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Report

Accumulation of *Hydrurus foetidus* (Chrysophyceae) in sand ripples of a volcanic inorganic acidified river in the southern part of Mount Ontake, central Japan

Kentaro NOZAKI [1], Yoshitaka MATSUMOTO [2] and Takashi TASHIRO [3]

Abstract

On 28 February 2018, rippled patterns were observed in the riverbed of a volcanic inorganic acidified river in the southern part of Mount Ontake located in central Japan. The patterns were formed by the accumulation of colony fragments of a golden alga, *Hydrurus foetidus* (Villars) Trevisan (Chrysophyceae). The mean values (±standard deviation) of the areal dry mass, ash free dry mass and chlorophyll-*a* amounts of *H. foetidus* deposit were 530±200 g m^{-2}, 170±60 g m^{-2} and 240±60 mg Chl.*a* m^{-2}, respectively. Compared with a previous study, this *H. foetidus* deposit was observed to be an extremely large biomass at the study site. We considered that *H. foetidus* does not grow in this river owing to carbon dioxide limitations, and the accumulated fragments of *H. foetidus* colonies found in the troughs of sand ripples flowed from tributaries of neutral or alkaline water.

Key words: ripple, *Hydrurus foetidus* (Villars) Trevisan, Chrysophyceae, volcanic inorganic acidified river, Mount Ontake

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Accumulation of *Hydrurus foetidus* in troughs of sand ripples

Sand ripples are a general pattern on a riverbed caused by the accumulation of particles less than 0.6 mm (Japanese Society of Limnology, 2006; Tashiro, 2014). On 28 February 2018, rippled patterns were observed on the riverbed of the Nigorigawa River in the southern part of Mount Ontake located in central Japan (N35°48'12", E137°28'54", elevation 1035 m). These ripples had formed on the sandy bottom of a pool 24-30 cm deep and were filled with the accumulation of dark brown matter in the troughs (Figs. 1A and 1B). The Nigorigawa River primarily consists of the Nigorizawa River in strong acidic flow from the Jigokudani Valley (Fig. 2), which has the vent of Mount Ontake, and the slightly alkaline Denjogawa River (Usami *et al*., 2019; Matsumoto *et al*., 2020). Matsumoto *et al*. (2020) stated that the Nigorigawa River is acidified by volcanic sulfuric acid (H_2SO_4) from the vents of Mount Ontake, with a mean pH value of 4.2.

The environmental parameters of the current study site are shown in Table 1. The water temperature, electric conductivity (EC), pH and turbidity were measured with an alcohol thermometer, an EC meter (CM-21P, TOA DKK), a colorimetric method (WAK-pH/WAK-BCG, Kyoritsu Rikagaku) and a water analyser (WA1, Nippon Denshoku), respectively. The collected water samples were brought back to the laboratory. The alkalinity of a 300-mL sample was measured via titrating until pH 4.8 by 0.2 N H_2SO_4. The river water on the sampling dates was not significantly acidic, with a pH value of 6.5 on 28 February and 6.3 on 1 March. The water temperature, EC, pH and alkalinity

[1] School of Education, Sugiyama Jogakuen University, Hoshigaoka Moto-machi 17-3, Chikusa-ku, Nagoya, Aichi 464-8662, Japan (E-mail: ken@sugiyama-u.ac.jp)
[2] Department of Civil Engineering, National Institute of Technology, Toyota College, 2-1 Eisei, Toyota, Aichi 471-8525, Japan
[3] Disaster Mitigation Centre, Nagoya University, Furo-cho 1, Chikusa-ku, Nagoya, Aichi 464-8601, Japan

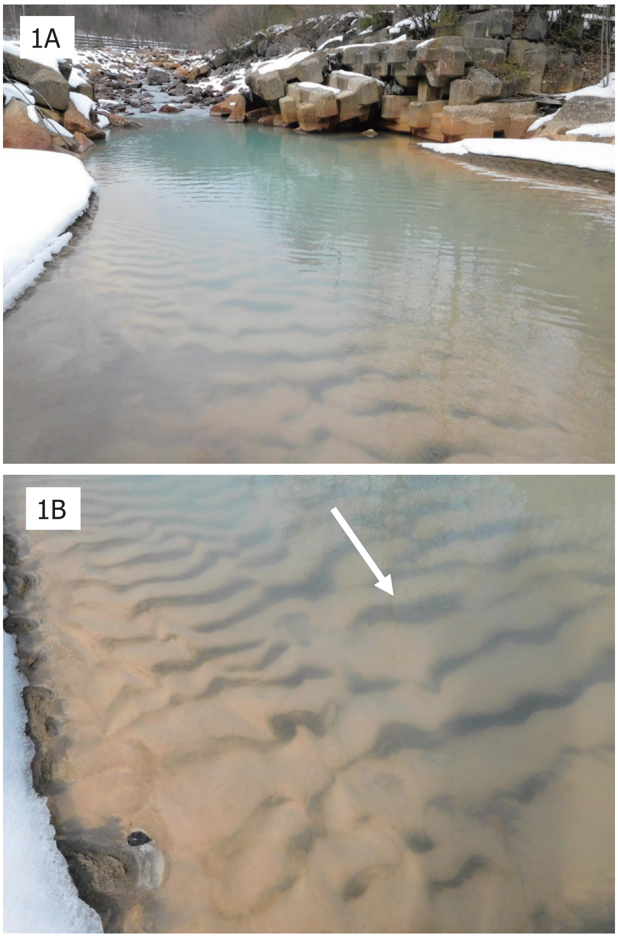

Fig. 1. Ripples in riverbed of a pool (1A) in a volcanic inorganic acidified river, Nigorigawa, at the southern part of Mount Ontake on 28 February 2018. Dark areas consist of brown particles found at troughs of ripples (1B). White arrow indicates the flow direction.

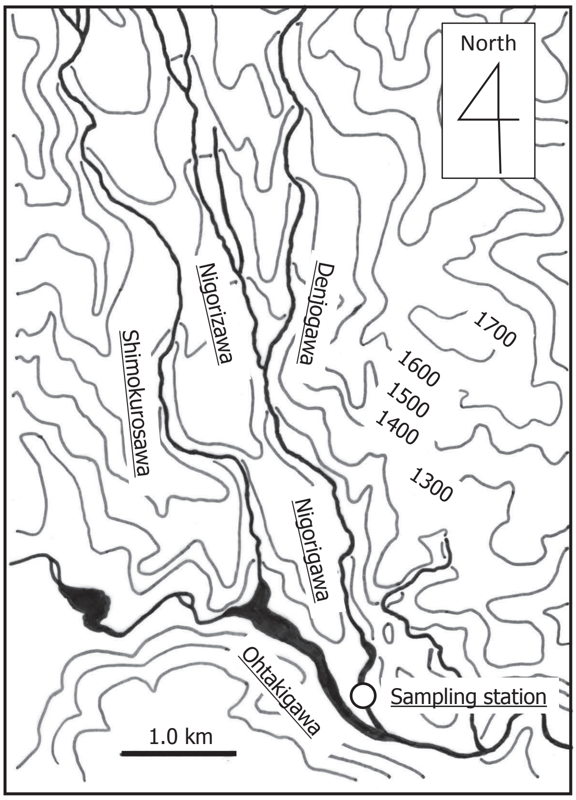

Fig. 2. Map of the study area.

Table 1. Environmental parameters in the sampling site of the Nigorigawa River.

	28 February	1 March
Weather	Fine	Cloudy
Sampling time	12:20	11:10
Water temperature (℃)	6.3	3.5
Electric conductivity (mS m^{-1})	40.0	32.5
pH	6.5	6.3
Alkalinity ($mgCaCO_3$ L^{-1})	6.1	2.4
Turbidity (mg L^{-1})	5.2	25.3

decreased, whereas the turbidity increased after 24.5 mm of rainfall occurred from 0:00 to 11:00 on 1 March. As the pH decreased within this short period, the alkalinity markedly reduced from 6.1 $mgCaCO_3$ L^{-1} to 2.4 $mgCaCO_3$ L^{-1}. Furthermore, the Shimokurosawa, a neutral river adjacent to the Nigorigawa, had an alkalinity of 16.3 $mgCaCO_3$ L^{-1} on 28 February. From these results, the Nigorigawa River was judged to be in a volcanic inorganic acidified state.

The deposited matter in the ripple troughs was gently collected with a glass pipette from a 3×3-cm area. When the samples were observed with an optical microscope (BX-51, Olympus Company) with a digital camera (DP 27, Olympus Company), they were observed to be colony fragments of golden alga *Hydrurus foetidus* (Villars) Trevisan (Figs. 3A-D). This freshwater alga is distributed worldwide (Kristiansen and Preisig, 2011; Klaveness, 2019) and forms bushy thalli up to 30 cm long on stones; it is known as a typical cold water species on the Japanese islands (Kobayasi, 1961; Fukushima, 1962; Kobayasi, 1972; Takahashi, 1977; Iyama *et al.*, 1984). Klaveness *et al.* (2011) found that *H. foetidus* is positioned at the Chrysophyceae clade in the phylogenetical tree based on 18S and 28S rRNA sequences. However, the position within the Chrysophyceae is still unclear, because of the limited numbers of sequences for Chrysophyceae taxa.

The dry mass, ash-free dry mass (AFDM) and chlorophyll-*a* amounts (UNESCO method) of the *H. foetidus* deposit are shown in Table 2. These factors were

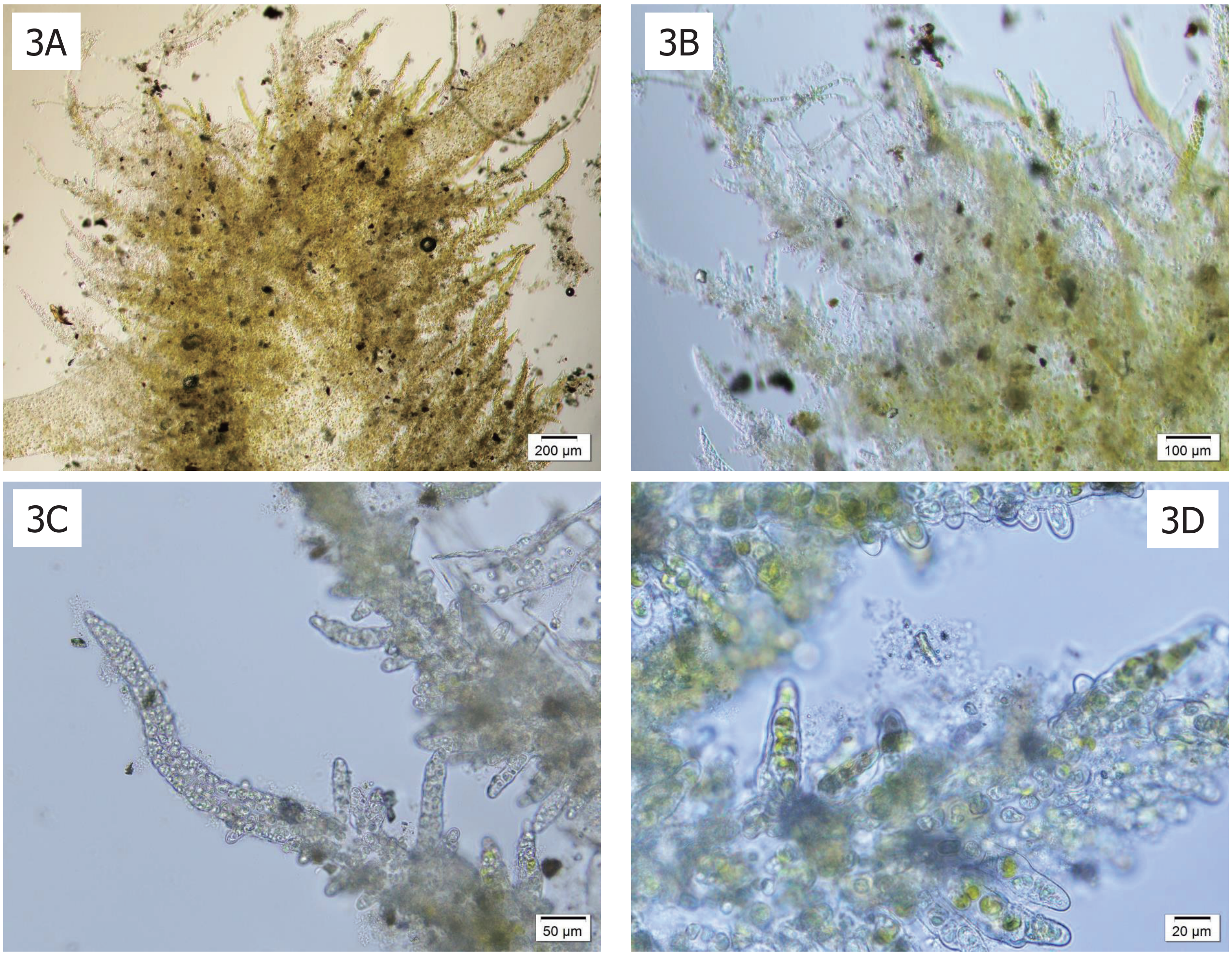

Fig. 3. Microscopic photos of a golden alga *Hydrurus foetidus* (Villars) Trevisan (Chrysophyceae) collected from the deposit in a pool of the Nigorigawa River on 28 February 2018. 3A: ×40, 3B: ×100, 3C: ×200, 3D: ×400.

measured according to Matsumoto and Nozaki's (2014) procedure. The mean values (±standard deviation) of the areal dry mass, AFDM and chlorophyll-*a* amounts were 530±200 g m^{-2}, 170±60 g m^{-2} and 240±60 mg Chl.*a* m^{-2}, respectively. Nozaki (2016) reported that the epilithic algal biomass in the Nigorigawa River was low at 0.02-0.06 mg Chl.*a* m^{-2} between September 2015 and February 2016. Therefore, this *H. foetidus* deposit at this study site was proven to be an extremely large biomass.

The growth potential and accumulation processes of *H. foetidus* at the sampling site were estimated using environmental factors. Normally, the alga is firmly attached to stone, and the colonies (20-30 cm long) form a slimy covering on riverbed materials (Takahashi, 1977; Kristiansen and Preisig, 2011). However, here, these collected *H. foetidus* deposits were colony fragments. Regarding its eco-physiological features, sufficient light (30-100 μmol m^{-2} s^{-1}), a low water temperature (2-3 ℃), and turbulence are important for growth (Klaveness and Lindstrøm, 2011). Current ripples are formed at a wavelength 600-800 times the mean diameter of sand particles under a steady flow (*e.g.* Charuru *et al*., 2013; Tashiro, 2014), and circulatory flow formed behind each lee slope of ripples, wherein the shear flow is separated from the crests and reattached to the stoss

Table 2. Dry mass and chlorophyll-*a* amount of *Hydrurus foetidus* deposit in 28 February 2018.

	Mean value (n = 3)	SD
Sampling depth (cm)	27	3
Dry mass (g m^{-2})	530	200
Ash-free dry mass (g m^{-2})	170	60
Ratio of ash-free dry mass (%)	33	5
Chlorophyll-*a* (mg Chl.*a* m^{-2})	240	60

Table 3. Dry mass and chlorophyll-*a* amount of epilithic materials in the main channel of the Nigorigawa River in 28 February 2018.

	Mean value (*n* = 3)	SD
Stagnation		
Sampling depth (cm)	13	5
Dry mass ($g\ m^{-2}$)	383	10
Ash-free dry mass ($g\ m^{-2}$)	36	1
Ratio of ash-free dry mass (%)	9.5	0.2
Chlorophyll-*a* (mg Chl.*a* m^{-2})	1.0	1.5
Riffle		
Sampling depth (cm)	25	8
Dry mass ($g\ m^{-2}$)	11	6
Ash-free dry mass ($g\ m^{-2}$)	1.4	0.6
Ratio of ash-free dry mass (%)	15.8	10.0
Chlorophyll-*a* (mg Chl.*a* m^{-2})	0.2	0.1

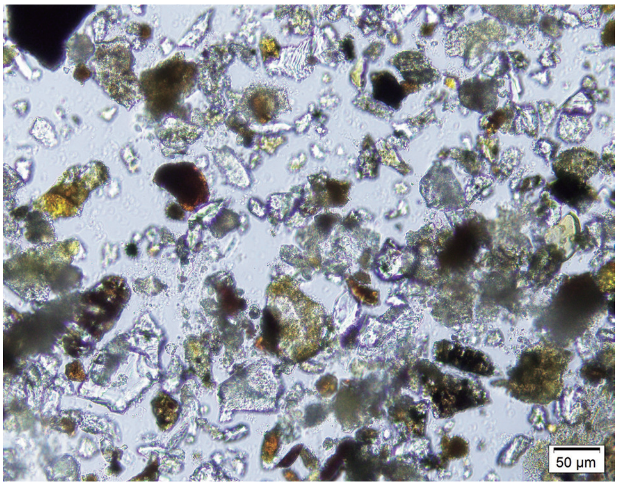

Fig. 4. Microscopic photo of epilithic materials collected from a cobble surface in a riffle of the Nigorigawa on 28 February 2018 (×200).

slopes (*e.g.* Sekine and Kikkawa, 1987; Raudkivi, 1996). Here, as the substrate was not stable enough to be attached to and the eddies were large enough to trap the fragments, we considered that the *H. foetidus* accumulated in the ripples had not grown there but drifted from the upper reaches.

Source of the *H. foetidus* deposit

The colony fragments of the *H. foetidus* might have been supplied from epilithic materials on stone surfaces in the Nigorigawa River and accumulated in the pool. However, the dry mass, AFDM and chlorophyll-*a* amount in the epilithic materials at the stagnation and riffle in the main channel were extremely low (Table 3). The alga could not be seen even when observing the epilithic materials with an optical microscope (Fig. 4). Certain factors seemed to be inhabiting the growth of the epilithic algae in this river. We assumed that the most influential factor was the depletion of carbon dioxide (CO_2), a source of photosynthesis. CO_2 concentration as dissolved inorganic carbon (DIC) is generally decreased in acidified freshwaters (Satake *et al.*, 1972; Satake and Saijo, 1974). In Experimental Lakes Area, Canada, a lake was artificially acidified with H_2SO_4, decreasing the pH from 6.8 to 4.5 over seven years. As the pH decreased, the alkalinity and DIC concentration also declined, and the net photosynthesis of the epilithic algal community was significantly attenuated (Turner *et al.*, 1991; 1995). Therefore, we considered that the *H. foetidus* in this study did not grow due to the CO_2 limitation

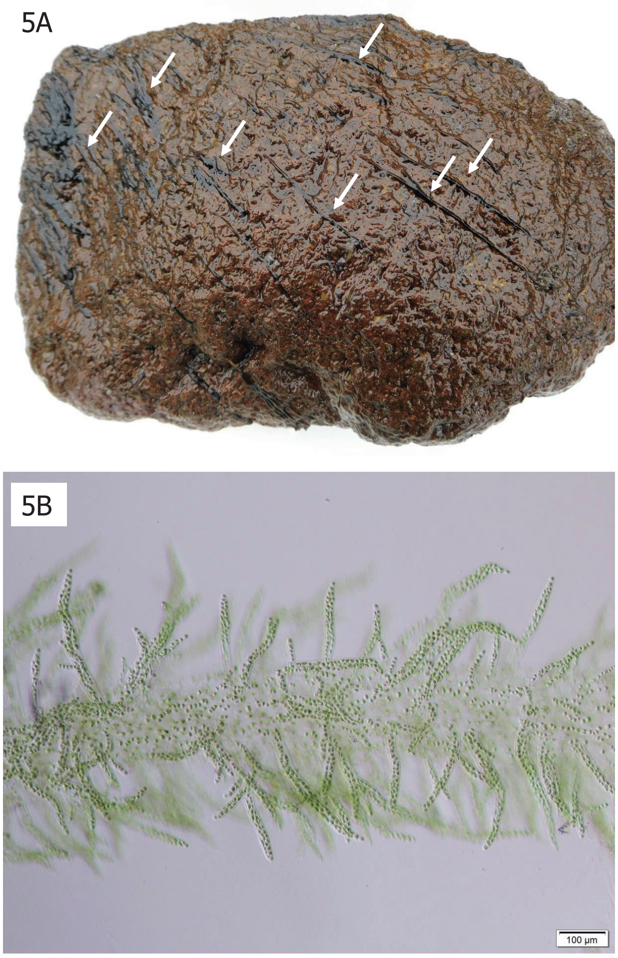

Fig. 5. Colony of *H. foetidus* growing on a cobble surface in a riffle of the Denjogawa River with the slightly alkaline water of a tributary of the Nigorigawa River on 9 November 2018. 5A: The white arrows indicate colonies. 5B: Microscopic photo of *H. foetidus* (×100).

in the Nigorigawa River, but that the colony fragments accumulated in the sand ripple troughs flowed in from tributaries of neutral or alkaline water. For example, on 9 November 2018, we observed the growth of *H. foetidus* on a cobble surfaces in the slightly alkaline Denjogawa River (pH 7.3), a tributary of the Nigorigawa River (Fig. 5A and 5B).

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摘　要

御嶽山南麓の火山性無機酸性河川における砂漣への黄金色藻ミズオ（*Hydrurus foetidus*）の堆積

野崎健太郎[1]・松本嘉孝[2]・田代　喬[3]

2018年2月28日に，御嶽山南麓の火山性無機酸性河川の河床において砂漣上に紋様が観察された。この紋様は，黄金色藻ミズオ *Hydrurus foetidus*（Villars）Trevisan の群体の断片が窪みに堆積することで形成されていた。ミズオ堆積物の単位面積あたりの乾燥重量，強熱減量およびクロロフィル *a* 量の平均値±標準偏差は，それぞれ，530±200 g m^{-2}，170±60 g m^{-2}，240±60 mg Chl.*a* m^{-2}であった。先行研究と比較すると，このミズオ堆積物は，本調査地において大変に大きな生物量であることがわかった。ミズオは，二酸化炭素律速によって，この川では成長できず，砂漣上に堆積していた群体の断片は，中性もしくはアルカリ性の支流から流入してきたと推察された。

キーワード：砂漣，ミズオ（*Hydrurus foetidus*），黄金色藻，火山性無機酸性河川，御嶽山

[1] 〒464-8662名古屋市千種区星が丘元町17-3椙山女学園大学教育学部（E-mail: ken@sugiyama-u.ac.jp）

[2] 〒471-8525愛知県豊田市栄生町2-1国立豊田工業高等専門学校都市環境工学科

[3] 〒464-8601名古屋市千種区不老町 名古屋大学減災連携研究センター

　