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原　著

Downstream drift of suspended matter and macroinvertebrates swept by a riverbed leveling work in the middle reaches of the Shinano River, Japan

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Abstract

The amounts of suspended matter and benthic macroinvertebrates swept by an experimental riverbed leveling work were investigated in the middle reaches of the Shinano River. The concentration of suspended solid (SS) was 8.43 mg/L at the four study sites on the day before the beginning of the riverbed leveling (Day -1), but it increased up to 115.53 mg/L at the site 200 m downstream from the working site (St. 2) on the day of the beginning of the work (Day 0). Ash-free dry mass of the SS showed that inorganic matter content accounted for 84.4% of the SS at St. 2 on Day 0 and was much higher than Day -1 (72.9%). The most abundant particle size class of SS at St. 2 on Day 0 was 1-75 μm, followed by <1 μm, and inorganic particles of 1-75 μm size class were the most abundant component swept by the leveling work. Downstream drift of benthic macroinvertebrates was mainly composed of Chironomidae, Oligochaeta, Ephemeroptera and Trichoptera at the study sites both on the Days -1 and 0. The drift densities of Oligochaeta and Chironomidae were 0.15 and 0.54 ind./m^3 at St. 2 on Day -1, but on Day 0, they increased up to 143.0 and 45.9 ind./m^3, respectively. The benthic macroinvertebrates swept by the riverbed leveling work were suggested to be flown away at least 1 km downstream from the working site.

Key words : Benthic macroinvertebrates, Suspended matter, River modification works, Downstream drift

Introduction

Research into the movement patterns of organisms and suspended matter in rivers has typically focused on downstream drift during floods (Mochizuki *et al.*, 2006 ; Wilcox *et al.*, 2008) and the recolonization of benthic macroinvertebrates in naturally or artificially disturbed areas (Niemi *et al.*, 1990 ; Mackay, 1992 ; Grzybkowska *et al.*, 1996 ; Kimura *et al.*, 2009). In rivers, benthic insects (e.g. caddisflies, mayflies, and chironomids) are transported downstream by both passive and active drift. This movement is countered by the recolonization of upstream areas by adults (Müller, 1982).

A number of rivers that pass through cities in Japan have been modified to prevent disasters (e.g. flooding and erosion). The changes to the river channel result in the removal of benthic macroinvertebrates at the site of construction (Kimura *et al*, 2009) which mirror the pattern of removal during floods (Mochizuki *et al.*, 2006). In addition, there is an increase in the downstream drift of suspended matter and macroinvertebrates that likely affects benthic communities in the downstream area. The conservation of river ecosystems is one of the primary objectives of river management in Japan. Thus, a detailed understanding of the responses of lotic ecosystems to river modification is needed to inform managers of the potential effects of flood control measures.

Our objective was to measure the amount and the distance of downstream drift of suspended matter and benthic macroinvertebrates associated with modifications to the river channel. We collected suspended matter and benthic macroinvertebrates in the middle reaches of the Shinano River before and after riverbed leveling work. In addition, we measured

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the particle size composition of the suspended organic and inorganic matter and the taxonomic composition of benthic macroinvertebrates to evaluate differences in particle size and macroinvertebrate taxa susceptibility to removal.

Materials and Methods

Study site

The Shinano River is 367 km in length, the longest river in Japan, and has a catchment area of 11,900 km². Because the basin has often suffered from flooding, the river has been modified for flood control. An experimental river leveling project took place between 7:00 on 11 March and 17:00 on 19 March, 2009, in the middle reaches of the Shinano River (36° 25' N, 138° 11' E ; Sakaki, Nagano, Japan). A total of 750 m² of riverbed was excavated and heaped with a backhoe to flatten the area. The operator of the backhoe worked 9 h/d during the 9 d of the working period (81 h total). The estimated efficiency of the leveling work was 9.3 m²/h. The project consisted of several phases as follows : excavation and heaping of the riverbed (7:10 – 7:45), crawling the backhoe (intermittently between 7:45 – 10:00), stopping the backhoe and checking the riverbed conditions (10:00 – 10:10) and restarting the crawling operation (after 10:10).

We selected four sampling sites : 500 m upstream of the project (St. 1) and 200 m (St. 2), 1 km (St. 3), and 1.5 km (St. 4) downstream of the project. The physicochemical characteristics of the four sites were similar. The substrate at all four sites was dominated by pebbles and cobbles.

Analysis of suspended matter and drifting macroinvertebrates

We collected water and drifting macroinvertebrate samples on the 10th (Day -1) and 11th March (Day 0), 2009. These dates corresponded to the day immediately prior to the beginning of the project and the day the project began, respectively. We collected water and drifting macroinvertebrate samples simultaneously at the 4 sites. Trained researchers collected samples at St. 2, 3 and 4. The water samples at St. 1 were collected by a volunteer on Day -1. Water and drifting macroinvertebrate samples were collected every 2 h between 7:00 to 13:00 on Day -1 and at 8:00, 9:30, and 10:30 on Day 0. In addition, we collected a water sample at 8:20 on Day 0 at St. 2 during a period when the turbidity increased rapidly as a result of the excavation.

The suspended solids (SS) in each water sample were aggregated on a Whatman GF/C glass filter by vacuum filtration then dried at 110℃ for 5 h. For highly turbid samples, we only filtered 0.5 or 0.25 L of the sample. After drying, the glass filters were ignited at 450℃ for 30 min then weighed to calculate the ash-free dry mass (AFDM) as a measure of organic matter content. The glass filters were weighed before and after filtration and ignition to the nearest 0.01 mg using an electric balance (CPA-225D ; Sartorius Mechatronics, Germany).

In addition, the suspended solids included in the water samples collected at 13:00 on Day -1 and at 10:30 on Day 0 were divided into five particle size classes by sieving through nets with the following mesh sizes : > 1 mm, 250 μm to 1 mm, 75 to 250 μm, 1 to 75 μm and < 1 μm. The >1 mm class was excluded from analyses due to the presence of large particles (e.g. leaf and twig debris) which could not be mixed evenly when preparing the water samples for sieving. We measured the SS and AFDM of each size class using the method outlined above for calculating particle size composition (%).

We collected drifting macroinvertebrates using a Surber net (30 × 30 cm² frame opening, 450 μm mesh) by placing the mouth of the net against the water flow for 3 min. We also measured the depth and current velocity at the point of placement for the net to calculate the density of drifting individuals per unit discharge through the Surber net. The samples were preserved in 10% formalin until sorting. Macroinvertebrates were sorted and counted under a binocular dissecting microscope.

Results

Suspended matter concentration

The mean concentration of SS was 8.43 mg/L at the four study sites on Day -1 and was similar among times and sites (**Fig. 1**). The SS concentration increased to 115.53 mg/L at St. 2 (8:20) on Day 0, but remained constant at St. 3 and 4 between Days -1 and 0. The AFDM of the SS revealed that inorganic matter content accounted for 84.4% of the SS at St. 2 on Day 0 and was much higher than on Day -1 (72.9%) (**Fig. 2**).

The most abundant particle size class of SS on both days was 1 – 75 μm, followed by the < 1 μm size class (**Fig. 3**). The frequency of the particles size classes larger than 75 μm was much lower than that of the smaller particles. At St. 2, the SS concentration of < 1 and 1−75 μm particles was 2.70 and 3.53 mg/L, respectively, on Day -1. This increased to 7.14 and 19.46 mg/L, respectively, on Day 0. In addition, the concentration of particles in the 75−250 μm class also increased from 0.37 mg/L on Day -1 to 2.48 mg/L on Day 0. The proportion of inorganic matter in the < 1 and 1−75 μm particle size classes was 49.6 and 65.4% at St. 2 on Day -1. The ratios increased to 57.7 and 81.4%, respectively on Day 0 (**Fig. 4**).

Benthic macroinvertebrates drift

The downstream drift of benthic macroinvertebrates consisted primarily of Chironomidae, Oligochaeta, Ephemeroptera, and Trichoptera at all sites on both days (**Figs 5, 6**). We also collected small numbers of Simuliidae, Tipulidae, Psychodidae, Plecoptera, Hemiptera, *Asellus* sp., Gammaridea, and Hirudinea. The mean drift densities of Oligochaeta and Chironomidae were 0.15 and 0.54 ind./m^3 at St. 2 on Day -1. The numbers increased on Day 0 to 143.0 and 45.9 ind./m^3, respectively. In addition, the drift densities of Trichoptera and Ephemeroptera also increased

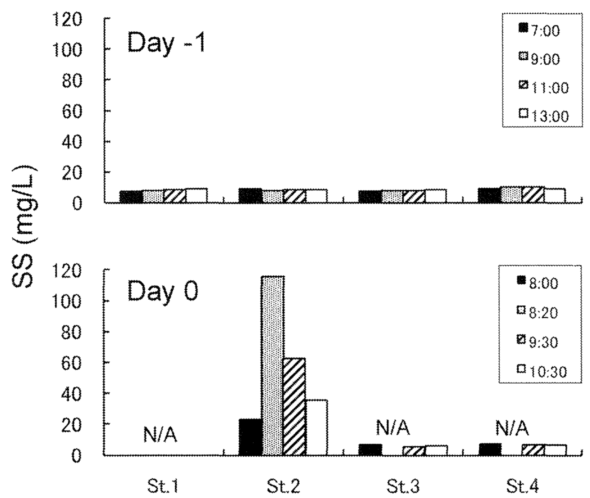

Fig. 1. Concentration of suspended solids (SS) at the four study sites before (Day -1) and after (Day 0) the beginning of the riverbed leveling project.

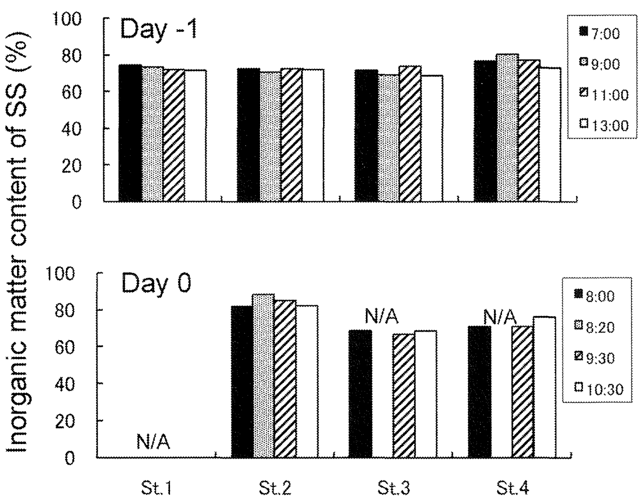

Fig. 2. Inorganic matter content in the SS at the four study sites on Days -1 and 0.

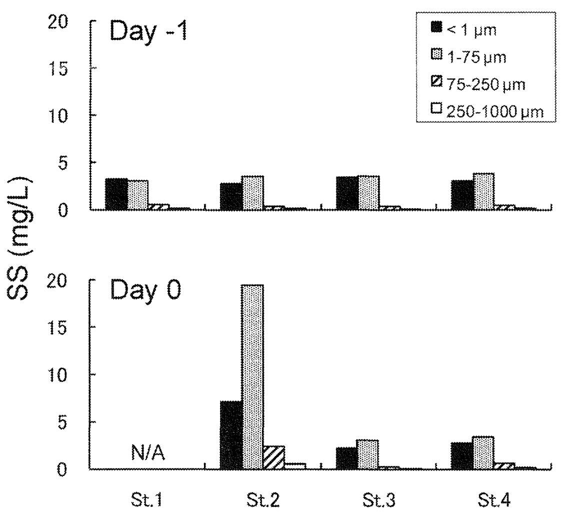

Fig. 3. Particle size composition of the SS at the four study sites on Days -1 and 0.

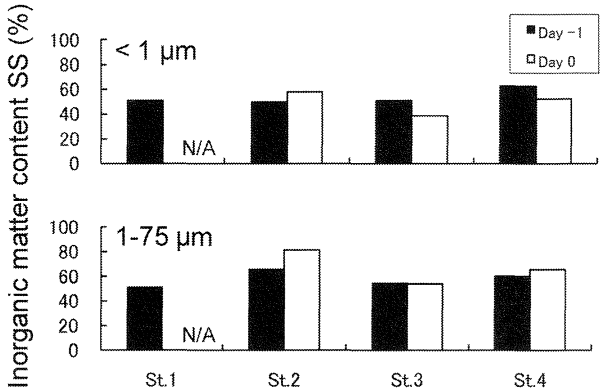

Fig. 4. Inorganic matter content of the suspended particles smaller than 75 μm at the four study sites on Days -1 and 0.

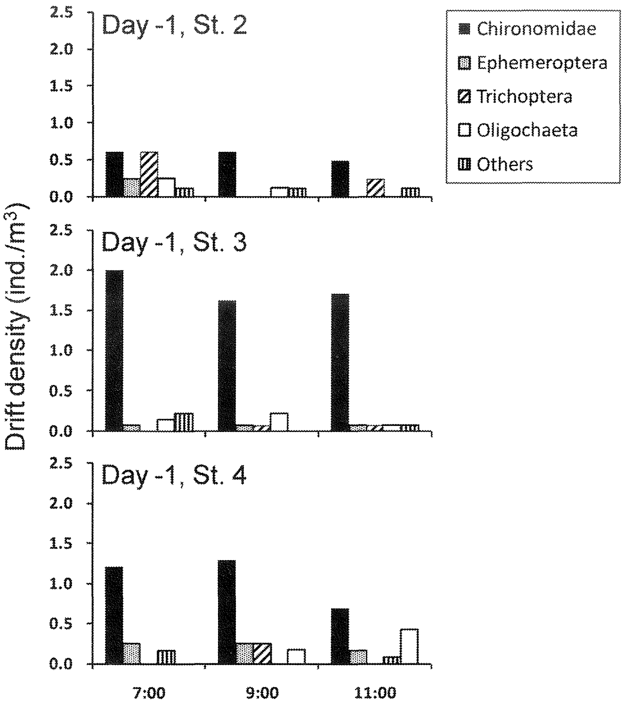

Fig. 5. Densities of drifting macroinvertebrates at St. 2, 3 and 4 on Day -1.

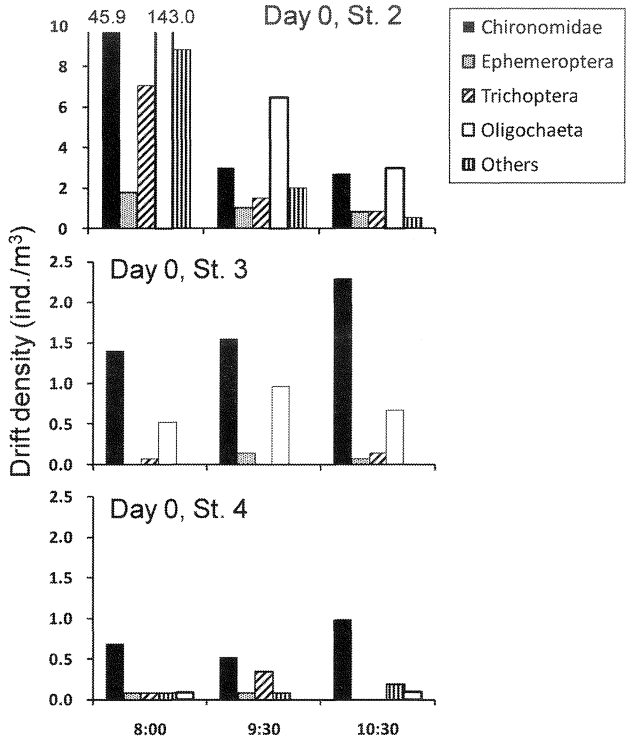

Fig. 6. Densities of drifting macroinvertebrates at St. 2, 3 and 4 on Day 0.

between Day -1 (mean 0.21 and 0.06 ind./m^3, respectively) and Day 0 (7.06 and 1.76 ind./m^3, respectively). The densities on Day 0 were much lower than those for Oligochaeta and Chironomidae. At St. 3, the mean drift density of Oligochaeta was 0.37 ind./m^3 on Day -1, but it increased to 0.71 ind./m^3 on Day 0.

Discussion

We demonstrated that the downstream drift of suspended matter and benthic macroinvertebrates increases rapidly during riverbed leveling. The suspended matter dislodged by the leveling work consisted largely of inorganic particles smaller than 75 μm. We observed a significant amount of large leaves and twigs drifting following the beginning of the project. The disturbance of such large particles should be evaluated independently to calculate the total amount of the matter displaced by such projects.

The peaks in suspended matter concentration and abundance of drifting macroinvertebrates occur prior to the peak discharge during a flood event (Mochizuki *et al.*, 2006). We observed a peak in the drift of suspended matter and benthic macroinvertebrates immediately following the beginning of the project when the backhoe was excavating and heaping the riverbed.

The increase in the drift density of Oligochaeta was the highest among the benthic taxa and was maintained at least 1 km downstream from the project. Benthic macroinvertebrates that have the ability to attach their case or retreat to the substrate, having a sucking apparatus, or are able to swim are more resistant to displacement during floods (Mochizuki *et al.*, 2006). Oligochaeta live in the deeper layers of the riverbed in riffles and do not have a case, silk threads, or a sucking apparatus. Thus, they are easily displaced when exposed to current as a result of excavation. The drift of Chironomidae also increased following the project. In contrast, the Trichoptera spin silk threads and Ephemeroptera have high swimming ability. Thus, these two taxa are likely more resistant to displacement during local disturbance events. The composition of benthic insect taxa in the middle reaches of the Shinano River consists of 37.4% Chironomidae, 29.4% Trichoptera and 28.4% Ephemeroptera (Inoue *et al.*). Because the differences in the benthic densities were much smaller between Chironomidae and Trichoptera/Ephemeroptera than the differences in the drift densities on Day 0, the large increase in the drift density of Chironomidae on Day 0 cannot be explained by its density in the benthos alone.

The amount of suspended matter and benthic macroinvertebrates removed as a result of river modification projects is likely dependent on the method used and the scale and geographical features of the river, as well as the occurrence of floods (Wilcox *et al.*, 2008). Mochizuki *et al.*, (2006) investigated the suspended matter and macroinvertebrate drifts dislodged by artificial floods in experimental channels (width from 2.5 to 6.0, length 800 m). They reported a maximum peak density of 73.7 mg/m³ of fine particulate organic matter (> 850 μm), 277.5 mg/m³ of fine particulate inorganic matter (> 850 μm), and 14,930 ind./m³ of total macroinvertebrate drift in December (base flow 0.3 m³/s, high flow 1.5 m³/s) (Mochizuki *et al.*, 2006). For the macroinvertebrates, the higher drift densities during the artificial floods compared with the leveling work can partly be explained by the difference in the scale of the simultaneously disturbed area. In addition, the length of time between disturbances also influences the amount of downstream drift of suspended matter and benthic macroinvertebrates (Mochizuki *et al.*, 2006). These observations are important as they highlight the need to reduce both contamination of downstream areas with turbid water and ecological damage during and following river modification projects. It would be interesting to evaluate the relationship between the scale of the river modification project and the increase in the amount of both suspended matter and benthic macroinvertebrate drift, with consideration for the differences in the modification methods.

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信濃川中流域における河床整正工事により流出した懸濁物質と底生動物

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信濃川中流域で試験的に行われた河床整正工事によって流出した懸濁物質量と底生動物量を調査した。工事開始前日のSS濃度は平均 8.43 ㎎/L であったが、工事開始当日には工事区より 200 m 下流の地点で最高 115.53 ㎎/L まで上昇した。同地点における SS 中の無機物の割合は、工事開始前日は 72.9%であったが、工事開始当日には 84.4%まで上昇した。SS の粒径別では、工事開始前日・当日ともに１－75 μm、１μm 未満の濃度が高く、工事開始当日には１－75μm の無機物の上昇が最も高かった。流下物中の主な底生動物はユスリカ科、貧毛綱、トビケラ目、カゲロウ目であり、工事区より 200 m 下流の地点ではユスリカ科と貧毛綱の流下個体密度は工事開始当日にそれぞれ最高で 85 倍、953 倍まで上昇した。貧毛綱については、工事区より１㎞ 下流の地点においても工事開始当日の流下個体密度が前日の平均 1.9 倍まで上昇した。