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DISTURBANCE AND CONSEQUENT CHANGES OF RIVERBED ENVIRONMENTS BY TYPHOON HAGIBIS FLOOD IN 2019 AT THE MIDDLE REACHES OF THE TAMA RIVER, CENTRAL JAPAN

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Abstract Typhoon Hagibis caused severe flooding and damage to the riverbed environments of the Tama River, in October 2019. Damages and consequent changes to the riverbed environments, particularly to the population of *Aster kantoensis* Kitamura (Kawara-nogiku), an endangered plant species, in Hamura City were investigated. Although the flood had severely harmed the flora population, the two-year period following the disaster allowed the population to regenerate. The wind direction frequency surrounding Hamura, which is influenced by geomorphological conditions, may have proved advantageous for maintaining *A. kantoensis* populations.

Keywords: Typhoon Hagibis, river flood, *Aster kantoensis* Kitamura, Tama River, Hamura City

1. Introduction

The Tama River is a representative urban river of Japan. In particular, the riverside area in the southern part of the Hamura City, western Tokyo Metropolis, is an interesting area for studying the relationship between human activities and the riverine environment because of the presence of the Hamura Intake Weir, entrance to the Tamagawa Aqueduct (Tamagawa Josui), and populations of *Aster kantoensis* Kitamura (Kawara-nogiku), an endangered plant species endemic to Japan.

Typhoon Hagibis (T1919) caused multiple damages including flooding of the Tama River basin in eastern Japan, in October 2019 (e.g. Muroi *et al.* 2021) causing bank collapses and gravel depositions in high-water level riverbeds including public areas (riverside parks and grounds) in the Hamura and Ome cities, which are located on the alluvial fan head of the Musashino Upland (Musashino Plateau) and the current Tama River valley. It also caused significant damages to the *A. kantoensis* population. We introduce damages by the Typhoon Hagibis around the Hamura Intake Weir briefly, and discuss damage and regeneration of *A. kantoensis* population in the Miyanoshita point bar near the Hamura Weir (Fig. 1).

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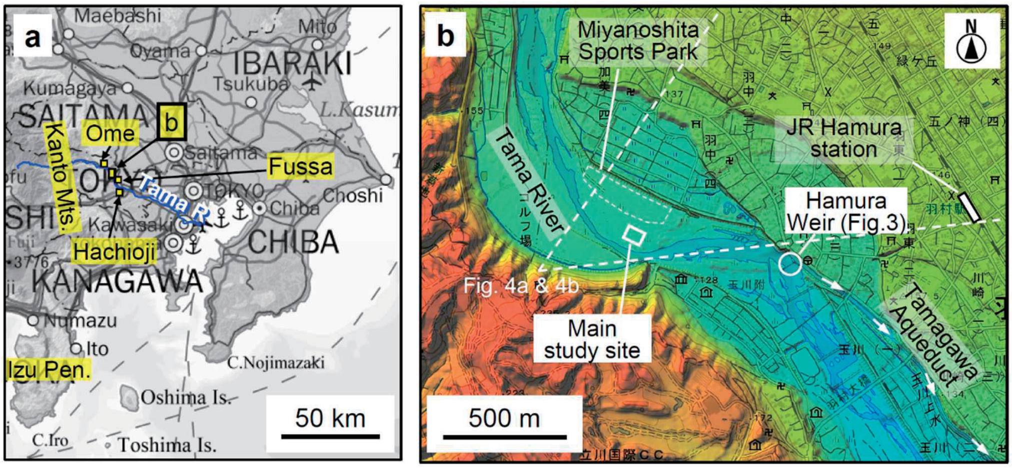

Fig. 1 Location of the study sites. (a) Index map showing the Tama River and cities surrounding the study sites. (b) Topography around the study sites. White arrows show course of the Tamagawa Aqueduct. The base map is topographic map by Geospatial Information Authority of Japan.

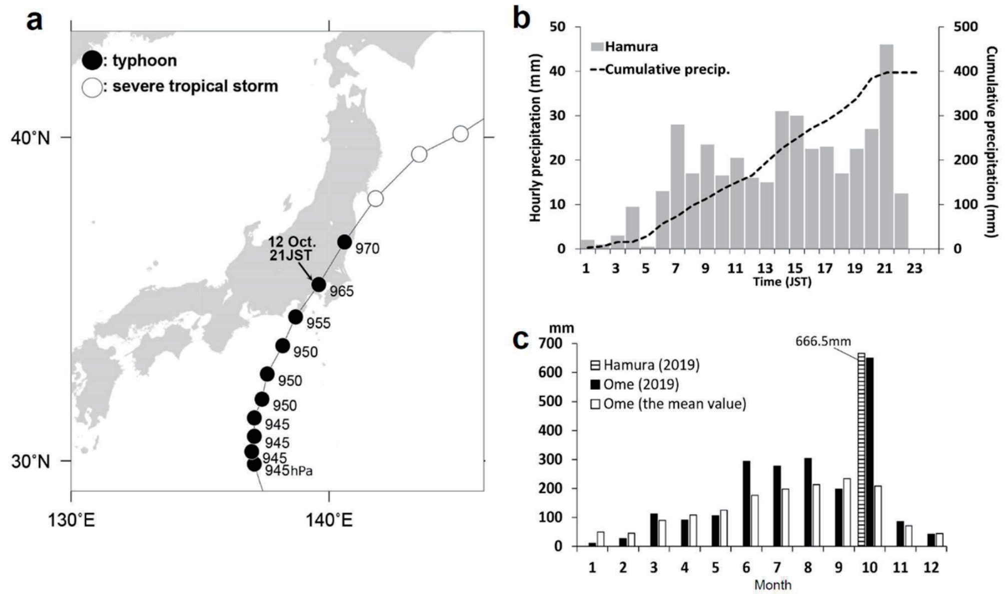

Fig. 2 Track of Typhoon Hagibis (T1919) and precipitation around the Hamura City in October 2019. (a) Track of Typhoon Hagibis. Circles and numerical values indicate the typhoon center position and central pressure (hPa) every 3-hourly, plotted based on the best track data by Regional Specialized Meteorological Center (RSMC) Tokyo - Typhoon Center, respectively. (b) Hourly and cumulative precipitation amounts during October 12, 2019, observed at the Hamura City office. (c) Monthly precipitation at AMeDAS Ome and the Hamura City office. White and black bar graphs indicate the climatological values averaged for 1991–2020 and the observed values of 2019 at AMeDAS Ome, respectively. Striped bar graph indicates the observed value at the Hamura City office in October 2019.

2. Heavy precipitation at the Hamura City caused by Typhoon Hagibis

Typhoon Hagibis made landfall on the Izu Peninsula around 19 JST on October 12, 2019, and moved northeastward through the Kanto Plain with a central pressure of around 965 hPa (Fig. 2a). Due to the typhoon, a record-high daily precipitation was observed around the Hamura City where it rained continuously from 6 JST to 22 JST on October 12, 2019, and the maximum hourly precipitation (49.0 mm) was recorded around 21 JST when the center of the typhoon passed near the Hamura City (Fig. 2b). The cumulative precipitation during the day was 397.0 mm, which was a new record that significantly exceeded the previously recorded maximum daily precipitation of 275.0 mm at the Hamura City from April 1984 to December 2014, as shown by Akasaka (2019). Additionally, the monthly precipitation of 666.5 mm in October 2019 corresponds to approximately 3.2 times of the mean precipitation in October, averaged for 1991–2020 at AMeDAS Ome (Fig. 2c) near the Hamura City (Fig. 1a).

3. Damages around the Hamura Intake Weir by Typhoon Hagibis flood

The Hamura Intake Weir itself was not damaged by the Typhoon Hagibis flood. The weir has "Nagi", one of the traditional types of movable weir (Fig. 3a and 3b), which is made of steel frame, wood logs, fascines, and gravels (Fig. 3c). During severe floods, logs, fascines and gravels are removed to avoid destruction of the weir and aqueduct. Although steel frame was added during early 20th century, the basic structure of the "Nagi" has not changed since the construction of the aqueduct and weir in 1653 during the Edo Era. Removal and reconstruction of "Nagi" have been done 56 times during 1989–2019. Whereas, concrete slopes and bank protections on downstream side of the

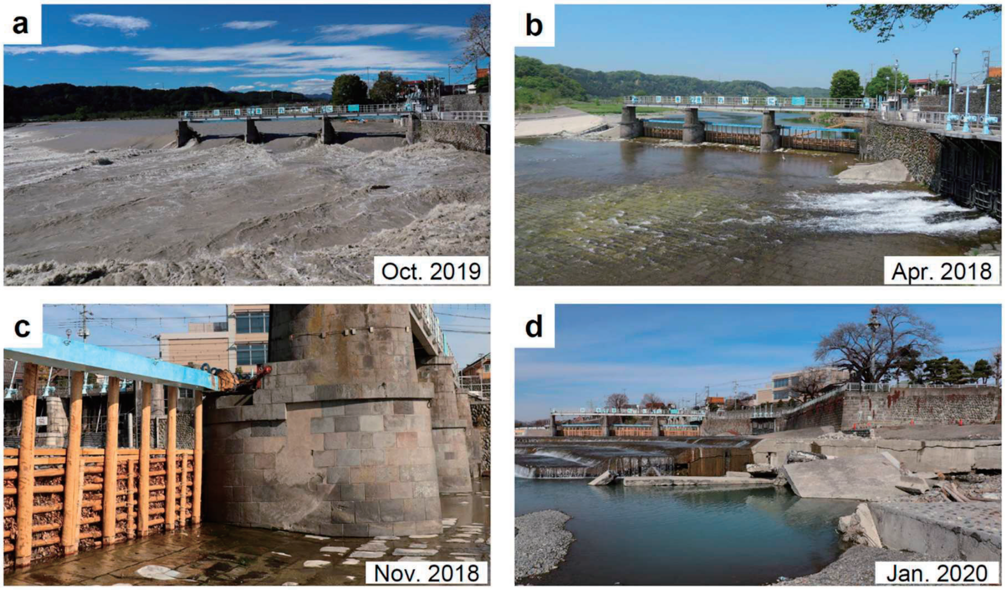

Fig. 3 Damages around the Hamura Intake Weir by the Typhoon Hagibis flood. (a) Removed "Nagi" during the Hagibis flood. (b) "Nagi" in usual condition of river flow. (c) Close-up view of "Nagi". (d) Damaged concrete slopes by the Typhoon Hagibis flood.

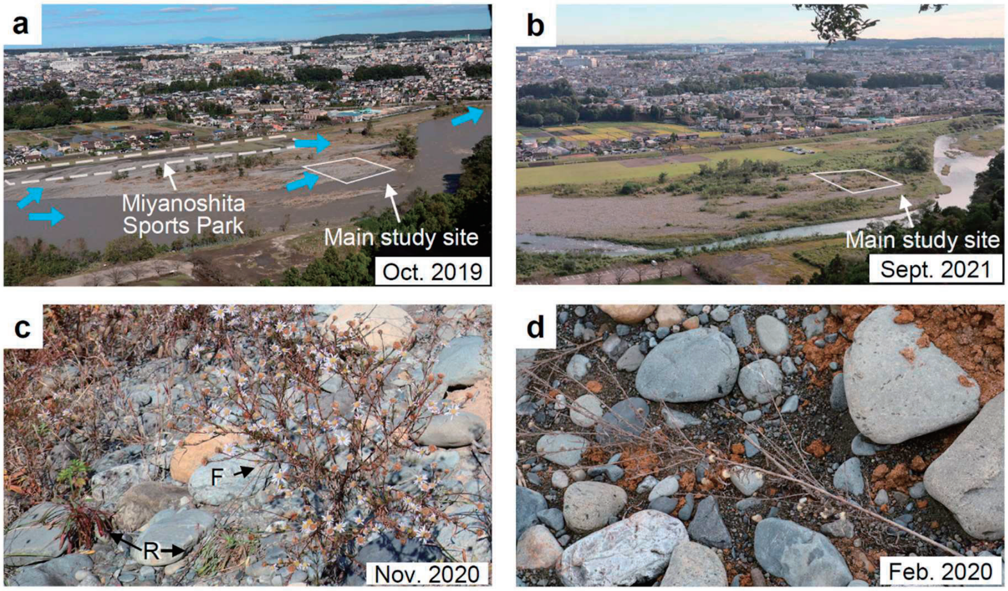

Fig. 4 Deposition of gravel–sand on the Miyanoshita point bar by the Typhoon Hagibis flood. (a) and (b) Whole view of the point bar on the next day of passage of the typhoon and two years later. Light blue colored arrows show flood flow direction. (c) Flowering individual "F" and rosette "R" of *A. kantoensis*. (d) A flowering individual of *A. kantoensis* survived the Typhoon Hagibis flood.

weir collapsed by the Hagibis flood (Fig. 3d), the partial subsidence of residual concrete blocks showed that collapse could have been caused by the erosion of riverbed gravels underlying the concrete structures.

At the Miyanoshita point bar (Fig. 1b), ca. 500 m upstream from the Hamura Intake Weir, a large volume of deposits was transported into the Miyanoshita Sports Park from the river channel (Fig. 4a). As described by Shirai and Utsugawa (2022), gravels tend to distribute from the middle portion of the bar to the downstream part, while suspended sand grains tend to distribute from the upstream to the far side of the river channel. The main study site, which includes a population of *A. kantoensis* (Fig. 4c) originated from artificial sowings in about 2007 (e.g. Takaoka 2019), is located downstream of the bar (Figs. 1b and 4b) and was covered by gravels and sands (Fig. 4d).

4. Regeneration of *A. kantoensis* population after the Typhoon Hagibis flood

A brief description of *Aster kantoensis*

Aster kantoensis Kitamura (Compositae), called Kawara-nogigu (riverbed wild aster) in Japanese, is an endangered plant species (Ministry of Environment, Government of Japan 2020) and is endemic in the middle reaches of gravelly high-water level riverbed of the Abe, Kinu, Sagami and Tama rivers in central Japan (e.g. Kuramoto 1998). The height of upright stalk with flower head is ca. 0.5–1 m, and the pale purple-colored flower (Fig. 4c) is ca. 3.5–4 cm in diameter (e.g. Takenaka *et al*. 1996). As a stalk of *A. kantoensis* sprouts from the gaps between gravels on the riverside, it is assumed that the stalk utilizes the moisture contained in sandy deposits under and/or between gravels to thrive and grow (Kagaya *et al*. 2008; Takaoka 2019). *A. kantoensis* seeds get dispersed in early January and germinate mainly in the spring season; in the first year, most of them overwinter as "rosettes in midair"; the leaves radiate from the root and leave the ground by a short stalk (Fig. 4c). In the following flowering year, the stalk elongates from late June to early July, and the plants flower from late October to early November (e.g. Inoue *et al*. 1998). Although the flowering age of *A. kantoensi*s is from 2 to 5 years (e.g. Kagaya *et al*. 2009), in most cases it is biennial.

Initial vegetation changes along a transect

Vegetation transect surveys were conducted in November 2020 and October 2021 in the Miyanoshita point bar that was flooded by the Typhoon Hagibis (Fig. 5). The site was previously covered by *A. kantoensis* growth until it was damaged by flood. A 125-meter transect was made from the stream edge (Fig. 6), with 63 contiguous plots of 2 × 2 m spaced along it. The plots were surveyed to measure vegetation coverage and height, and count the number of flowering and rosette *A. kantoensis*.

In 2020, a total of 34 flower bearing and 16 rosettes were found in plots 38–44 m from the stream edge, while 2 flowering plants were found in plots 90–94 m from the stream edge (Fig. 5d). During the 2019 flood, nearly all of the *A. kantoensis* population in the area was wiped out. The height of the flowering plants in 2020 were above 50 cm, indicating that they had not germinated after the flood of 2019, but rather survived from plants that were growing prior to the storm and flooding.

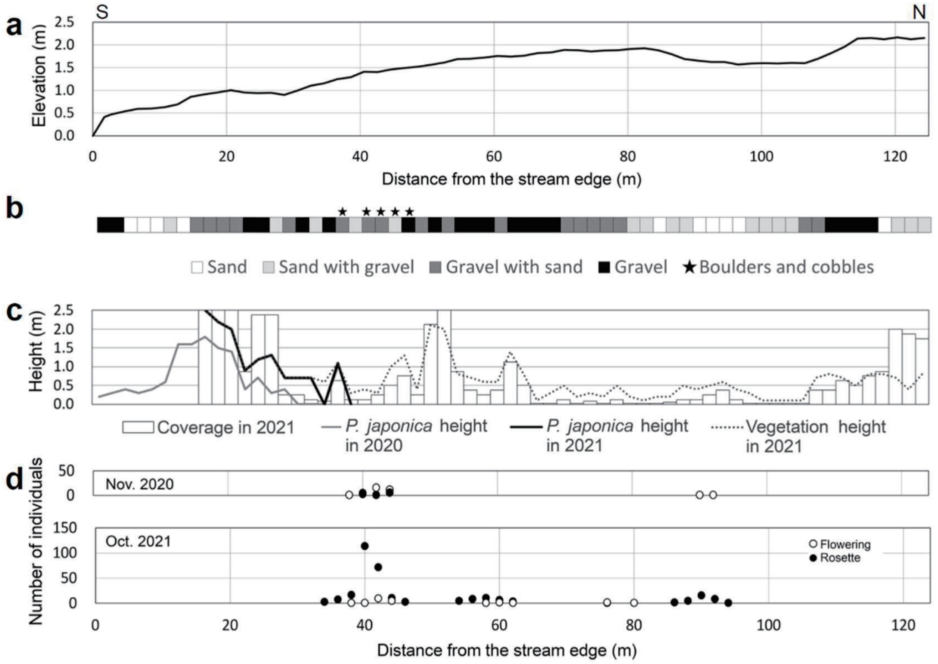

Fig. 5 Changes in vegetation along the transect. (a) Elevation from the water surface on November 15, 2020. (b) Surface materilas. (c) Vegetation height and coverage and height of *P. japonica* in November 2020 and October 2021. (d) Number of flowering and rosette *A. kantoensis* in November 2020 and October 2021. Note that no surveys were conducted in 0–14 m plots in 2021.

In October 2021, flowering and rosette-stage plants were concentrated in the plots located at 34–48 m, 54–64 m and 86–96 m from the stream edge (Fig. 5d). Of these, flowering plants in the plots where no rosettes had been observed in 2020 were less than 20 cm in height, suggesting that individuals in their first year of germination may have flowered. The majority of the 2021 rosettes were discovered near plots where flowering individuals were present in 2020, especially in plots 36–46 m from the stream edge, where boulders and cobble gravel predominated. This suggested that the microenvironmental condition created by the gravel was important for seedling establishment, as pointed out by Kagaya *et al*. (2008).

The height and coverage of herbaceous vegetation dominated by *Miscanthus sinensis* was high in the 50–54 m plots (Fig. 5c). The absence of *A. kantoensis* rosettes in these plots, even though they were close to the plots with flowering individuals in 2020, is probably related to the tall grass vegetation. *Phragmites japonica*, which was dominant in the 14–22 m plots in 2020, was regenerated by vegetative propagation from runners remaining after the flood. By October 2021, *P. japonica* had expanded its vegetative cover to the 38 m plot by extending its runners. The regeneration of *P. japonica* and *M. sinensis* communities is expected to reduce the suitable habitat for *A. kantoensis*.

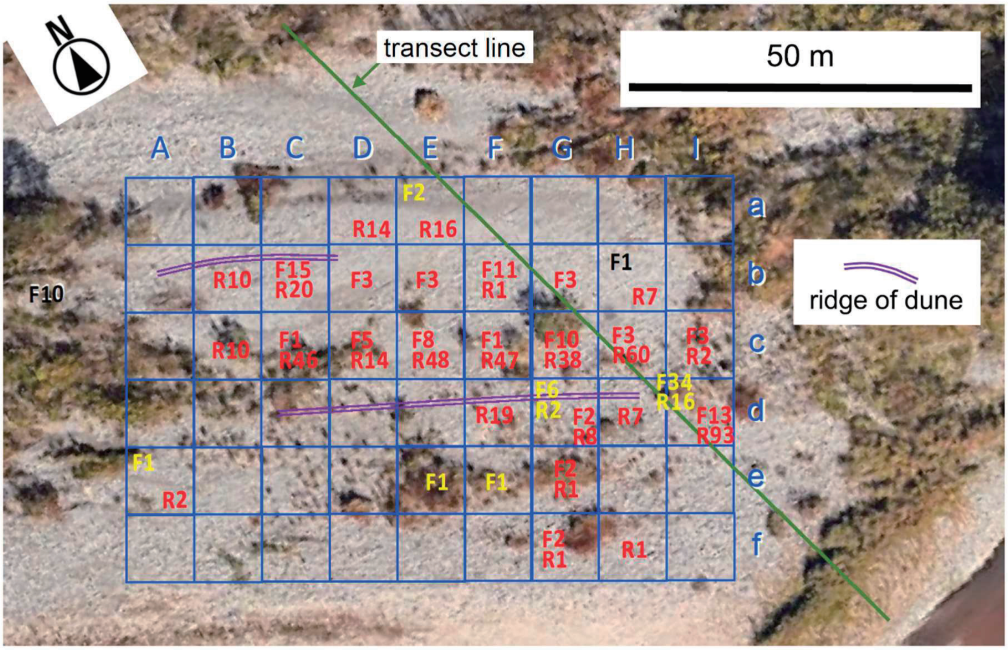

Fig. 6 Result of areal survey of *A. kantoensis* in Oct. 2021 (red). "F" and "R" mean number of flowering individual and rosette individual, respectively. Locations of flowering individual and rosette individual observed in Feb. 2020 (black) and Nov. 2020 (yellow) surveys are also shown. The base map is aerial photo by Google Earth.

Change in distribution of *A. kantoensis* individuals

In addition to the vegetation transect survey, areal survey was conducted to grasp spatial distribution of individuals of the *A. kantoensis* population after the Typhoon Hagibis flood at the Miyanoshita point bar. A plot of 60 × 90 m size including the *A. kantoensis* individuals observed by the transect survey and being parallel to axes of troughs and ridges on the point bar was set and divided into 54 quadrates of 10 × 10 m size (Fig. 6). Numbers of flowering and rosette individuals in each quadrate are shown in the figure. For comparison, results of field surveys immediately after the flood (November 2019 to February 2020) and the next flowering season (November 2020) are also shown in Fig. 6. Because the population of *A. kantoensis* at the site was severely damaged by the flood due to deposition of gravel and sand, we found just one flowering individual in quadrate H-b (Fig. 4d) and ten flowering individuals on the upstream side of quadrate A-b (covered by vegetation on October 2021 survey). However, a large number of flowering individuals in the next flowering season (November 2020) was observed, suggesting the possibility of our failure to find the rosettes immediately after the flood. If a flowering individual shorter than 20 cm in height flowered in their first year of germination based on the results of the transect survey, 56 or more rosettes might have survived the flood, because 45 flowering individuals higher than 20 cm were observed in the following flowering season. Similarly, although only 18 rosettes were recognized on November 2020 survey, 87 or more rosettes might have existed because 69 flowering individuals with height more than 20 cm were observed on October 2021 survey. The number of rosette and flowering individuals increased to approximately 500 and 100, respectively, after two years of recovery from the Typhoon Hagibis flood.

The majority of rosette individuals observed in October 2021 would have derived from two large (height > 80 cm) flowering individuals in quadrate E-a and/or 34 flowering individuals in and around quadrate I-d in November 2020. In any case, from the flowering individuals in 2020, about half of the rosette individuals in 2021 spread west–northwestward. During the months of December to February, *A. kantoensis* seeds are thought to be distributed mostly by the northwesterly wind (e.g. Kuramoto *et al*. 2005). Kuramoto *et al.* (2005) found that two to three times the total amount of seeds were carried south–eastward in contrast to north–westward based on seed-trap observations set on a population of *A. kantoensis* in the Fussa City, adjacent to the Hamura City (Fig. 1a). The NW–NNE wind was predominant during December to February, based on wind direction data of AMeDAS Hachioji (Fig. 1a) from December 2002 to February 2003. Whereas, Akasaka (2019) and other climatologists pointed out that in winter, the northwesterly wind around the Hamura City is weakened by a barrier effect of the Kanto Mountains, which is located on western margin of the Kanto District (Fig. 1a) and the frequency of S–SE wind increases from February. Given the repeated transportation of seeds up to being trapped by high-relief ground surfaces such as unembedded gravel beds (Kuramoto *et al*. 2005), it is plausible that *A. kantoensis* seeds are transported northwestward as many as south–southeastward due to the wind condition around the Hamura area. Seed movement upstream may be beneficial in maintaining *A. kantoensis* populations along the Tama River.

5. Conclusions

The Typhoon Hagibis in October 2019 greatly affected the riverside environment of the Tama River, one of the representative urban rivers in Japan. The Hamura Intake Weir itself was not damaged due to "Nagi", one of the traditional types of movable weir system, but the modern concrete slopes and bank protection system downstream side of the weir collapsed. Despite the fact that the population of *A. kantoensis* was severely damaged by the flood, two years after the flood, the plant population began to regenerate on the refreshed gravelly river bed. The wind direction around Hamura, which is regulated by geomorphological setting (a barrier effect of the Kanto Mountains) was found to be advantageous for upstream seed transportation and growth of *A. kantoensis* spread; however, invasion of other plant species into the refreshed riverbed can pose a threat to the population of *A. kantoensis*.

Acknowledgments

On the occasion of Professor Makiko Watanabe's retirement from Tokyo Metropolitan University, this report is dedicated to her. This report utilizes a part of results of the History of Hamura-city compilation project, and the editing room of the History of Hamura-city allowed us to publish a part of the results.

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