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AQUATIC MOSSES ON COBBLE IN RIFFLES AND THOSE RESISTANCE TO DISTURBANCES DUE TO HIGH FLOW AND SEDIMENT IMPACT

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ABSTRACT

The growth of aquatic mosses attached to cobbles as a bed material in riffles was confirmed in a river in Japan. Covering bed material with aquatic mosses reduces the biomass of attached algae that is a source of energy for commercial fish. We sought to understand how aquatic mosses maintain coverage on the river bed in riffles from the viewpoint of response to flood disturbance. Resistance to disturbances due to water flow and sediment impingement on mosses was investigated with a laboratory experiment. We observed that intermediate impact seems to remove silt in the biofilm but that the majority of mosses maintain coverage. Based on visual inspection of moss cover following the experiment, we found that remaining moss consists of short fresh stems. In general, mosses seem well adapted to the high-speed flow environment typical in riffles.

Keywords: aquatic moss, gravel-bed river, riffle, response to flood disturbance

1 INTRODUCTION

Gravel-bed rivers are a place for the production of attached algae. Fauna use attached algae as an energy source. Some moss plants seem to be well adapted to a high flow environment, so can grow on cobbles and boulders in riffles. On rare occasions, some birds and mammals are reported to eat terrestrial mosses. Although mosses do not seem to be the regular diet of most animals, attached algae are a popular energy source for herbivorous animals.

Japanese trout, *Plecoglossus altivelis*, is a popular commercial fish in Japan. Attached-algae, especially blue-green algae and diatoms, are said to be the main energy source for these fish (e.g. Shiragane et al., 2019). Figure 1 shows a river bed covered with a biofilm consisting of attached-algae (Whitton, 1970) and mosses. In Figure 1, bite marks are only found in areas covered by attached algae. More or less, the growth of mosses on river beds excludes the cover area of attached-algae, so the growth of mosses serves as a regulator of animal populations if attached algae are used as an energy source (Shiragane et al., 2019).

In this study, we sought to clarify the eco-hydraulic characteristics of mosses adapted to gravel-bed rivers and their response to flood disturbances. In the study, as illustrated in Figure 2, three types of disturbances were assumed (Ishio et al., 2013): **a)** moss removal due to strong shear stress and turbulence caused by high speed flow (Tsubaki et al., 2000), **b)** gravel impingement (Kitamura et al., 2000), and **c)** substrate rolling (Ogawa & Uchida, 2005).

2 MATERIALS AND METHODS

In earlier studies (Kitamura et al., 2000; Ishio et al., 2013), flow and sediment impingement impacts were evaluated using experimental channels. In this study, a jet flow made by a pump was used to represent water flow. Cobble covered with moss was sampled at riffles where the bulk velocity under normal flow conditions can reach a level of 2 m/s. A jet flow was used because a much stronger flow was expected for moss removal. Obtaining such high flow conditions, while maintaining sufficient water depth, was not possible in our flumes. Therefore, jet flow was incorporated in our study in order to reproduce: **a)** high speed flow and **b)** sediment impingement. For this purpose, we fixed a cobble with moss in a flume. Jet flow was impinged for 30 minutes. The bulk impinging flow velocity was changed to two ranges, ~2 m/s and ~4 m/s.

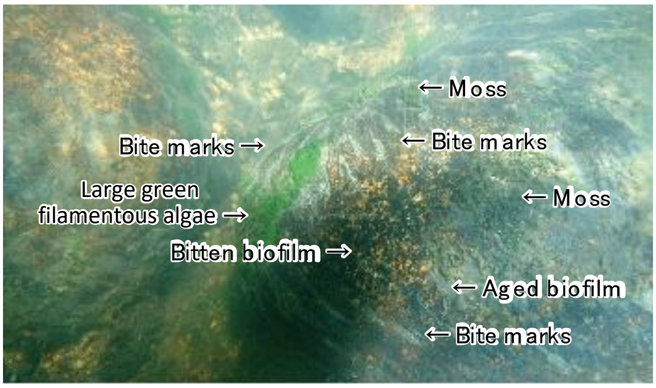


Figure 1. Photo of a river bed consisting of cobbles covered by large green filamentous algae, biofilm consisting of algae and moss plants. Bite marks made by Japanese trout were only found on the biofilm, implying that Japanese trout selectively ingest the biofilm.

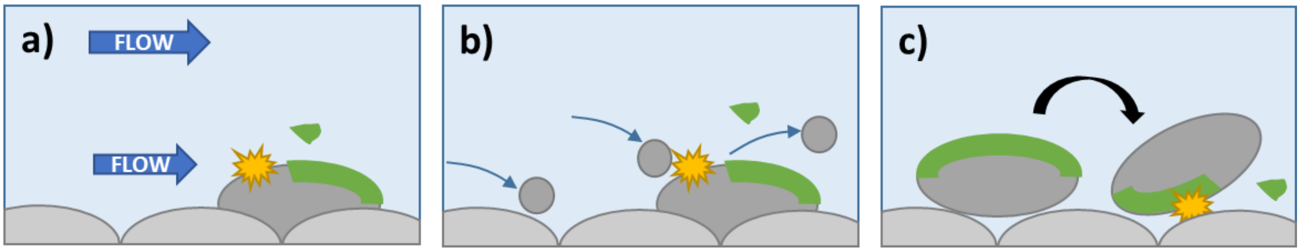


Figure 2. Types of disturbance on moss covering cobbles. **a)** Moss removal by strong shear stress and turbulence, **b)** gravel impingement, and **c)** a cobble rolling on the substrate.

Table 1. Results obtained from high flow and sediment impingement experiments. Cases containing L and H in the name indicate low and high-speed flow conditions, respectively. The number in the case name corresponds to the size of sediment impinged on the cobble.

	Case L0	Case L2a	Case L2b	Case H0	Case H5	Case H10	Case H15
Bulk velocity (m/s)	2	2	2	5	4	4	4
Impinging grain size (mm)	-	2	2	-	5	10	15
Reduction of moss cover area (%)	0.7	-0.7	-1.4	-3.8	7.0	-3.7	6.0

For the gravel impingement experiment **b)**, 2 kg of gravel was released in the jet flow generated by the pump. To represent **c)** a cobble rolling on the substrate, cobbles with moss were manually rotated by hand (Ogawa & Uchida, 2005).

Prior to, during, and following the disturbance experiments explained above, true color and near-infrared color photos were recorded. The NDVI (normalized difference vegetation index) of the surface of a cobble was calculated and the coverage area of moss and the bare cobble surface were distinguished by the magnitude of the NDVI. The criteria are determined based on a visual inspection of the true color photo. Recorded photos were also reviewed in order to track the change in the structure of moss covering the cobbles.

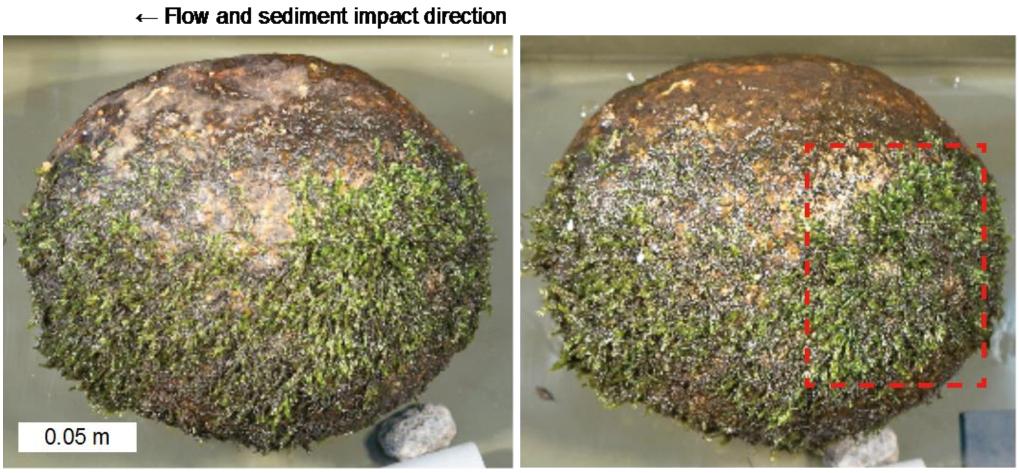
3 RESULTS

Table 1 summarizes the results of: **a)** high-speed flow and **b)** gravel impact experiments. The moss was hardly removed by water flow alone (Case L0, H0). However, an area of moss reduction of approximately 6% was confirmed by the collision of gravel of 5 mm and 15 mm in diameter (Case H5, H15).

According to the results of **c)** the rolling experiments, the area covered with moss decreased by approximately 20 to 40% following a rolling of cobbles to a distance of 40 m.

Based on the results, moss on cobbles was not extensively removed following: **a)** high speed flow and **b)** sediment impingement. Figure 3 compares the cover of moss prior to (Figure 3a) and following 10 kg of sediment impact (Figure 3b). Moss was partially removed but the stems and roots of moss remained on the cobble. In the present study, jet flow directly impinged to the cobble with moss. Such a flow situation is quite different from the structure of the boundary layer formed on cobbles in riffles during normal and flood conditions in actual streams. So, a much greater direct and strong impact was expected based on our experimental conditions. However, the reduction of moss cover was quite limited. Thus, moss in riffles is expected to maintain its cover area during small to medium floods when the magnitude of the flood is not strong enough to transport cobbles with moss. The impact of **c)** cobble rolling seems effective in reducing the moss cover area. If a cobble is transported by flood flow, the posture of each cobble after passing the flood would be expected to be random. Thus, there may not only be a reduction in moss cover area but also cobbles that are moss covered on the downward side following floods (Suren & Duncan, 1999). As a result, cobble sides not covered with moss will be the foreground of a river bed. The growth of biofilm with attached algae is faster than that of moss (Shiragane et al., 2019). Therefore, such a mixture in a river bed would cause, at least temporally, the dominance of blue-green alga and diatoms as the main energy source for *Plecoglossus altivelis*. Figure 4 compares close-ups of moss and changes occurring during the cobble rolling experiment. Stems of moss had become sparse and the length of the moss was shortened. Removed moss fragments were mainly aged stems and leaves. The remaining portions appeared to consist of fresh and active stems and roots.

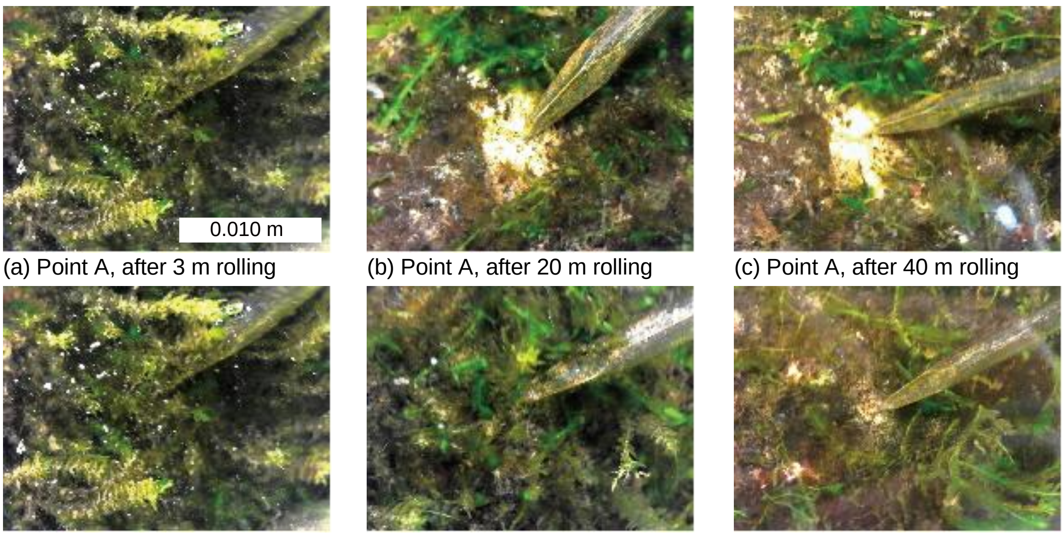
Based on observations in Figures 3 and 4, the structure of the moss system and its changes during experiments are schematically depicted in Figure 5 (i.e. the structure of moss (Figure 5a), and the removal of moss by sediment impact and cobble rolling (Figure 5b)). Remaining moss portions can grow again and recover cover areas even if the density is temporally reduced following a disturbance of sediment impact and cobble rolling.



(a) Prior to sediment impingement

(b) Following 10 kg of 10-mm-diameter gravels were impinged

Figure 3. Photos of a cobble with moss prior to and following sediment impact. In the area depicted by the red dashed-line box that is upstream of the cobble, moss cover was partially removed (i.e. the length was shortened and the blank area was enlarged).



(a) Point A, after 3 m rolling
(b) Point A, after 20 m rolling
(c) Point A, after 40 m rolling
(d) Point B, after 3 m rolling
(e) Point B, after 20 m rolling
(f) Point B, after 40 m rolling

Figure 4. A close-up of fixed points on a cobble obtained during the cobble rolling experiment. In the photos, the steel needle is used to temporarily point to specific observation points.

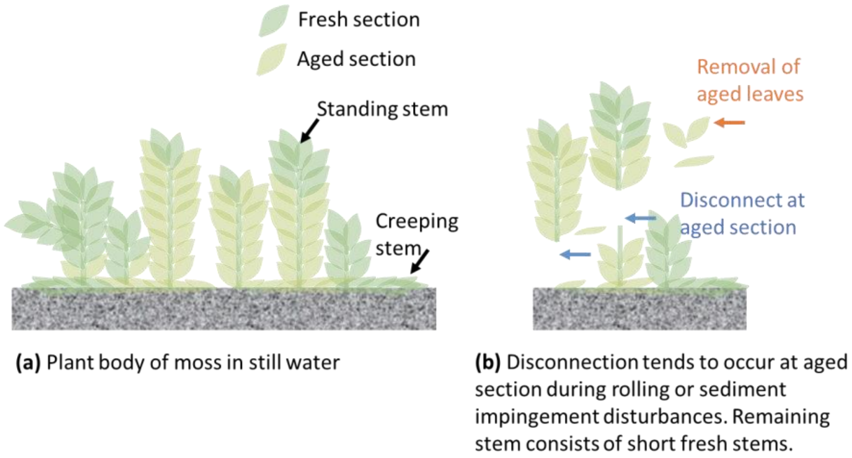


Figure 5. Schema of **(a)** the aquatic moss system formed on cobbles and its response to **(b)** sediment impingement and a rolling cobble.

4 CONCLUSIONS

In this study, we experimentally explored responses to flood disturbances on moss covering cobbles. Flood disturbance was categorized into: a) high speed flow, b) sediment impingement, and c) cobble rolling. Only cobble rolling showed substantial reduction of the cover area of moss. Based on visual inspection of moss cover and its change during experiments, the impact of flood disturbances on the moss system formed on cobbles is discussed. Further quantitative analysis is needed in order to conduct predictive analysis of population dynamics of moss and attached algae and responses to floods.

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