International Journal of GEOMATE, Sept., 2017, Vol. 13, Issue 37, pp. 108-115
Special Issue on Science, Engineering & Environment, ISSN: 2186-2990, Japan
DOI: http://dx.doi.org/10.21660/2017.37.2611

EVALUATION OF METAL CONTAMINATION FOR RIVER USING BRYOPHYTE IN THE KINOKAWA RIVER CATCHMENT

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ABSTRACT: Metal concentration of river water is not always useful for evaluating metal contamination in a catchment because metal concentration of river water is neither always high nor uniform. Therefore, we studied the evaluation of river metal contamination using the metal concentration of bryophyte. Metal concentrations of bryophyte sampled in both the lower stream of the closed Cu mine (120 to 26,000, 25 to 2,400 and 50 to 190 mg/kg-dry for Cu, Co and Ni) and the serpentinite (24 to 59 and 58 to 650 mg/kg-dry for Co and Ni) were higher than background metal concentrations of bryophyte (2 to 96, 2 to 20 and 2 to 43 mg/kg-dry for Cu, Co and Ni). Therefore, it was thought that metal concentrations of bryophyte sampled in the lower stream of the closed Cu mine (Cu, Co and Ni) and the serpentinite (Co and Ni) were affected by the closed Cu mine and the serpentinte, respectively. A kind of hyper accumulator bryophyte similar *Scopelophila cataractae* was often found around the closed Cu mine and was found around the serpentinite. Its metal concentration was high (1,100 to 26,000, 33 to 2,400 and 81 to 650 mg/kg-dry for Cu, Co and Ni). Metal concentrations of another hyper accumulator bryophyte similar *Scopelophila cataractae* had high and a wide range of metal concentrations (2 to 5,900, 2 to 150 and 2 to 590 mg/kg-dry for Cu, Co and Ni). Therefore, those of hyper accumulator bryophyte were thought to be useful for a Cu, Co and Ni contamination indicator.

Keywords: Bryophyte, Heavy Metal, Metal Contamination Evaluation, River

1. INTRODUCTION

Metal concentration of river water is neither always high nor stable. Therefore, metal concentration of river water is not always useful for evaluating metal contamination in a catchment. On the other hand, in the past study, it was reported that bryophyte was useful species for an index of metal contamination for river among river plants [1]. It is known that *Scopelophila cataractae* lives in high copper concentration environment like under the copper roof in a temple and soil around a metal mine including a large amount of copper [2]. And then, the tolerance ability of *Scopelophila cataractae* for copper is high [3]. Moreover, it is known that bryophyte has been used to an index of atmospheric pollution [4], [5], [6]. However, river metal contamination has not been evaluated using the metal concentration of bryophyte. Therefore, we measured metal concentrations of bryophyte in the Kinokawa River catchment and studied the evaluation of river metal contamination using the metal concentration of bryophyte.

2. STUDY AREA

Figs.1 and 2 show location of study area and the Kinokawa River catchment. The Kinokawa River is located in the center of Kinki district and flows into the Kii Channel through the Kii plain. The Kinokawa River is classified into A river based on the Ministry of Land, Infrastructure, Transport and Tourism of Japan. The length and total area of the Kinokawa River are 136 km and 1,750 km^2 [7]. The Izumi Group composed of sedimentary rocks, sandstone, mudstone and conglomerate is distributed in the northwest part of the catchment. The Sanbagawa Belt composed of metamorphic rocks, serpentinite and crystalline schist is distributed in the southwest part and the northeast part of the catchment. The Hidakagawa Group composed of sedimentary rocks, sandstone and shale is distributed from the southern part to the northeast part of the catchment. The Chichibu Belt composed of sedimentary rocks, sandstone, mudstone, limestone and chert is distributed in the eastern part of the catchment [8]. The Ryoke Complex composed of plutonic rocks, granite and gneiss is distributed in the northeast part of the catchment.

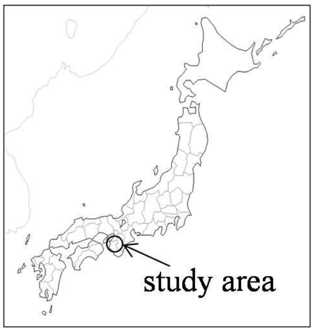

Fig.1 Study area

In the Kinokawa River catchment, there are

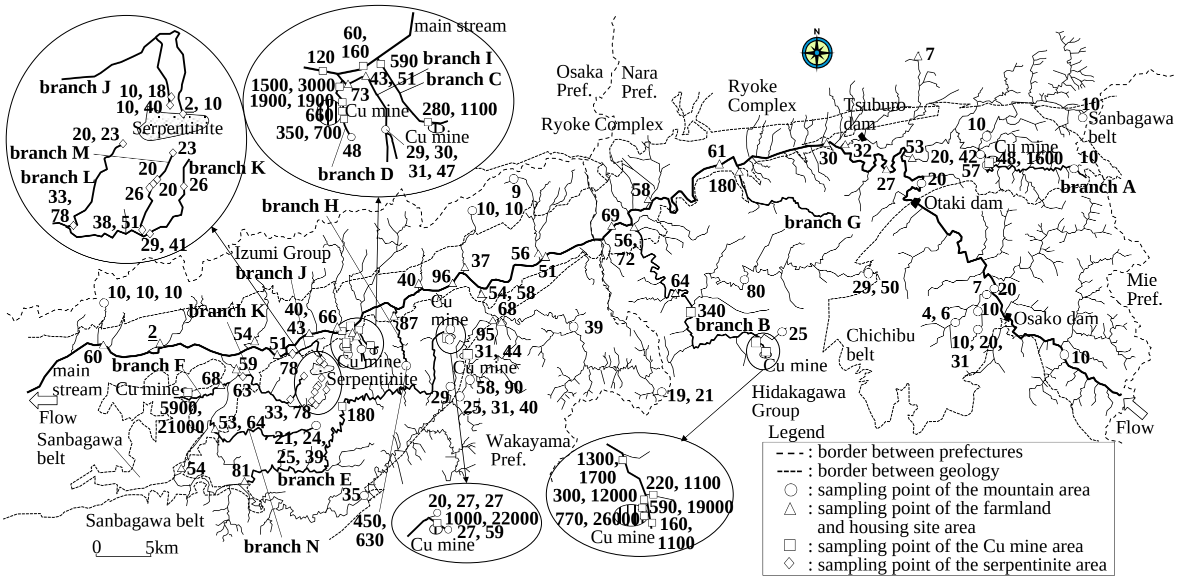

Fig.2 Distribution of Cu concentrations of bryophyte in the catchment

serpentinite and the closed Cu mines. The chemistry of serpentinite is quite different from the other rocks and in particular Mg and Ni concentrations of serpentinite are high. The closed Cu mine produced a lot of Cu and Fe sulfide ore and the waste water was low pH and high concentration of sulfate with metal.

3. STUDY METHOD

Bryophytes in the river bed were sampled in the Kinokawa River catchment. Sampling points were shown in Fig.2. The numbers of sampling points and samples were 97 points and 146 samples, respectively. Those sampling points were classified into four groups, the mountain area, the farmland and housing site area, the Cu mine area and the serpentinite area. The sampled bryophyte species were 12 species. Table 1 shows names of species. Bryophytes species were determined by reference number 9 [9]. The species 1 was sampled in the farmland and housing site area, the Cu mine and the serpentinite area. The species 2 and 5 were sampled in four groups. The species 3 and 4 were sampled in the mountain area, the farmland and housing site area and the Cu mine area. The species 6 was sampled in the farmland and housing site area and the Cu mine area. The species 7 was sampled in the mountain area, the Cu mine area and the serpentinite area. The species 8 was sampled in the farmland and housing site area and the serpentinite area. The species 9 was sampled in the mountain area, the farmland and housing site area and the serpentinite area. The species 10 to 12 were sampled in the mountain area. Investigation period is April 2014 to April 2016. Cu, Co and Ni concentrations of bryophyte were measured. The

Table.1 Names of bryophyte species

species No.	bryophyte name	species No.	bryophyte name
1	Pottiaceae	7	Conocephalaceae
2	Brachytheciaceae	8	Bryaceae
3	Marchantiaceae	9	Hypnaceae
4	Philonotis	10	Mniaceae
5	Pelliaceae	11	Thuidiaceae
6	Hedwigiaceae	12	Fissidentaceae

sampled bryophytes were desiccated by dryer at first. After drying, the whole body of bryophytes (including leaf, stem and root) were dissolved with concentrated nitric acid and it was filtered with the membrane filter with 0.45 micrometer of pore size before analysis. Cu, Co and Ni concentrations of bryophyte were measured by ICP-AES (Seiko Instruments Inc., SPS1700HVR) in the laboratory of Wakayama University. The actual detection limit of ICP-AES is 0.01ppm for Cu, Co and Ni.

4. RESULTS AND DISCUSSION

4.1 Evaluation for Cu

4.1.1 Distribution of Cu concentrations of bryophyte in the catchment

Fig.2 shows the distribution of Cu concentrations of bryophyte in the Kinokawa River catchment. Underlined value indicates Cu concentration of bryophyte under the detection limit of concentration for sample solution. Plural values at one point indicate plural species of sampled bryophyte.

Cu concentrations of bryophyte in the catchment were 2 to 26,000 mg/kg-dry. In the past study, Cu concentrations of bryophyte in the normal area in the Kinokawa River catchment were 9 to 87 mg/kg-dry [1]. Therefore, it was thought that Cu concentrations of bryophyte in the non-contaminated area were up to about 90 mg/kg-dry.

Cu concentrations of bryophyte in the lower stream of main stream, branch A, B, C, D, E, F, G and H were over 90 mg/kg-dry. Some of Cu concentrations of bryophyte in the lower stream of main stream, the lower stream of branch A located in the eastern part of the catchment, the upper stream of branch B located in the center part of the catchment were 120 to 160, 1,600 and 160 to 26,000 mg/kg-dry, respectively. In the western part of the catchment, some of Cu concentrations of bryophyte in branch C, the middle and lower stream of branch D, the upper and middle stream of branch E and the upper stream of branch F were 280 to 1,100, 350 to 3,000, 180 to 22,000 and 5,900 to 21,000 mg/kg-dry, respectively. The closed Cu mines were located in the lower stream of branch A, the upper stream of branch B, the upper stream of branch C, the middle stream of branch D, the upper stream of branch E and the upper stream of branch F. The closed Cu mine produced a lot of Cu and Fe sulfide ore and then the waste water was low pH and contained high concentration of sulfate with metal. Moreover, it is known that the closed Cu mine in the Kinokawa River catchment contains Cu and Co [10]. Therefore, it was thought that high Cu concentrations of bryophyte in the lower stream of main stream and branch A to F were caused by waste water and Cu sulfide ore from the closed Cu mines. Some of Cu concentrations of bryophyte in the lower stream of branch G located in the eastern part of the catchment and the upper stream of branch H located in the western part of the catchment were 180 and 450 to 630 mg/kg-dry, respectively. The closed Cu mines were not located in branch G and H. Therefore, it was thought that high Cu concentrations of bryophyte were caused by other factors excluding the closed Cu mines. Cu concentrations of bryophyte excluding the high Cu concentration points were 2 to 96 mg/kg-dry. Therefore, it was thought that the concentrations were background concentration.

4.1.2 The relationship between bryophyte species and Cu concentrations of bryophyte

From Fig.2, variation for Cu concentrations of bryophyte sampled at one point in the branch A to F was large. For example, in the upper stream of branch B, Cu concentrations of two kinds of bryophyte were 300 and 12000 mg/kg-dry and variation of their concentrations was 40 times. On the other hand, Cu concentrations of same kind of bryophyte in the upper stream of branch D were 47 to 50 mg/kg-dry and variation of concentrations for same kind of bryophyte was small. Therefore, the large Cu concentration variation depended on difference of species but Cu concentration variation for same species at the same point was small.

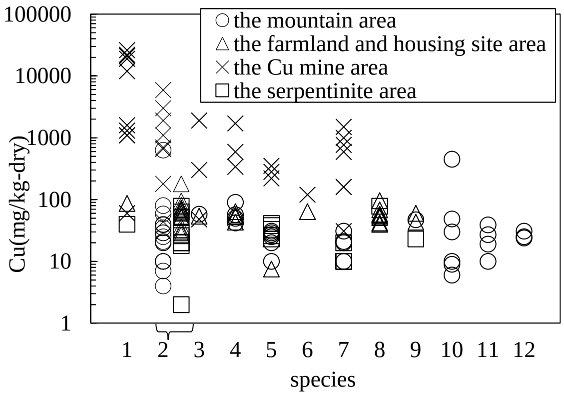

Fig.3 Cu concentrations of bryophyte species

Fig.3 shows Cu concentrations of bryophyte for each species. Most of Cu concentrations of a kind of copper bryophyte similar *Scopelophila cataractae*, the species 1 in the Cu mine area were high, 1,100 to 26,000 mg/kg-dry. Therefore, it was found that a kind of copper bryophyte similar *Scopelophila cataractae*, the species 1 lived around the Cu mine and had high accumulation ability. It is known that copper bryophyte lives in high copper concentration environment like under the copper roof in a temple and soil around a metal mine including a large amount of copper [2]. It is reported that Cu concentrations of the cupriferous pyrite in the closed Cu mine in the Kinokawa River catchment were 100 to 100,000 ppm [11]. Moreover, it is reported that copper bryophyte have high Cu accumulation ability at the past study [12]. Therefore, a kind of copper bryophyte similar *Scopelophila cataractae*, the species 1 was thought to be a Cu contamination indicator. Cu concentrations of species 2 and 3 to 12 were 2 to 5,900 and 6 to 1,900 mg/kg-dry, respectively. Most of Cu concentrations of species 2 to 7 in the Cu mine area were more than 90 mg/kg-dry and were high. Therefore, the species 2 had the highest and a wide range of Cu concentrations among species 2 to 12. Moreover, maximum Cu concentration of species 2 was high next to species 1. And then, the species 2 can be sampled in all sampling groups in the catchment. Therefore, the species 2 was useful species for an index of Cu contamination in the catchment. Moreover, it was thought that the species 2 was another copper bryophyte similar *Scopelophila cataractae*.

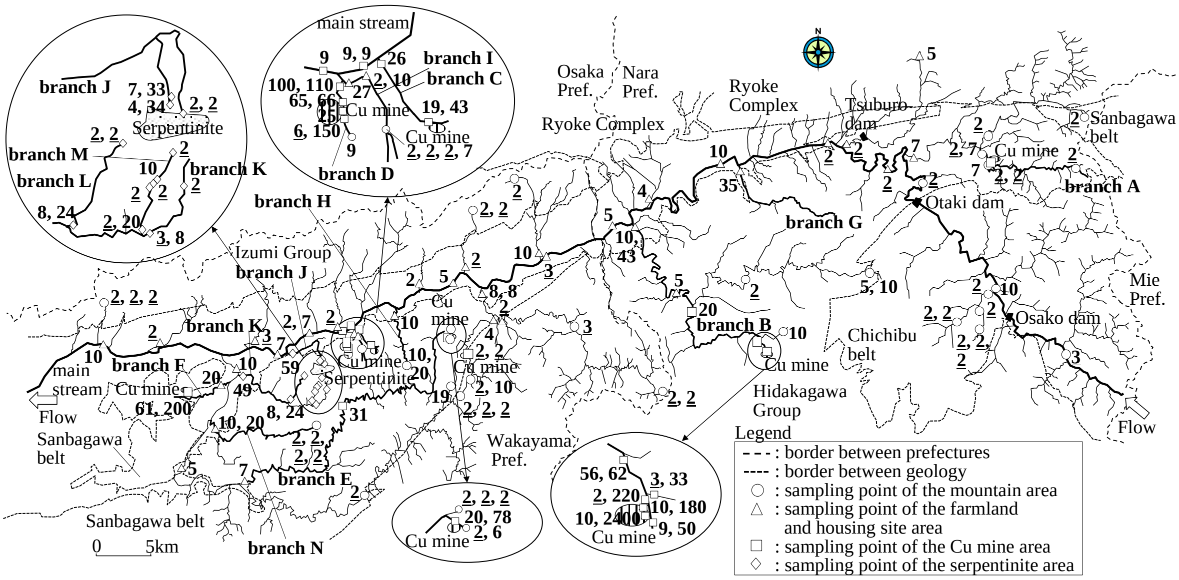

Fig.4 Distribution of Co concentrations of bryophyte in the catchment

4.2 Evaluation for Co

4.2.1 Distribution of Co concentrations of bryophyte in the catchment

Fig.4 shows the distribution of Co concentrations of bryophyte in the Kinokawa River catchment. Underlined value indicates Co concentration of bryophyte under the detection limit of concentration for sample solution. Plural values at one point indicate plural species of sampled bryophyte.

Co concentrations of bryophyte in the catchment were 2 to 2,400 mg/kg-dry. In the past study, Co concentrations of bryophyte in the normal area in the Kinokawa River catchment were 2 to 19 mg/kg-dry [1]. Therefore, it was thought that Co concentrations of bryophyte in the non-contaminated area were up to about 20 mg/kg-dry.

Co concentrations of bryophyte in branch B, C, D, E, F, G, I, J, K and L were over 20 mg/kg-dry. In the center part of the catchment, some of Co concentrations of bryophyte in the upper stream of branch B and the lower stream of branch B were 33 to 2,400 and 43 mg/kg-dry, respectively. In the western part of the catchment, some of Co concentrations of bryophyte in branch C, the middle and lower stream of branch D, the upper and middle stream of branch E and the upper stream of branch F were 26 to 43, 25 to 150, 31 to 78 and 61 to 200 mg/kg-dry, respectively. The closed Cu mines were located in the upper stream of branch B, the upper stream of branch C, the middle stream of branch D, the upper stream of branch E and the upper stream of branch F. The closed Cu mine produced a lot of Cu and Fe sulfide ore and then the waste water was low pH and contained high concentration of sulfate with metal. Moreover, it is known that the closed Cu mine in the Kinokawa River catchment contains Cu and Co [10]. Therefore, it was thought that high Co concentrations of bryophyte in the upper stream of branch B, branch C, D, E and F were caused by waste water and Cu and Fe sulfide ore from the closed Cu mines. In branch B, Co concentrations of bryophyte in the middle stream of branch B were low but those in the upper stream of branch B were high. It was thought that Co concentrations of bryophyte were not affected by Cu mine below the middle stream of branch B. Therefore, it was thought that high Co concentration of bryophyte in the lower stream of branch B were caused by other factors excluding the closed Cu mines.

Some of Co concentrations of bryophyte in the lower stream of branch G located in the eastern part of the catchment and the lower stream of branch I located in the western part of the catchment were 35 and 27 mg/kg-dry, respectively. The closed Cu mines were not located in branch G and I. Therefore, it was thought that high Co concentrations of bryophyte were caused by other factors excluding the closed Cu mines.

In the western part of the catchment, some of Co concentrations of bryophyte in branch J, the lower stream of branch K and the lower stream of branch L were 33 to 59, 49 and 24 mg/kg-dry, respectively. The serpentinite was located in the upper stream of branch J, K and L. It is known that the serpentinite contains a large amount of Ni and Co [13]. Therefore, it was thought that high Co concentrations of bryophyte in branch J, K and L were affected by the serpentinite.

High Co concentrations of bryophyte in the upper stream of branch B and branch C to F around the closed Cu mines were 25 to 2,400 mg/kg-dry.

High Co concentrations of bryophyte in branch J to L around the serpentinite were 24 to 59 mg/kg-dry. Co concentrations of bryophyte in the upper stream of branch B and branch C to F were higher than those in branch J to L. It is reported that Co concentrations of the cupriferous pyrite in the closed Cu mine in the Kinokawa River catchment and the serpentinite were 35 to 2,500 and 62 to 94 ppm, respectively [11], [14]. Co concentrations of the cupriferous pyrite were higher than those of the serpentinite. Therefore, it was thought that Co concentrations of bryophyte in the upper stream of branch B and branch C to F around the closed Cu mines were higher than those in branch J to L around the serpentinite.

Co concentrations of bryophyte excluding the high Co concentration points were 2 to 20 mg/kg-dry. Therefore, it was thought that the concentrations were background concentration.

4.2.2 The relationship between bryophyte species and Co concentrations of bryophyte

From Fig.4, variation for Co concentrations of bryophyte sampled at one point in the branch B to F and J were large. For example, in the upper stream of branch B, Co concentrations of two kinds of bryophyte were 10 and 2,400 mg/kg-dry and variation of their concentrations was 240 times. On the other hand, Co concentrations of same kind of bryophyte in the upper stream of branch D were 8 to 10 mg/kg-dry and variation of concentrations for same kind of bryophyte was small. Therefore, the large Co concentration variation depended on difference of species but Co concentration variation for same species at the same point was small.

Fig.5 shows Co concentrations of bryophyte for each species. Most of Co concentrations of the species 1 in the Cu mine area were high, 33 to 2,400 mg/kg-dry. Therefore, it was found that the species 1 lived around the Cu mine and had high accumulation ability. From subsection 4.1.2, it was thought that the species 1 was a kind of copper bryophyte similar *Scopelophila cataractae*. It is reported that the tolerance ability of *Scopelophila cataractae* for Cu, Co, Ni et al is high [15]. Therefore, the species 1 was thought to be a Co contamination indicator. Moreover, it was thought that the species 1 was a kind of hyper accumulator bryophyte similar *Scopelophila cataractae* for Co. Co concentrations of species 2 and 3 to 12 were 2 to 150, 2 to 100 mg/kg-dry, respectively. Most of Co concentrations of species 2 and 4 in the Cu mine area were more than 20 mg/kg-dry and were high. Therefore, the species 2 had the highest and a wide range of Co concentrations among species 2 to 12.

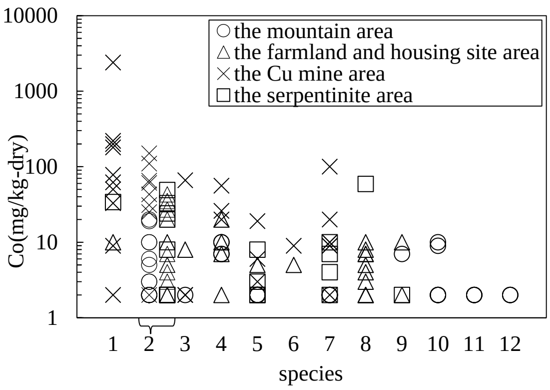

Fig.5 Co concentrations of bryophyte species

Moreover, maximum Co concentration of species 2 was high next to species 1. And then, the species 2 can be sampled in all sampling groups in the catchment. Therefore, the species 2 was useful species for an index of Co contamination in the catchment. Moreover, it was thought that the species 2 was another hyper accumulator bryophyte similar *Scopelophila cataractae* for Co.

4.3 Evaluation for Ni

4.3.1 Distribution of Ni concentrations of bryophyte in the catchment

Fig.6 shows the distribution of Ni concentrations of bryophyte in the Kinokawa River catchment. Underlined value indicates Ni concentration of bryophyte under the detection limit of concentration for sample solution. Plural values at one point indicate plural species of sampled bryophyte.

Ni concentrations of bryophyte in the catchment were 2 to 650 mg/kg-dry. In the past study, Ni concentrations of bryophyte in the normal area in the Kinokawa River catchment were 2 to 40 mg/kg-dry [1]. Therefore, it was thought that Ni concentrations of bryophyte in the non-contaminated area were up to about 40 mg/kg-dry.

Ni concentrations of bryophyte in branch B, D, G, H, I, J, K, L, M and N were over 40 mg/kg-dry. Some of Ni concentrations of bryophyte in the upper stream of branch B located in the center part of the catchment and the lower stream of branch D located in the western part of the catchment were 81 to 190 and 50 mg/kg-dry, respectively. The closed Cu mines were located in the upper stream of branch B and the middle stream of branch D. The closed Cu mine produced a lot of Cu and Fe sulfide ore and then the waste water was low pH and contained high concentration of sulfate with metal. Moreover, it is reported that the cupriferous pyrite in the closed Cu mine in the Kinokawa River

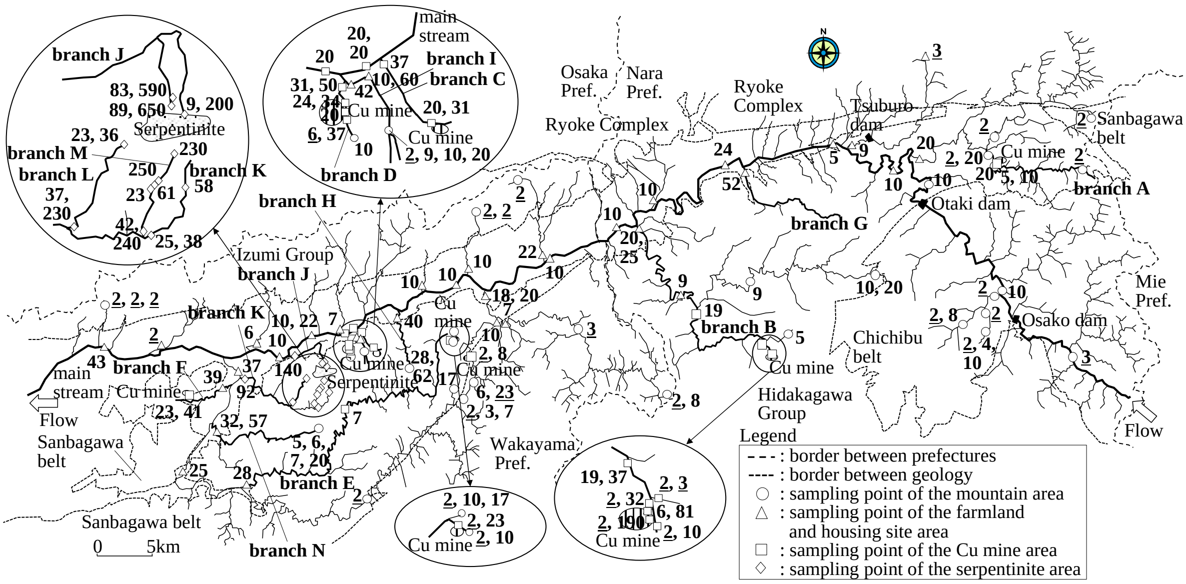

Fig.6 Distribution of Ni concentrations of bryophyte in the catchment

catchment contains Ni. Ni concentrations of the cupriferous pyrite were 20 to 300 ppm [11]. Therefore, it was thought that high Ni concentrations of bryophyte in branch B and D were caused by waste water and Cu and Fe sulfide ore from the closed Cu mines.

In the western part of the catchment, some of Ni concentrations of bryophyte in branch J, branch K, the lower stream of branch L and branch M were 83 to 650, 58 to 92, 230 and 61 to 250 mg/kg-dry, respectively. The serpentinite was located in the upper stream of branch J, K, L and M. It is known that the serpentinite contains a large amount of Ni. Ni concentrations of the serpentinite were 1,100 to 2,900 ppm [14]. Therefore, it was thought that high Ni concentrations of bryophyte in branch J, K, L and M were affected by the serpentinite.

Some of Ni concentrations of bryophyte in the lower stream of branch G located in the eastern part of the catchment, the upper stream of branch H located in the western part of the catchment, the lower stream of branch I located in the western part of the catchment and the lower stream of branch N located in the western part of the catchment were 52, 62, 60 and 57 mg/kg-dry, respectively. The closed Cu mines and the serpentinite were not located in branch G, H, I and N. Therefore, it was thought that high Ni concentrations of bryophyte were caused by other factors excluding the closed Cu mines and the serpentinite.

High Ni concentrations of bryophyte in branch B and D around the closed Cu mines and branch J to M around the serpentinite were 50 to 190 and 58 to 650 mg/kg-dry, respectively. Ni concentrations of bryophyte in branch J to M were higher than those in branch B and D. It is reported that Ni concentrations of the cupriferous pyrite in the closed Cu mine in the Kinokawa River catchment and the serpentinite were 20 to 300 and 1,100 to 2,900 ppm, respectively [11], [14]. Ni concentrations of the serpentinite were higher than those of the cupriferous pyrite. Therefore, it was thought that Ni concentrations of bryophyte in branch J to M around the serpentinite were higher than those in branch B and D around the closed Cu mines.

Ni concentrations of bryophyte excluding the high Ni concentration points were 2 to 43 mg/kg-dry. Therefore, it was thought that the concentrations were background concentration.

4.3.2 The relationship between bryophyte species and Ni concentrations of bryophyte

From Fig.6, variation for Ni concentrations of bryophyte sampled at one point in branch B, J, L and M was large. For example, in the upper stream of branch B, Ni concentrations of two kinds of bryophyte were 2 and 190 mg/kg-dry and variation of their concentrations was 95 times. On the other hand, Ni concentrations of same kind of bryophyte in the upper stream of branch D were 10 mg/kg-dry and their Ni concentrations for same kind of bryophyte was the same. Therefore, the large Ni concentration variation depended on difference of species but Ni concentration variation for same species at the same point was small.

Fig.7 shows Ni concentrations of bryophyte for each species. Ni concentrations of species 1, 2 and 3 to 12 were 2 to 650, 2 to 590 and 2 to 250 mg/kg-dry, respectively. Therefore, the species 1 had the highest Ni concentration among species 1 to 12. Moreover, Ni concentrations of the species 1 were high in the Cu mine area and the serpentinite area.

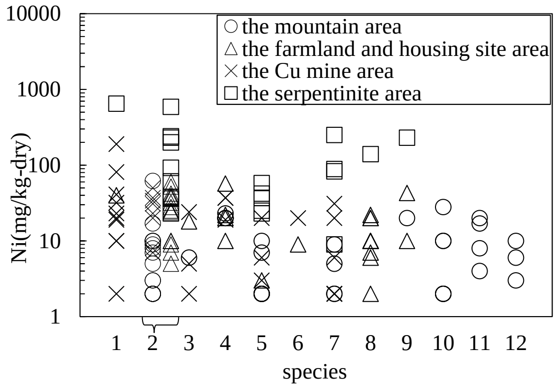

Fig.7 Ni concentrations of bryophyte species

Therefore, it was found that the species 1 had high Ni accumulation ability as well as Cu and Co. From subsection 4.1.2, it was thought that the species 1 was a kind of copper bryophyte similar *Scopelophila cataractae*. It is reported that the tolerance ability of *Scopelophila cataractae* for Cu, Co, Ni et al is high [15]. Therefore, the species 1 was thought to be a Ni contamination indicator. Moreover, it was thought that the species 1 was a kind of hyper accumulator bryophyte similar *Scopelophila cataractae* for Ni. On the other hand, most of Ni concentrations of species 2 in the serpentinite area were more than 40 mg/kg-dry and were high. Therefore, the species 2 had the high and a wide range of Ni concentrations among species 1 to 12. Moreover, maximum Ni concentration of species 2 was high next to species 1. And then, the species 2 can be sampled in all sampling groups in the catchment. Therefore, the species 2 was useful species for an index of Ni contamination in the catchment. Moreover, it was thought that the species 2 was another hyper accumulator bryophyte similar *Scopelophila cataractae* for Ni.

5. CONCLUSION

In this study, Cu, Co and Ni concentration of bryophyte in the Kinokawa River catchment were investigated in order to evaluate river metal contamination. High metal concentrations of bryophyte were over 90 for Cu, over 20 for Co and over 40 mg/kg-dry for Ni, respectively because normal values in the area at the past study were 9 to 87 for Cu, 2 to 19 for Co and 2 to 40 mg/kg-dry for Ni, respectively.

High metal concentrations of bryophyte in the lower stream of the closed Cu mines were 120 to 26,000 for Cu, 25 to 2,400 for Co and 50 to 190 mg/kg-dry for Ni, respectively. The closed Cu mine produced a lot of Cu and Fe sulfide ore and then the waste water was low pH and contained high concentration of sulfate with metal. Therefore, high Cu, Co and Ni concentrations of bryophyte in the lower stream of the closed Cu mines were thought to be caused by waste water and Cu sulfide ore from the closed Cu mines. High metal concentrations of bryophyte in the lower stream of the serpentinite were 24 to 59 for Co and 58 to 650 mg/kg-dry for Ni, respectively. The serpentinite contains a large amount of Ni and Co. Therefore, high Co and Ni concentrations of bryophyte in the lower stream of the serpentinite were thought to be caused by the serpentinite. Co concentrations of bryophyte in the lower stream of the closed Cu mines were higher than those in the lower stream of the serpentinite because Co concentrations of the cupriferous pyrite (35 to 2,500 ppm) were higher than those of the serpentinite (62 to 94 ppm). Ni concentrations of bryophyte in the lower stream of the serpentinite were higher than those in the lower stream of the closed Cu mines because Ni concentrations of serpentinite (1,100 to 2,900 ppm) were higher than those of the cupriferous pyrite (20 to 300 ppm). Background metal concentrations of bryophyte sampled at the non-mine area and the non-serpentinite area were 2 to 96 for Cu, 2 to 20 for Co and 2 to 43 mg/kg-dry for Ni, respectively.

A kind of hyper accumulator bryophyte similar *Scopelophila cataractae* were often sampled in the Cu mine area. And then, their metal concentrations were high, 1,100 to 26,000 for Cu and 33 to 2,400 mg/kg-dry for Co, respectively. Moreover, a kind of hyper accumulator bryophyte similar *Scopelophila cataractae* had the highest Ni concentration among all species and some of their Ni concentrations in the Cu mine area and the serpentinite area were high, 81 to 650 mg/kg-dry. Therefore, a kind of hyper accumulator bryophyte similar *Scopelophila cataractae* was thought to be a Cu, Co and Ni contamination indicator. Another hyper accumulator bryophyte similar *Scopelophila cataractae* was sampled in all group of geological condition and its metal concentrations were 2 to 5,900 for Cu, 2 to 150 for Co and 2 to 590 mg/kg-dry for Ni, respectively. Therefore, it was useful species for an index of Cu, Co and Ni contamination in the catchment because of its wide concentration depending on geological condition and wide distribution for geological condition.

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