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Report

Autumn and winter periphyton biomass in the Ohtakigawa River watershed 1 year after the 2014 eruption of Mount Ontake, central Japan

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Abstract

To understand the effect of the 2014 Mount Ontake eruption on the river periphyton community in the Ohtakigawa River watershed and its recovery processes, several parameters associated with water quality and chlorophyll-*a* amounts on stones reflecting the biomass of epilithic algae were investigated between September 2015 and February 2016. The adjoining Nigorigawa and Shimokurosawa rivers are tributaries of the Ohtakigawa. Erupted materials from Mount Ontake accumulated in the Nigorigawa riverbed. The pH and electrical conductivity of the Ohtakigawa changed drastically after the junction with the Nigorigawa, indicating that the Nigorigawa strongly affected the water quality of the Ohtakigawa. Periphyton biomass, quantified as chlorophyll-*a* amount in the Nigorigawa was low at 0.02-0.06 mg Chl.*a* m^{-2}. Chlorophyll-*a* in the Shimokurosawa was also low at 0.3 mg Chl.*a* m^{-2} in September and October, however, a rapid increase to 26 mg Chl.*a* m^{-2} was observed in November in the absence of the shading effects of riparian vegetation. Propagation of the filamentous green alga *Stigeoclonium lubricum* and the unicellular diatom *Gomphonema* was observed. Chlorophyll-*a* amounts at the Ohtakigawa 1 station ranged from 35 to 74 mg Chl.*a* m^{-2} with propagation of the large filamentous green alga, *Cladophora*. However, these values dropped sharply at the Ohtakigawa 2 station after the junction with the Nigorigawa, and the markedly low biomass was maintained during the investigation period. The periphyton community was not established at the Nigorigawa and Ohtakigawa 2 stations, which received the flow of erupted materials during the investigation period, within 12-16 months after the eruption. The physical disturbance of the riverbed and the chemical components of the river water, acidified by volcanic activity, are presumed to have had a negative effect on periphyton biomass accumulation and algal growth in the Nigorigwa River and at Ohtakigawa 2 station.

Key words: periphyton biomass, Ohtakigawa River watershed, Mount Ontake, volcanic eruption

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Introduction

Volcanic eruption results in a remarkable disruption to the freshwater periphyton habitat through the physical destruction of the community, changes in water quality, and volcanic ash accumulation on substrates (Ward *et al*., 1983; Rushforth *et al*., 1986; Steinman and Lamberti, 1988). Although active volcanoes are widely distributed throughout the Japanese Islands (National Astronomical Observatory, 2016), the influence of volcanic eruption on the periphyton community and its subsequent recovery processes have yet to investigated. Mount Ontake (elevation 3067 m), an active volcano located in the central part of the Japanese Islands, suddenly erupted on September 27 in 2014 (Oikawa *et al*., 2015; Kaneko *et al*., 2016; Maeno *et al*., 2016). Large amounts of erupted materials fell on the mountainside, and

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the ash flowed into the Ohtakigawa River. To understand the effect of the disturbance caused by the eruption of the volcano on the river periphyton community and its recovery processes, the present study investigated several parameters indicative of water quality and chlorophyll-*a* amounts on stones, as indicators of the biomass of epilithic algae, between September 2015 and February 2016 in the Ohtakigawa River watershed.

Table 1. Geographical information for each sampling station. Values were taken from the GSI（Geospatial Information Authority of Japan）web site.

Sampling station	Latitude	Longitude	Elevation m
Nigorigawa	N35°48'12"	E137°28'54"	1035
Shimokurosawa	N35°48'42"	E137°28'17"	1031
Kurokawa	N35°52'32"	E137°40'31"	844
Ohtakigawa 1	N35°47'56"	E137°28'59"	1019
Ohtakigawa 2	N35°47'54"	E137°29'05"	1013

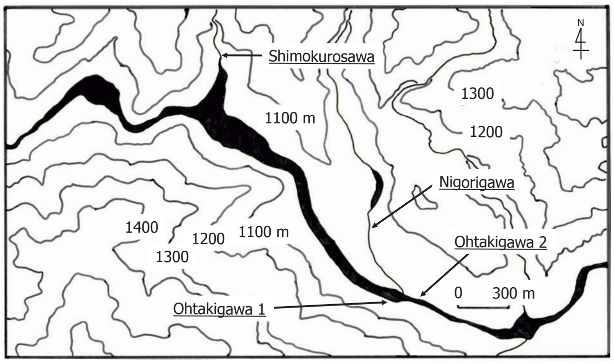

Fig. 1. A map of the locations of each sampling station in the Ohtakigawa watershed.

Methods

Geographical information of each sampling station is listed in Table 1. Latitude, longitude and elevation values were obtained from the web site of the Geospatial Information Authority (GSI) of Japan. Figure 1 shows a map of the locations of each sampling station in the Ohtakigawa watershed. Location of the Kurokawa shows in Onoda and Kayaba (2016). The adjoining Nigorigawa and Shimokurosawa rivers both flow from the top of Mount Ontake, and are tributaries of the Ohtakigawa River. The Nigorigawa was open environment (Fig, 2A）. Erupted materials from a vent on Mount Ontake flowed along the Jogokudani Valley (Oikawa *et al*., 2015; Kaneko *et al*., 2016), at the headwaters of the Nigorigawa. Thus, fine sediments such as volcanic ash accumulated in the riverbed of the Nigorigawa (Fig. 2B). In contrast, the Shimokurosawa runs through dense deciduous forests (Fig. 2C). For this study, a control station was established in the Kurokawa River, a branch of the Kisogawa River flowing from the Kaidakogen highland at the foot of Mount Ontake (Fig. 2D). To investigate the ecological effects of the erupted materials on periphytic algae, two sampling stations were established in the Ohtakigawa River. Ohtakigawa 1 station was located before the junction with the Nigorigawa (Fig. 2E), and Ohtakigawa 2 station was established after the junction with that river (Fig. 2F). All stations were located on sections or river with gravel riverbeds.

Field surveys were conducted four times on September 6-8, October 8-10 and November 29-30 in 2015, and February 27-28 in 2016. Water temperature (using an alcohol thermometer), pH (WAK-pH/WAK-BCG Pack Test, Kyoritsu Rikagaku Company), electrical conductivity (CM21P electrical conductivity meter, TOA-DDK Company) and water turbidity (WA1 water analyzer, Nippon Denshoku Company) were measured at each sampling station. Water samples were transferred to glass fiber filters (GF-75, Advantec Company) in preparation for analyses of water color and nutrient concentrations. Water color was measured with a water analyzer (WA1 water analyzer, Nippon Denshoku Company). Nutrient analyses were performed by measuring NH_4^+-N, NO_2^--N, NO_3^--N, PO_4^{3-}-P and SiO_2 concentrations.

Three gravel clasts were collected at each station for periphyton sampling. The surface area of the stones growing periphytic algae was calculated as simple geometric shapes such as triangle, quadrangle, trapezoid and ellipse. Large filamentous green algae, such as *Cladophora*, were gently removed from the stones. Other periphytic algae were collected using a steel brush. Each sample was filtered using a glass fiber filter (GF-75, Advantec Company). Filters collecting periphyton were used for analyses of chlorophyll-*a* (UNESCO method) and dry weight. The dry weight of the periphyton was measured after drying for 48 hours at 50℃. Periphytic algae were observed under an optical microscope (BX-51, Olympus Company), and photomicrographs were acquired using a digital camera (Camedia C-5060, Olympus Company). Nutrient analysis, periphyton collection, and chlorophyll-*a* and dry weight measurements were performed according to the Tokai Branch of the Japanese Society of Limnology (2014).

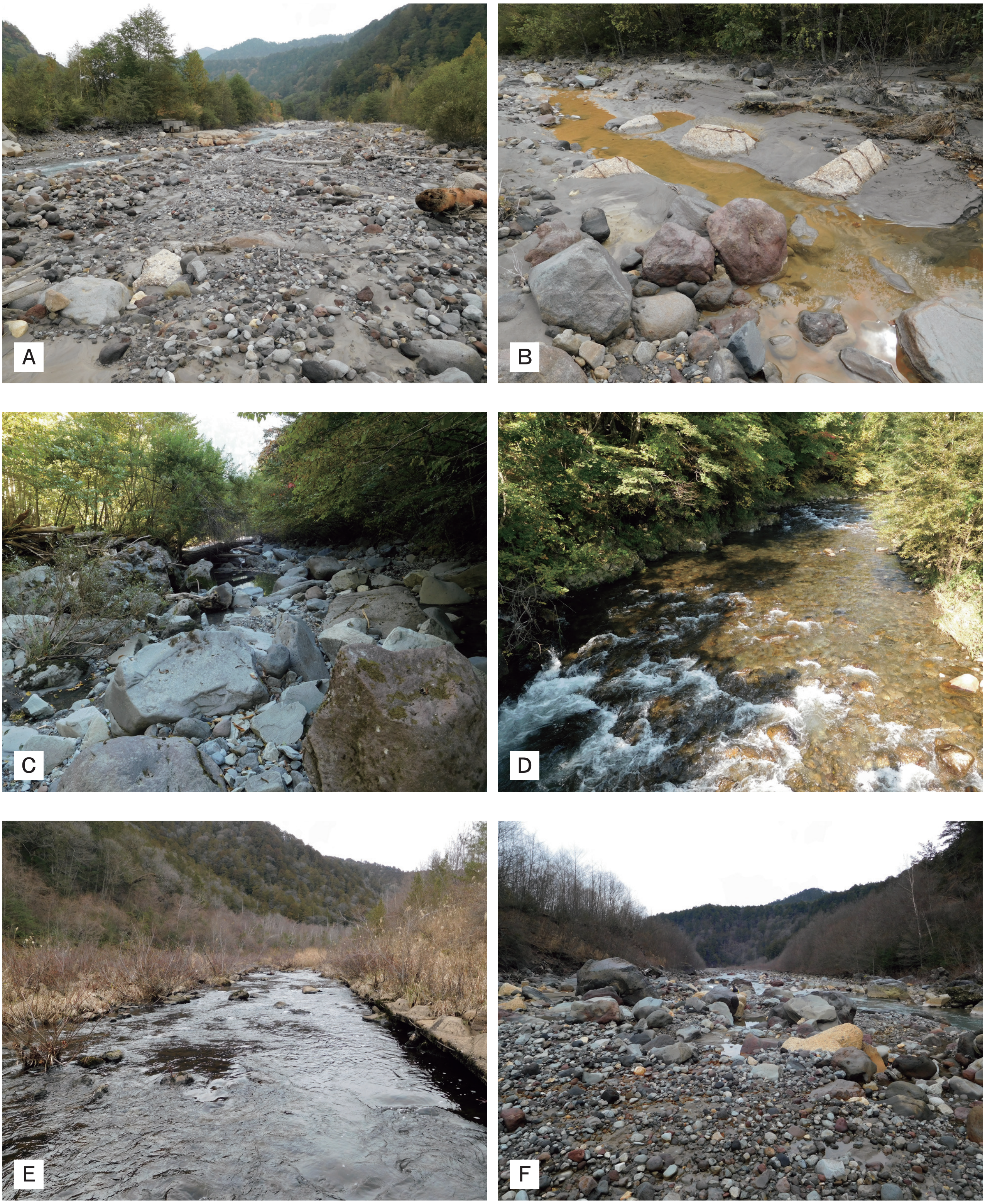

Fig. 2. Photographs of sampling stations. 2A: Nigorigawa (October 10, 2015), 2B: Accumulation of volcanic ash in the riverbed of the Nigorigawa (October 10, 2015), 2C: Shimokurosawa (October 8, 2015), 2D: Kurokawa (October 9, 2015), 2E: Ohtakigawa 1 (November 29, 2015) and 2F: Ohtakigawa 2 after the junction with the Nigorigawa (November 29, 2015).

Table 2. Parameters of water quality at each sampling station. E. C. is electrical conductivity. W. T. is water temperature.

Date	Time	Weather	W.T. ℃	E.C. mS m^{-1}	pH	Turbidity	Color
Nigorigawa							
7 September 2015	10:40	rain	13.8	27.30	5.0	139.6	0.0
8 October	16:35	fine	9.9	34.40	5.2	7.6	0.2
9 October	17:15	fine	10.7	34.70	5.3	3.6	0.2
10 October	13:55	cloud	11.4	34.80	5.3	3.4	0.8
29 November	13:30	fine	7.5	36.30	5.2	4.0	0.0
30 November	8:45	fine	5.6	36.80	5.1	4.8	0.0
28 February 2016	15:20	fine	6.8	39.00	5.0	3.3	0.0
Shimokurosawa							
6 September 2015	14:30	rain	11.9	5.26	6.5	0.4	0.0
7 September	13:15	rain	13.1	2.24	7.0	39.7	0.0
8 October	14:00	fine	10.6	3.60	6.5	0.7	2.0
30 November	13:15	fine	7.6	2.61	6.3	4.6	3.1
27 February 2016	13:40	snow	2.0	3.32	6.5	3.2	3.0
Kurokawa							
8 September 2015	9:15	rain	12.6	3.41	6.5	1.2	0.2
9 October	9:45	fine	9.6	5.08	6.2	0.4	1.1
29 November	10:30	fine	6.1	4.65	6.2	0.2	0.8
27 February 2016	10:55	cloud	3.0	5.07	6.2	0.3	0.0
Ohtakigawa 1							
10 October 2015	13:20	cloud	12.8	2.76	6.8	0.9	4.3
29 November	14:30	fine	8.1	3.48	6.8	1.0	1.7
28 February 2016	16:10	fine	5.0	2.88	6.8	1.9	1.3
Ohtakigawa 2							
10 October 2015	14:15	cloud	11.7	28.50	5.4	2.8	0.4
29 November	15:10	fine	7.4	22.40	5.4	3.0	0.8
28 February 2016	16:30	fine	5.6	18.53	5.4	3.9	1.8

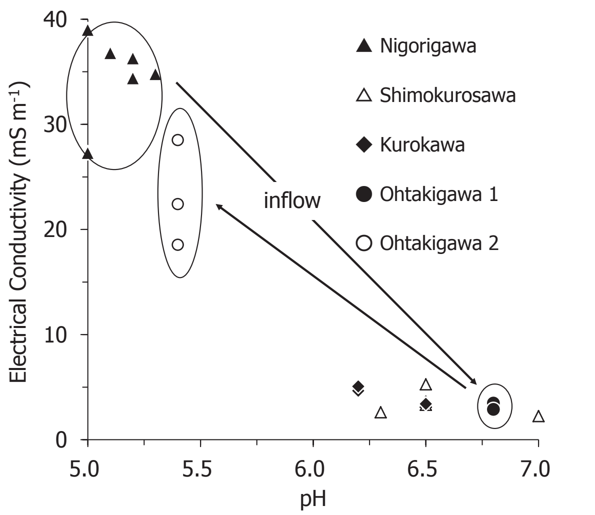

Fig. 3. Relationship between pH and electrical conductivity at each sampling station. The pH and electrical conductivity of the Ohtakigawa changed drastically after the junction with the Nigorigawa, indicating that the Nigorigawa strongly affected the water quality of the Ohtakigawa.

Results and Discussion

Parameters of water quality

General information of water quality at each sampling station is listed in Table 2. At the Nigorigawa and Ohtakigawa 2 stations, electrical conductivity was higher and pH was lower than at the other stations. Tanaka *et al*. (1984) measured the pH in the Ohtakigawa watershed on November 13-15 and December 22 in 1979, and on March 10-11 in 1980, after the Mount Ontake eruption on October 28 in 1979. Values in the upper reaches of the Nigorigawa and the Shimokurosawa were 3.1 and 7.3-7.6, respectively, and pH in the Ohtakigawa was 4.9 after the junction with the Nigorigawa. Tomatsu *et al*. (1994) reported pH values 8 years after a large-scale landslide caused by the Western Nagano Prefecture Earthquake in 1984. Values in the lower reaches of the Nigorigawa and at the Ohtakigawa after the

Table 3. Nutrient concentrations in the river water at each sampling station (N.D. = not detected).

Date	NH_4^+-N μg L^{-1}	NO_2^--N μg L^{-1}	NO_3^--N μg L^{-1}	PO_4^{3-}-P μg L^{-1}	SiO_2 mg L^{-1}
Nigorigawa					
7 September 2015	28.1	4.5	77.9	7.6	3.4
8 October	23.8	0.5	47.1	9.0	4.4
9 October	7.4	N.D.	45.3	9.8	4.3
10 October	5.6	N.D.	46.2	6.8	4.8
29 November	2.3	N.D.	42.7	0.9	33.3
30 November	7.1	N.D.	50.8	0.9	33.6
28 February 2016	12.8	N.D.	72.4	1.2	33.1
Shimokurosawa					
6 September 2015	4.9	N.D.	43.6	19.4	15.2
8 October	16.5	N.D.	40.9	9.8	10.7
30 November	N.D.	N.D.	32.0	2.3	9.7
27 February 2016	9.0	N.D.	117.0	4.1	9.0
Kurokawa					
8 September 2015	4.0	0.1	149.0	10.6	9.1
9 October	15.6	9.2	113.2	6.8	10.8
29 November	1.4	N.D.	102.6	5.3	11.0
27 February 2016	9.0	N.D.	99.1	4.1	10.9
Ohtakigawa 1					
10 October 2015	11.0	13.2	34.6	2.3	9.2
29 November	7.1	N.D.	41.8	0.9	11.6
28 February 2016	N.D.	N.D.	58.1	1.2	10.3
Ohtakigawa 2					
10 October 2015	2.9	N.D.	41.8	9.0	4.5
29 November	0.6	N.D.	48.1	2.3	20.6
28 February 2016	3.7	N.D.	48.5	2.7	19.2

junction with the Nigorigawa were 4.4 and 4.5 in July, 6.4 and 6.4 in September, and 6.8 and 6.8 in October 1992, respectively. Figure 3 shows the relationship between pH and electrical conductivity at each station. The values for the Ohtakigawa changed drastically after the junction with the Nigorigawa, indicating that the Nigorigawa strongly affected the water quality of the Ohtakigawa.

The Nigorigawa water became white and turbid during the investigation period. Suspended particles such as volcanic ash appeared to be the cause of the turbidity, because water color measurements using filtered samples showed almost clear values (Table 2). On November 30 in 2015 and February 27 in 2016, the turbidity values at the Shimokurosawa were similar to those at the Nigorigawa. Water color increased in parallel, suggesting that dissolved organic matter such as humic substances resulted in increased turbidity.

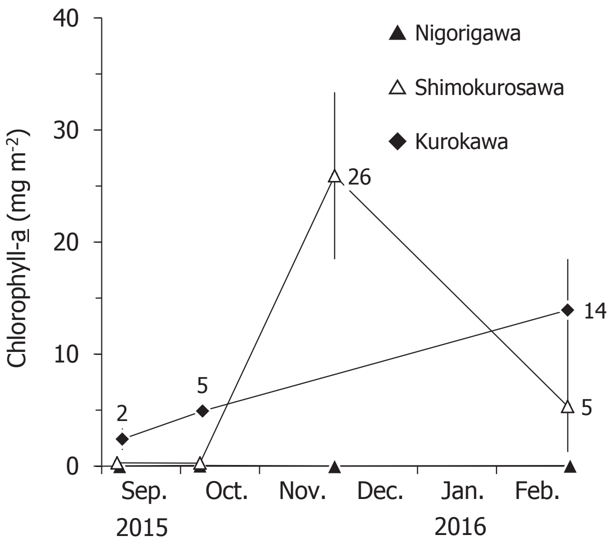

Fig. 4. Temporal changes in chloropyll-*a* amounts at sampling stations in the Nigorigawa and Shimokurosawa rivers as tributaries of the Ohtakigawa River, and at the Kurokawa River as control. Error bars show the SD (n=3).

Nutrient concentrations are listed in Table 3. The concentrations of dissolved inorganic nitrogen and phosphorus did not differ significantly among the stations. The analyses showed nitrogen- and phosphorus-poor conditions at all stations. SiO_2 concentrations were comparable to those measured in July, September and October 1992 by Tomatsu *et al*. (1994), except for the values recorded in the Nigorigawa in September and October 2015. The cause of the low SiO_2 concentrations remains unclear.

Periphyton biomass

Changes in periphytic chlorophyll-*a* amounts in the Nigorigawa, Shimokurosawa and Kurokawa are shown in Figure 4. Chlorophyll-*a* amounts, indicating periphyton biomass, on the Nigorigawa riverbed, where the erupted materials accumulated, were low at 0.02-0.06 mg Chl.*a* m^{-2}. The values were also low in the adjacent Shimokurosawa in September and October 0.3 mg Chl.*a* m^{-2}, however, a rapid increase in biomass was observed in November. Propagation of the filamentous green alga *Stigeoclonium lubricum* and the unicellular diatom *Gomphonema* was observed (Fig. 5). Chlorophyll-*a* amounts in the Kurokawa showed a tendency to increase toward February (Fig. 4). Previous field studies performed in Japan reported that the periphyton biomass in the upper and middle reaches of rivers with stony and gravel riverbeds is often high from late autumn to winter (Tominaga and Ichimura, 1966; Nakanishi and Yamamura, 1984; Nozaki, 2004; Nozaki,

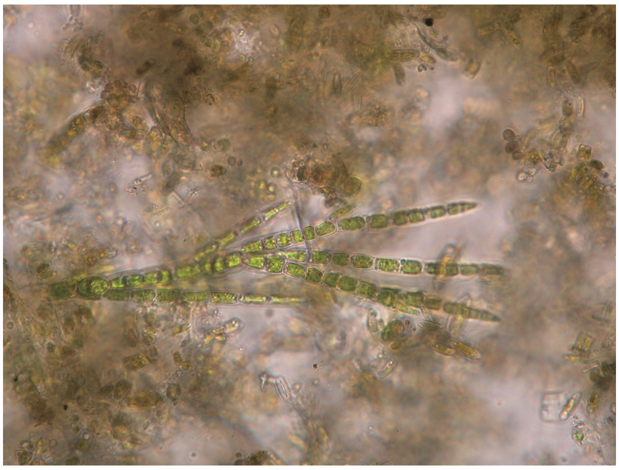

Fig. 5. Photomicrograph of a periphytic algal community collected from the Shimokurosawa on November30, 2015 (maginification 200×).

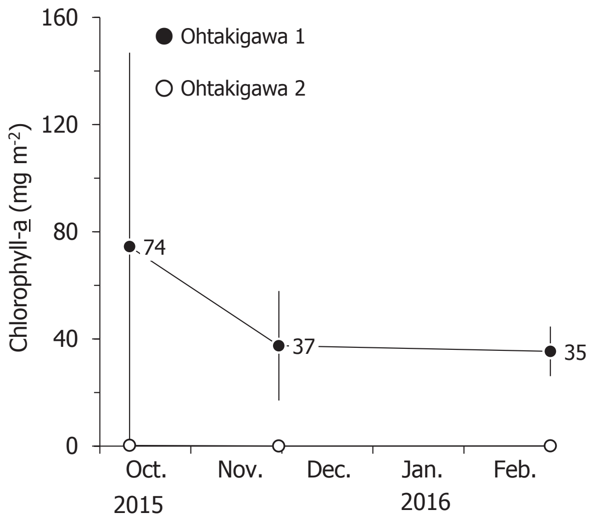

Fig. 7. Temporal changes in chlorophyll-*a* amounts at stations 1 and 2 on the Ohtakugawa River. Error bars show the SD (*n*=3).

Fig. 6. Shimokurosawa on November 30, 2015.

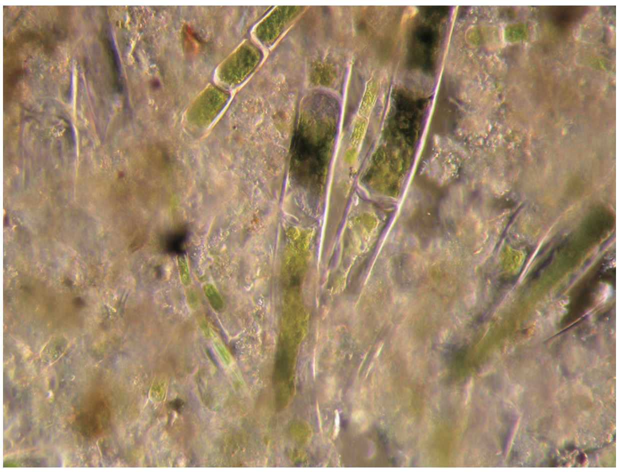

Fig. 8. Photomicrograph of a periphytic algal community collected from the Ohtakigawa 1 station on October 10, 2015 (maginification 200×).

2013; Nozaki and Shimura, 2013).

Light availability, nutrient concentration, and water temperature have a significant effect on the growth of river periphyton by affecting photosynthetic activity and respiration, and the periphyton biomass is regulated by physical disturbances such as floods, and grazing (Biggs, 1996). Along the Shimokurosawa (Fig. 6), the periphyton biomass showed a rapid increase in November despite low water temperatures and nitrogen- and phosphorus-poor conditions. This suggests that the periphytic algae were not restricted by the shading effects of riparian vegetation after leaf fall (Sumner and Fisher, 1979; Allan, 1995, p. 89-90). Hill *et al*. (1995) reported that leaf canopies can intercept 95 % or more incident radiation in some small streams.

Chlorophyll-*a* amounts at stations along the Ohtakigawa are shown in Figure 7. The average values of periphytic algal biomass at the Ohtakigawa 1 station ranged from 35 to 74 mg Chl.*a* m^{-2}. Propagation of the large filamentous green alga *Cladophora* was detected at each sampling date (Fig. 8), however, periphyton biomass decreased sharply at Ohtakigawa 2 station after the junction with the Nigorigawa, and a remarkably low biomass was maintained during the investigation period. The extremely low chlorophyll-*a* amounts at the Nigorigawa and Ohtakigawa 2 stations in the absence of canopy shading could be attributed to unstable riverbed conditions caused by the inflow of sediments transported from the large landslide zone of the upper reaches of the Nigorigawa (Ashida and Egashira, 1986; Inokuchi and Yagi, 2014). The effect of natural physical disturbances on riverbed stability is a major factor regulating periphytic algal biomass (Uehlinger, 1991; Biggs, 2000). In fact, the main channel of both rivers was covered with newly accumulated sediment and driftwood (Fig.2A and F).

Although acidification resulting from volcanic emissions is another possible explanation of inhibiting algal growth, the complete disappearance of periphytic algal vegetation does not occur at a pH of 5 (Planas, 1996). When the Western Nagano Prefecture Earthquake occurred in 1984, an acidic hot spring (pH 5.4), the Nigorigawa-onsen, located in the middle reaches of the Nigorigawa was buried by a debris flow (Inokuchi and Yagi, 2014). Kokubu *et al*., (1977) reported that hot spring water collected on June 29 in 1975 contained abundant dissolved inorganic matter such as Na^{+} (735 mg L^{-1}), Cl^{-} (760 mg L^{-1}), SO_4^{2-} (645 mg L^{-1}), Fe^{2+} (9.1 mg L^{-1}), Fe^{3+} (14.5 mg L^{-1}), Al^{3+} (5.4 mg L^{-1}) and SiO_2 (229 mg L^{-1}). This chemical composition strongly suggests that the hot springs were influenced by volcanic emissions

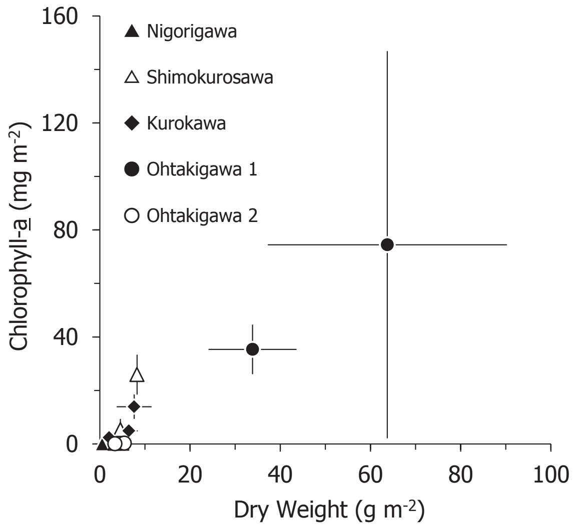

Fig. 9. Relationships between periphyton dry weight and chlorophyll-*a* amounts at each sampling station. Error bars show the SD（*n*=3）.

(Yoshiike, 2003; Sanada *et al*., 2013). The present-day Nigorigawa water is acidic (pH 5) and shows higher electrical conductivity indicating an abundance of dissolved inorganic matter (Fig. 3). Thus, the volcanic activity at Mount Ontake affects the water quality of the Nigorigawa via hot springs welling up from vents. The present study did not investigate the inhibiting effect of dissolved inorganic matter derived from acid hot springs (especially certain metals such as iron and aluminum) on periphyton growth (Planas, 1996). Therefore physiological activities such as photosynthesis and respiration in the periphyton collected from the Ohtakigawa 1 station should be measured by incubation in the Nigorigawa water in future studies to determine the influence of water chemistry on such activity.

Recovery of periphyton community

Periphyton communities were not established at the Nigorigawa and Ohtakigawa 2 stations (which received the flow of erupted materials) during the investigation period within 12-16 months after the eruption. Ward *et al*. (1983) reported the recovery of many different species of algae at various aquatic habitats in the blast zone within 3-4 months after the May 18, 1980 eruption of Mount St. Helens. Rushforth *et al*. (1986) also reported that algal communities were established throughout the blast impact area within 15 months or less of the eruption.

Ash derived from volcanic eruptions accumulates on periphytic algal communities on colonized substrates (Rushforth *et al*., 1986). Ash sediments appear to regulate algal growth through a shading effect. Figure 9 shows the relationship between the dry weight and chlorophyll-*a* amounts of the periphyton at each sampling station. If the erupted materials accumulated, dry weight would be increasing. In actual, a tendency towards an increase in dry weight on stones was not observed, indicating that algal growth was not inhibited by shading due to volcanic ash accumulation.

As discussed above, physical disturbance of the riverbed and the chemical components of volcanically acidified river water are presumed to have had a negative effect on periphyton biomass accumulation and algal growth at the Nigorigwa and Ohtakigawa 2 stations. These factors will be investigated further in future studies. Steinman and Lamberti (1988) found that species richness and diversity index values of periphytic algae tended to be lowest at the most heavily disturbed sites in the Mount St. Helens region 6 years after its eruption. Therefore, long-term studies are needed to understand the recovery processes of periphytic algal communities after the Mount Ontake 2014 eruption in the Ohtakigawa watershed.

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摘　要

2014年の御嶽山噴火から1年後の王滝川水系における秋と冬の付着藻現存量

野崎健太郎

2014年9月27日に発生した御嶽山（長野県，海抜3067 m）噴火が河川の付着藻群集に及ぼすかく乱および回復過程を理解するために，2015年9月～2016年2月に水質とクロロフィル *a* 量の調査を王滝川水系で行った。隣接した濁川と下黒沢川は王滝川の支流となる。火山噴出物は濁川の河原に堆積していた。王滝川の水質は，濁川が流入した後に大きく変化し，濁川が王滝川の水質形成に強く影響していることが明らかになった。クロロフィル *a* 量で示した濁川の付着藻現存量は0.02～0.06 mg Chl.*a* m^{-2}であり，常に低かった。下黒沢川の現存量は9月と10月の調査では0.3 mg Chl.*a* m^{-2}で低かったが，11月には河畔林の遮光が解消され26 mg Chl.*a* m^{-2}の急激な上昇を示し，糸状緑藻 *Stigeoclonium lubricm* や単細胞の珪藻 *Gomphonema* 属の繁茂が観察された。濁川が流入する前の王滝川地点1のクロロフィル *a* 量は35～74 mg Chl.*a* m^{-2}であり，大型糸状緑藻の *Cladophora* 属が繁茂していた。しかしながら，濁川が流入した後の王滝川地点2では，クロロフィル *a* 量は激減した。本研究の期間中に，御嶽山からの噴出物が流入した濁川と王滝川地点2では，付着藻群集の形成は観察できなかった。この原因は，河床の物理的かく乱と火山性の酸性河川水であると考えられた。

キーワード：付着藻現存量，王滝川水系，御嶽山，火山噴火

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