continuous monitoring is required for floods of 1500 m^3 s^{-1} or more that occur at least once a year and those of 3000 m^3 s^{-1} or more that occur once every two years.

5. Conclusions

Several plants were growing in and around the rock-ramp fishway, raising concerns over vegetation maintenance, including vegetation overgrowth blocking channels and hangouts and reducing visibility from the ground or fishway observation room. The vegetation on the lower reaches of the fishway, which is strongly affected by floods, was left to develop naturally. Therefore, the removal of specific alien organisms as recommended in the guidelines was not carried out in daily maintenance. As a result of the advancing adaptive management for the rock-ramp fishway, monitoring confirmed the highest number of fish species in the rock-ramp fishway compared to the other two fishways. Therefore, in the rock-ramp fishway, management that leads to the occurrence of the desired vegetation type is strongly recommended in the future. However, the following two points were raised as current issues for continuously managing the rock-ramp fishway as a good environment: (1) it is difficult to continuously remove alien species on an individual or strain basis, and (2) some factors are difficult to predict and manage, such as disturbances by river-specific floods and the influx of water-dispersed seeds. Based on these issues, it is essential to review the vegetation management policy in the fishway while performing continuous monitoring to maintain the ideal vegetation profile in the rock-ramp fishway. In the future, we will continue to monitor fish and vegetation in the fishway, improve the maintenance method as appropriate, and continue adaptive management to harmonize the river environment with water use.

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Appendix A

List of plant species confirmed for each survey area. Valuable Species and Life-Form were also organized to aid in the discussion each year.

2013	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
1	*Equisetum arvense*		◎	◎	◎		◎				P
2	*Deparia japonica*	◎									P
3	*Salix gilgiana*					◎					W
4	*Salix jessoensis*							◎			W
5	*Zelkova serrata*					◎					W
6	*Fatoua villosa*				◎						A
7	*Morus australis*		◎		◎						W
8	*Boehmeria nivea* var. *concolor*			◎							P
9	*Boehmeria silvestrii*							◎			P
10	*Persicaria lapathifolia*		◎			◎		◎			A
11	*Persicaria longiseta*							◎			A
12	*Rumex acetosa*	◎	◎	◎	◎	◎					P
13	*Rumex japonicus*					◎					P
14	*Rumex obtusifolius*				●	●	●				P
15	*Arenaria serpyllifolia*		◎								A
16	*Silene armeria*				●	●			●		A
17	*Stellaria alsine* var.*undulata*				◎						A
18	*Chenopodium album*							◎			A
19	*Chenopodium ambrosioides*							●			P
20	*Ranunculus sceleratus*	◎									A
21	*Ranunculus silerifolius*					◎					P
22	*Akebia trifoliata*				◎						W
23	*Cocculus orbiculatus*				◎						W
24	*Hypericum erectum*					◎					P
25	*Barbarea vulgaris*				●	●		●			P
26	*Cardamine flexuosa*			◎							A
27	*Lepidium virginicum*							●			A
28	*Nasturtium officinale*					●					P
29	*Rorippa indica*							◎			A
30	*Rorippa islandica*					◎		◎			A
31	*Rorippa sylvestris*					●					P
32	*Sedum sarmentosum*	●	●	●	●	●					P
33	*Aeschynomene indica*		◎					◎			A
34	*Albizia julibrissin*					◎					W
35	*Amorpha fruticosa*				●	●					W
36	*Glycine max* ssp. *soja*						◎	◎			A
37	*Kummerowia striata*						◎	◎	◎		A
38	*Melilotus officinalis* ssp. *alba*					●		●	●		A
39	*Melilotus officinalis* ssp. *alba* f. *suaveolens*					●					A
40	*Robinia pseudoacacia*							●			W
41	*Trifolium pratense*				●			●			P
42	*Trifolium repens*					●					P
43	*Oxalis corniculata*				◎						P
44	*Geranium thunbergii*		◎								P
45	*Acalypha australis*			◎	◎			◎			A
46	*Euphorbia maculata*					●		●			A
47	*Celastrus orbiculatus*						◎				W
48	*Actinostemma lobatum*							◎			A
49	*Sicyos angulatus*							▲			A
50	*Ludwigia epilobioides*	◎									A
51	*Oenothera biennis*				●	●		●	●		A
52	*Oenanthe javanica*	◎									P
53	*Galium spurium*				●						A
54	*Clinopodium gracile*				◎						P
55	*Mosla dianthera*	◎			◎			◎			A
56	*Veronica anagallis-aquatica*	▲		▲		▲	▲	▲			A
57	*Plantago asiatica*					◎					P
58	*Anaphalis margaritacea* ssp. *yedoensis*				◎						P
59	*Artemisia capillaris*				◎						P

2013	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
60	*Artemisia indica* var. *maximowiczii*	◎	◎	◎				◎			P
61	*Bidens frondosa*	●	●		●			●			A
62	*Conyza sumatrensis*							●	●		A
63	*Coreopsis lanceolata*				▲						P
64	*Eclipta prostrata*	◎		◎			◎				A
65	*Erigeron canadensis*	●	●								A
66	*Erigeron philadelphicus*				●	●					A
67	*Lactuca indica*					◎					A
68	*Petasites japonicus*	◎	◎	◎				◎			P
69	*Sonchus asper*			●	●	●					A
70	*Sonchus oleraceus*	◎									A
71	*Stenactis annuus*	●	●		●			●			A
72	*Taraxacum laevigatum*				●						P
73	*Taraxacum officinale*	●		●	●	●					P
74	*Xanthium occidentale*							●			A
75	*Juncus effusus* var. *decipiens*						◎				P
76	*Commelina communis*	◎	◎	◎	◎			◎			A
77	*Agrostis clavata* ssp. *matsumurae*		◎								P
78	*Arthraxon hispidus*					◎					A
79	*Beckmannia syzigachne*					◎					A
80	*Digitaria ciliaris*						◎	◎	◎		A
81	*Echinochloa crus-galli*							◎			A
82	*Echinochloa crus-galli* var. *echinata*							◎			A
83	*Eragrostis cilianensis*							◎			A
84	*Eragrostis poaeoides*					●					A
85	*Eriochloa villosa*							◎			P
86	*Festuca arundinacea*				●						P
87	*Microstegium japonicum*							◎			P
88	*Miscanthus sinensis*				◎						P
89	*Phalaris arundinacea*	◎				◎		◎			P
90	*Phragmites japonica*					◎					P
91	*Poa acroleuca*		◎								A
92	*Setaria faberi*							◎	◎		A
93	*Setaria pumilla*				◎			◎	◎		A
94	*Lemna aoukikusa*					◎					P
95	*Spirodela polyrhiza*	◎									P
Total of native species		13	12	9	16	16	7	25	4		
Total of alien species		5	4	3	15	16	1	12	4		
Total		18	16	12	31	32	8	37	8		

Note(s): ◎: Native species; ●: Alien Species; ▲: Specified Alien Species; NT: Near Threatened; LP: Local Population; A: Annual glass, P: Perennial, W: Woody.

2014	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
1	*Equisetum arvense*		◎	◎	◎	◎	◎	◎	◎		P
2	*Deparia japonica*							◎	◎		P
3	*Juglans ailantifolia*				◎			◎			W
4	*Pterocarya rhoifolia*							◎			W
5	*Salix jessoensis*				◎				◎		W
6	*Humulus japonicus*							◎	◎		W
7	*Morus australis*		◎		◎						W
8	*Persicaria lapathifolia*			◎			◎	◎	◎		A
9	*Persicaria longiseta*						◎	◎	◎		A
10	*Persicaria perfoliata*								◎		A
11	*Persicaria thunbergii*							◎	◎		A

2014	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
12	*Reynoutria japonica*								◎		P
13	*Rumex acetosa*	◎			◎	◎			◎		P
14	*Rumex japonicus*			◎			◎	◎			P
15	*Rumex obtusifolius*			●	●	●	●		●		P
16	*Portulaca oleracea*	◎									A
17	*Cerastium glomeratum*								●		A
18	*Sagina japonica*								◎		P
19	*Silene armeria*				◎				◎		A
20	*Stellaria alsine* var. *undulata*								◎		A
21	*Chenopodium album*								◎		A
22	*Ranunculus sceleratus*	◎		◎			◎				A
23	*Ranunculus silerifolius*	◎		◎				◎			P
24	*Akebia trifoliata*				◎						W
25	*Cocculus orbiculatus*		◎		◎						W
26	*Barbarea vulgaris*	●		●	●	●	●	●	●		P
27	*Cardamine flexuosa*			◎				◎			A
28	*Lepidium virginicum*				●						A
29	*Nasturtium officinale*					●	●	●	●		P
30	*Rorippa indica*	◎			◎				◎		A
31	*Rorippa islandica*	◎				◎		◎	◎		A
32	*Sedum sarmentosum*		◎	◎	◎	◎					P
33	*Aeschynomene indica*		◎				◎	◎	◎		A
34	*Albizia julibrissin*				◎						W
35	*Amorpha fruticosa*					●	●	●	●		W
36	*Cassia mimosoides* ssp.*nomame*								◎		A
37	*Glycine max* ssp. *soja*							◎	◎		A
38	*Kummerowia striata*					◎	◎	◎	◎		A
39	*Melilotus officinalis* ssp. *alba*								●		A
40	*Melilotus officinalis* ssp. *alba* f. *suaveolens*						●		●		A
41	*Pueraria lobata*								◎		W
42	*Robinia pseudoacacia*							●	●		W
43	*Trifolium pratense*				●	●			●		P
44	*Trifolium repens*			●					●		P
45	*Vicia angustifolia*								◎		A
46	*Oxalis corniculata*		◎		◎						P
47	*Geranium thunbergii*		◎								P
48	*Acalypha australis*				◎	◎	◎	◎	◎		A
49	*Euphorbia maculata*		●						●		A
50	*Euphorbia supina*				●						A
51	*Rhus javanica* var. *chinensis*							◎			W
52	*Acer pictum* ssp.*mayrii*								◎		W
53	*Celastrus orbiculatus*						◎				W
54	*Viola verecunda*						◎				P
55	*Elatine triandra* var.*pedicellata*							◎			A
56	*Actinostemma lobatum*			◎			◎	◎	◎		A
57	*Sicyos angulatus*			▲				▲			A
58	*Ludwigia epilobioides*	●		◎							A
59	*Oenothera biennis*			●			●		●		A
60	*Oenanthe javanica*			◎			◎	◎			P
61	*Galium spurium*				◎						A
62	*Calystegia japonica*				◎						P
63	*Cuscuta pentagona*								●		P
64	*Clinopodium gracile*						◎				P
65	*Mosla dianthera*	◎		◎		◎	◎	◎			A
66	*Perilla frutescens* var. *acuta*								◎		A
67	*Mimulus nepalensis*							◎			P
68	*Veronica anagallis-aquatica*	▲		▲		▲	▲	▲	▲		A
69	*Veronica arvensis*				●						A

2014	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
70	*Veronica persica*						●		●		A
71	*Plantago asiatica*				◎				◎		P
72	*Ambrosia trifida*						●	●	●		A
73	*Anaphalis margaritacea* ssp. *yedoensis*								◎		P
74	*Artemisia indica* var. *maximowiczii*	◎	◎	◎	◎	◎	◎	◎	◎		P
75	*Bidens frondosa*	●	●	●		●	●	●	●		A
76	*Coreopsis lanceolata*				▲						P
77	*Eclipta prostrata*	◎		◎		◎	◎	◎			A
78	*Erigeron canadensis*	●		●					●		A
79	*Erigeron philadelphicus*	●									A
80	*Petasites japonicus*	◎	◎	◎			◎	◎			P
81	*Sonchus asper*				◎	◎					A
82	*Sonchus oleraceus*		◎		◎						A
83	*Stenactis annuus*	●	●	●	●			●	●		A
84	*Taraxacum laevigatum*								●		P
85	*Taraxacum officinale*	●		●	●	●	●				P
86	*Xanthium occidentale*						●	●	●		A
87	*Iris pseudacorus*	●		●				●			P
88	*Juncus effusus* var.*decipiens*					◎	◎				P
89	*Commelina communis*	◎	◎		◎	◎	◎	◎	◎		A
90	*Alopecurus aequalis* var.*amurensis*						◎	◎	◎		A
91	*Digitaria ciliaris*		◎		◎				◎		A
92	*Eragrostis cilianensis*				◎						A
93	*Eragrostis curvula*	●									P
94	*Eriochloa villosa*								◎		A
95	*Festuca arundinacea*					●					P
96	*Miscanthus sinensis*		◎		◎						P
97	*Panicum bisulcatum*		◎								A
98	*Phalaris arundinacea*					◎	◎	◎	◎		P
99	*Phragmites japonica*					◎		◎			P
100	*Poa acroleuca*	◎	◎		◎						A
101	*Poa annua*								◎		P
102	*Poa annua* var.*reptans*		◎			◎			◎		P
103	*Poa hisauchii*						◎				A
104	*Setaria viridis*					◎	◎		◎		A
105	*Setaria viridis* f.*misera*							◎	◎		A
106	*Sorghum halepense*					●					P
107	*Zoysia japonica*			◎	◎						P
108	*Cyperus microiria*								◎		A
109	*Eleocharis acicularis* var.*longiseta*							◎			A
	Total of native species	12	16	15	25	16	23	31	39		
	Total of alien species	9	3	9	8	9	11	9	20		
	Total	21	19	24	33	25	34	40	59		

Note(s): ◎: Native species; ●: Alien Species; ▲: Specified Alien Species; NT: Near Threatened; LP: Local Population; A: Annual glass, P: Perennial, W: Woody.

2020	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
1	*Equisetum arvense*	◎	◎	◎	◎	◎	◎	◎	◎		P
2	*Houttuynia cordata*					◎			◎		P
3	*Elodea nuttallii*	●		●							P
4	*Potamogeton oxyphyllus*			◎							P
5	*Iris pseudacorus*			●			●				P
6	*Commelina communis*	◎	◎	◎	◎	◎	◎	◎	◎		A
7	*Juncus decipiens*			◎							P

2020	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
8	*Juncus tenuis*			◎		◎	◎				P
9	*Cyperus amuricus*								◎		A
10	*Cyperus brevifolius* var. *leiolepis*			◎		◎			◎		A
11	*Cyperus difformis*					◎	◎	◎	◎		A
12	*Cyperus eragrostis*					●					A
13	*Cyperus flaccidus*					◎					A
14	*Cyperus glomeratus*					◎	◎	◎	◎	NT	A
15	*Cyperus iria*					◎		◎			A
16	*Cyperus microiria*					◎	◎	◎	◎		A
17	*Cyperus nipponicus*					◎			◎		A
18	*Cyperus pacificus*					◎					A
19	*Fimbristylis dichotoma* var. *tentsuki*					◎					A
20	*Fimbristylis littoralis*						◎				A
21	*Lipocarpha microcephala*					◎			◎		A
22	*Schoenoplectiella triangulata*			◎							P
23	*Agrostis clavata* var. *nukabo*		◎								P
24	*Alopecurus aequalis* var. *amurensis*						◎	◎	◎		A
25	*Arthraxon hispidus*			◎							A
26	*Bromus japonicus*				◎						A
27	*Cynodon dactylon*			◎	◎						P
28	*Digitaria ciliaris*	◎			◎	◎		◎	◎		A
29	*Echinochloa crus-galli*			◎		◎	◎	◎	◎		A
30	*Eleusine indica*			◎							A
31	*Elymus tsukushiensis* var. *transiens*							◎			P
32	*Eragrostis minor*					●					A
33	*Eragrostis multicaulis*					◎		◎			A
34	*Lolium multiflorum*								●		A
35	*Microstegium vimineum*			◎			◎				A
36	*Miscanthus sinensis*	◎									P
37	*Panicum bisulcatum*					◎		◎			A
38	*Panicum dichotomiflorum*					●		●	●		A
39	*Phalaris arundinacea*	◎		◎	◎	◎	◎	◎	◎		P
40	*Phragmites japonica*					◎	◎				P
41	*Poa annua*	◎		◎				◎			A
42	*Poa pratensis*		●								P
43	*Poa trivialis*	●				●					P
44	*Polypogon fugax*		◎	◎			◎	◎			A
45	*Schedonorus phoenix*				●						P
46	*Setaria faberi*			◎	◎			◎	◎		A
47	*Vulpia myuros* var. *myuros*	●							●		A
48	*Zoysia japonica*			◎							P
49	*Cocculus trilobus*				◎						W
50	*Ranunculus sceleratus*	◎		◎			◎	◎			A
51	*Ranunculus silerifolius*	◎		◎			◎	◎			P
52	*Sedum bulbiferum*	◎		◎							A
53	*Sedum sarmentosum*	●	●	●	●	●	●		●		P
54	*Aeschynomene indica*			◎	◎		◎	◎			A
55	*Amorpha fruticosa*			●			●				W
56	*Chamaecrista nomame*							◎			A
57	*Glycine max* ssp. *soja*							◎			A
58	*Kummerowia stipulacea*					◎					A
59	*Kummerowia striata*			◎							A
60	*Lotus corniculatus* ssp. *japonicus*							◎			P
61	*Melilotus officinalis* ssp. *albus*					●	●	●	●		A
62	*Trifolium pratense*				●	●					P
63	*Trifolium repens*			●			●	●	●		P
64	*Vicia japonica*				◎						P
65	*Humulus scandens*			◎					◎		A
66	*Morus australis*		◎						◎		W

2020	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
67	*Boehmeria silvestrii*			◎							P
68	*Pilea pumila*			◎		◎	◎	◎	◎		A
69	*Potentilla centigrana*						◎				P
70	*Rubus parvifolius*			◎							W
71	*Sicyos angulatus*			▲	▲			▲	▲		A
72	*Celastrus orbiculatus* var. *orbiculatus*			◎							W
73	*Oxalis corniculata*			◎	◎						P
74	*Oxalis dillenii*			●	●	●					P
75	*Acalypha australis*		◎		◎	◎			◎		A
76	*Euphorbia maculata*			●	●	●		●	●		A
77	*Euphorbia nutans*			●	●						A
78	*Salix dolichostyla*			◎							W
79	*Viola verecunda* var. *verecunda*						◎	◎			P
80	*Geranium thunbergii*		◎								P
81	*Ammannia coccinea*					●		●			A
82	*Rotala indica*						◎				A
83	*Ludwigia epilobioides* ssp. *epilobioides*					◎	◎	◎			A
84	*Oenothera biennis*			●							A
85	*Ailanthus altissima*								●		W
86	*Barbarea vulgaris*			●	●	●					P
87	*Cardamine occulta*			◎			◎	◎			A
88	*Lepidium virginicum*								●		A
89	*Nasturtium officinale*						●	●	●		P
90	*Rorippa palustris*			◎		◎	◎	◎	◎		A
91	*Persicaria hydropiper*					◎	◎	◎			A
92	*Persicaria lapathifolia* var. *lapathifolia*			◎		◎		◎	◎		A
93	*Persicaria longiseta*			◎		◎	◎	◎			A
94	*Persicaria perfoliata*								◎		A
95	*Persicaria sagittata* var. *sibirica*			◎				◎			A
96	*Persicaria thunbergii* var. *thunbergii*					◎	◎	◎	◎		A
97	*Rumex acetosa*	◎		◎	◎	◎					P
98	*Rumex acetosella* ssp. *pyrenaicus*	●			●						P
99	*Rumex japonicus*						◎				P
100	*Rumex obtusifolius*			●	●	●	●	●			P
101	*Arenaria serpyllifolia* var. *serpyllifolia*	◎		◎	◎	◎			◎		A
102	*Cerastium glomeratum*	●		●							A
103	*Sagina japonica*			◎							A
104	*Silene armeria*					●		●	●		A
105	*Stellaria aquatica*			◎							A
106	*Stellaria uliginosa* var. *undulata*			◎				◎			A
107	*Amaranthus retroflexus*			●				●	●		A
108	*Chenopodium album* var. *centrorubrum*								●		A
109	*Dysphania pumilio*			●		●			●		A
110	*Mollugo verticillata*					●			●		A
111	*Trigastrotheca stricta*					◎					A
112	*Portulaca oleracea*					◎		◎	◎		A
113	*Impatiens textorii*			◎							A
114	*Galium gracilens*			◎	◎	◎	◎	◎		LP	P
115	*Galium spurium* var. *echinospermon*			◎							A
116	*Calystegia pubescens*				◎						P
117	*Cuscuta campestris*							●	●		P
118	*Solanum ptychanthum*							●	●		A
119	*Callitriche japonica*	◎	◎	◎							A
120	*Plantago asiatica* var. *asiatica*	◎		◎			◎				A
121	*Veronica anagallis-aquatica*	▲		▲		▲	▲	▲	▲		P
122	*Veronica arvensis*			●	●	●		●			A
123	*Veronica undulata*						◎	◎		NT	A
124	*Lindernia dubia*						●	●			A
125	*Lindernia procumbens*			◎		◎	◎	◎			A

2020	Scientific Name	Area								Valuable Species	Life-Form
		1	2	3	4	5	6	7	8		
126	*Vandellia micrantha*					◎					A
127	*Clinopodium gracile*			◎	◎	◎	◎				P
128	*Mosla dianthera*	◎		◎		◎	◎	◎			A
129	*Mazus pumilus*					◎					A
130	*Ambrosia trifida*			•	•	•		•	•		A
131	*Artemisia indica* var. *maximowiczii*		◎	◎	◎	◎			◎		P
132	*Bidens frondosa*	•	•	•	•	•	•	•	•		A
133	*Eclipta alba*	•		•	•	•	•	•	•		A
134	*Erigeron annuus*	•		•	•	•	•				A
135	*Erigeron canadensis*				•						A
136	*Erigeron philadelphicus*				•						A
137	*Erigeron sumatrensis*			•			•	•			A
138	*Petasites japonicus* var. *japonicus*	◎	◎	◎				◎			P
139	*Pseudognaphalium affine*			◎	◎	◎					A
140	*Solidago altissima*			•			•				P
141	*Sonchus oleraceus*			◎			◎				A
142	*Taraxacum officinale*				•						P
143	*Xanthium orientale* ssp. *italicum*								•		A
144	*Youngia japonica* ssp. *japonica*	◎									P
145	*Oenanthe javanica* ssp. *javanica*			◎		◎	◎	◎			P
Total of native species		16	10	52	19	42	35	40	26		
Total of alien species		9	3	21	17	20	13	17	21		
Total		25	13	73	36	62	48	57	47		

Note(s): ◎: Native species; •: Alien Species; ▲: Specified Alien Species; NT: Near Threatened; LP: Local Population; A: Annual glass, P: Perennial, W: Woody.

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