Conference Paper, Published Version

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EFFECTS OF GEOLOGICAL HETEROGENETIY IN WATERSHED AREA ON SEDIMENT DISTRIBUTION AND BENTHIC MACROINVERTEBRATE COMMUNITY IN RIVER SYSTEM

Tashiro T.[1] and T. Tsujimoto[2]

Abstract: *Geological distribution is one of the fundamental information for screening sediment yield in mountainous region. The objective of this study is to discuss source and flux of sediment and these effects on benthic macroinvertebrate community in a river basin system with heterogenic topography, geology and lithology, from the viewpoint of grain size distribution with downstream fining process. Physicochemical characteristics of stream bed materials in the river basin system were clarified by analyzing field measurement of their topography. Two kinds of laboratory experiments for these sediments were conducted by employing the X-ray fluorescence (XRF) spectrometer and the abrasion-mixer. The XRF spectrometer examined that characteristics of sediment element distribution partly corresponded to the geological distribution. Furthermore, we could relatively evaluate the relative contribution of sediment flux from each tributary watershed with the element proportion of sediment. And the abrasion-mixer experiment clarified the differences in decreasing mass of tested cobble and in size distribution of produced sediment, and hence suggested that the splitting, chipping, crushing, cracking and chipping process were caused by the each sample friability related to the geological characteristics. On the other hand, the species identification of macroinvertebrates could clarify the characteristics of benthic macroinverterate community in the each site. Consequently, by combining these results in the present study, we could examine that source and flux of sediment and these effects on benthic macroinvertebrate community in a river basin system with heterogenic topography, geology and lithology, from the viewpoint of grain size distribution with downstream fining process.*

Keywords: *geology; lithology; riverbed material; abrasion; macroinvertebrate; size and element distribution; x-ray fluorescence analysis (XRF); sediment flux ratio.*

INTRODUCTION

Geological distribution is crucial for river basin management not only as the background information, but also as the screening map for sediment yield in mountainous region. Conventionally, many works for evaluating sediment yields in mountainous regions have been conducted by using the sediment storage in dam reservoir (e.g. Brune, 1954) with the

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dam structure. Some of them have suggested that the geological composition in watershed area has been one of the effective factors on its sediment yield (e.g. Inoue et al., 1992; Hasegawa et al., 2005). Hence, the geological information has been used for designing of dam location and structure in practice. Although the most of studies have been conventionally developed for the evaluation of amount or rate of sediment yield (e.g. Enomoto et al., 1967; Inoue et al., 1992; Wallbrink et al., 1998; Hirabayashi, 2000; Hasegawa et al., 2005), a few studies have pointed out the grain size distribution of sediment changing in the processes of production, storage, runoff and transport (e.g. Kodama, 1994a; Frings, 2008; Tashiro et al., 2008). Furthermore, these sediment size distributions have been recognized as one of the important factors for maintaining habitat condition in rivers or streams (e.g. Kawai and Tanida, 2005). Consequently, the objective of this study is to discuss source and flux of sediment and these effects on benthic macroinvertebrate community in a river basin system with heterogenic topography, geology and lithology, from the viewpoint of grain size distribution with downstream fining process.

METHODS AND MATERIALS

Study Location

The research location was set in the Kushida river basin, Matsuzaka city, Mie prefecture in the central area of Japan. The Kushida river basin is mainly composed by the Ryoke igneous (RI), the Sambagawa metamorphic (SM) and the Chichibu sedimentary (CS) terrains, and supplies a large amount of sediment to the broad tidal flat in its estuary (Nakajo, 1994). The sites to investigate were selected in the main stem (6 stations located at 3 km, 20 km, 40 km, 60 km, 80 km and 100 km from the river mouth) and in the 6 main tributaries with 3 stations set for the each upper, middle and lower reaches, as shown in Figure 1. Each of the station was characterized as typical distribution of these geological terrains.

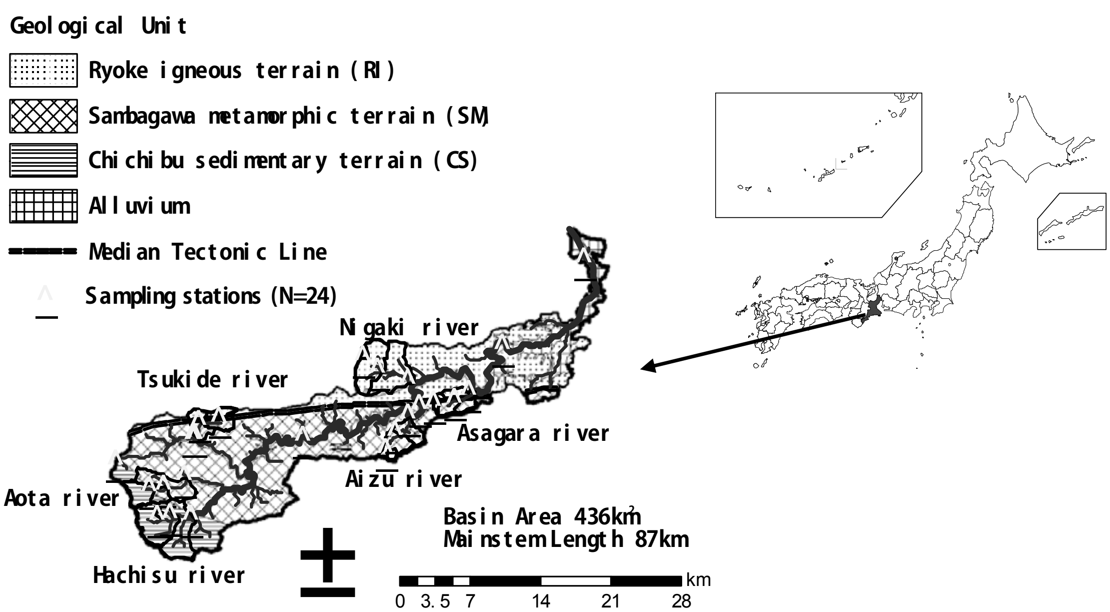

Fig. 1. Sampling locations in the Kushida river basin, central area of Japan.

Field Investigation and Analytical Procedures

A series of investigations in each station were consisted of topographic measurements for channel-unit distribution, sediment samplings of bed surface area (400 cm^2) in 5 cm thickness at 4 pools, and water quality monitors (temperature, pH, electric conductivity, DO concentration and ORP [mV]) with the multiple meter (556 MPS, YSI/Nanotech Inc.). The sampled sediments were divided into organic / inorganic materials. The former ones were identified species compositions as macroinvertebrate communities according to Kawai and Tanida (2005), and wheras the latter ones were analyzed grain size distributions by sieving. In order to analyze sources and contributions of sediment, the element mass percentages with x-ray fluorescence (XRF) analysis were measured at the stations in all over the river basin system (see Figure 1), according to Yamamoto et al. (1986), Ortiz and Roser (2006), Shimatani et al. (2006) and etc. The energy dispersive x-ray fluorescence spectrometer (Rayney EDX-700, SHIMADZU Co. Ltd.) was utilized for the finer materials in 0.075 - 0.85 mm grain size, in the each sediment sample.

We also conducted to calculate contribution of sediment flux by using the dominant element mass percentages before and after confluence of tributaries in accordance with the conventional works (e.g. Enomoto et al., 1967; Wallbrink et al., 1998; Hirabayashi, 2000). Figure 2 shows the schematic image for confluence with sediment fluxes in a region located from 20 km to 60 km in the Kushida river system including tributaries such as Aizu, Nigaki and Asagara rivers. Defining r values as the proportion of each element, we could have the following simultaneous equations and could simulate relative contributions of sediment flux in tributary watersheds.

$$r_{\mathrm{K.\,M.\,60\,k}} \cdot Q_{\mathrm{K.\,M.\,60\,k}} + r_{\mathrm{Aizu\_SM}} \cdot Q_{\mathrm{Aizu\_SM}} = r_{\mathrm{K.\,M.\,40\,k}} \cdot Q_{\mathrm{K.\,M.\,40\,k}} \quad (1)$$

$$r_{\mathrm{K.\,M.\,40\,k}} \cdot Q_{\mathrm{K.\,M.\,40\,k}} + r_{\mathrm{Nigaki\_RI}} \cdot Q_{\mathrm{Nigaki\_RI}} + r_{\mathrm{Asagara\_SM\text{-}RI}} \cdot Q_{\mathrm{Asagara\_SM\text{-}RI}} = r_{\mathrm{K.\,M.\,20\,k}} \cdot Q_{\mathrm{K.\,M.\,20\,k}} \quad (2)$$

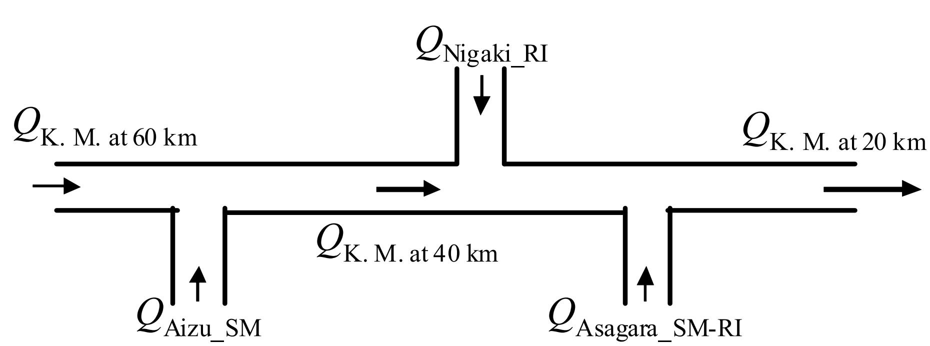

Fig. 2. Schematic image for calculating the contribution of sediment flux in a region located from 20 km to 60 km in the Kushida river system including tributaries. *Q* means relative contributions of sediment flux; and K. M. means the Kushida river mainstem.

Experimental Procedures

An experiment with a concrete mixer was undertaken to clarify abrasion phenomena of bed materials in sediment transport processes by referring Parker (1991), Kodama (1994b) and Frings (2008). This abrasion-mixer was performed for 180 minutes with a set of two cobbles of riffle sediment and two samples of pool sediment in the each tributary with a homogeneous geology. These samples were utilized after collecting other kinds of data as above mentioned. Temporal changes of the each cobble weight were measured, and whereas grain size distributions were analyzed before and after the each abrasion-mixer experiment.

RESULTS AND DISCUSSIONS

Grain Size Distribution of Sediment

Figure 3 shows sediment size distributions in upper, middle and lower reaches of the tributary stations ($N = 4$, see Figure 1). It was found that a large amount of fine materials were included in all of the samples in Nigaki river, and whereas a large amount of coarse materials were included in all of the samples in Hachisu river. On the other hand, Figure 4 shows the channel bed slopes (SL) and median grain sizes (D50) of the pool sediments in the stations with a homogeneous terrain. Although they were almost equal in channel bed slope, there was remarkably different in D50 between the upper reach stations of Nigaki and Hachisu rivers. The each of tributary watershed has homogeneous different geology: the former Nigaki located in the Ryoke igneous terrain, and whereas the latter Hachisu located in the Chichibu sedimentary terrain. Hence, by combining the sediment distributions and the topographic characteristics, the difference in grain size of sediment were caused not only by fluvial processes related to channel characteristics, but also by lithology distribution dependent on background geology.

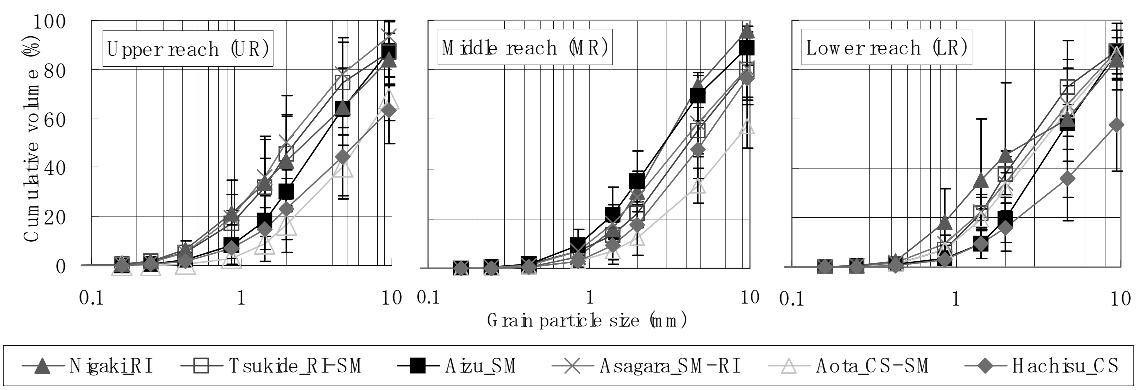

Fig. 3. Grain size distributions of the sediment sampled in pools of tributary stations. Each plot / error bar means the average/ the standard deviation value of the cumulative volume at the each size of samples.

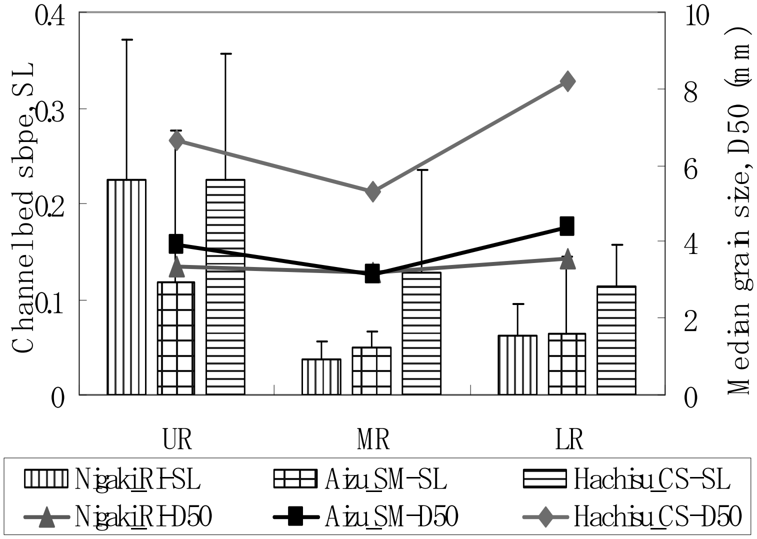

Fig. 4. Channel bed slopes (bars: averages and standard deviations) and median grain sizes (plots: averages) of the pool sediments in the stations with a homogeneous terrain.

XRF Analysis and Sediment Flux Contribution

In order to distinguish g roups in e ach environmental c ondition of tri butary w atersheds, a multivariate statistical analysis using principal components (PCA) was performed taking into account most of element percentages (Si, Al, Fe, K, Mg and Ca) of tested sediments. PCA is a reliable tool to separate emergent functional groups (Lavorel et al., 1997), these results are shown in Table 1 and Figure 5. In this study, two principal components were considered; PC 1 and PC 2 summarized 81.1% of orig inal data variation, w hich we re re presentative of original data variance. According to the Pearson's correlations in Table 1, controlling factors of the plot distributions in Figure 5 were found as follows: PC 1 mainly depended on Si and Fe relative ma ss and whereas PC 2 mostly de pendent on Al r elative m ass. Therefore, the geological characteristics, especially for the Ryoke igneous terrain as shown in the Nigaki and Tsukide plots of Fig ure 5, were also ex amined i n t he P C1 sc ore, dominant ele ment composition (low percentages of Si and high percentages of Fe) of the finer materials.

Table 1. Results for Pearson's correlations between the scores of the principal components and the each dominant element in tested sediments.

	Si	Al	Fe	K	Mg	Ca	% explanation
PC 1	-0.93	0.51	0.90	-0.71	0.70	0.71	57.5
PC 2	-0.31	0.79	0.03	0.64	0.13	-0.51	23.6

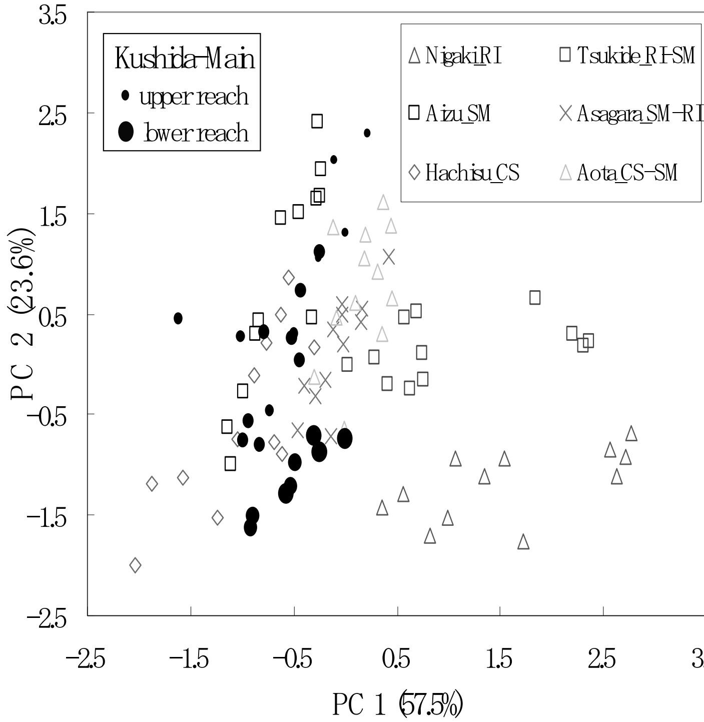

Fig. 5. Ordination graph of principal component analysis performed with six dominant element percentages of the finer materials in pool sediments. PC1, first principal component; PC2, second principal component.

Figure 6 shows the contributions for the region located from 20 km to 60 km in the Kushida river system including tributaries such as Aizu, Nigaki and Asagara rivers (see Figure 2). We could clarify that the Sambagawa metamorphic terrain have relatively higher contribution of sediment flux by calculating with the simultaneous equations (1) and (2) with proportions *r* of dominant elements such as Si, Al, Fe, K and Ca (reached 93 - 97%). Each of vertical values in this figure was estimated as the each relative contribution of sediment flux divided by the relative watershed area of each tributary, and was equal to multiples of the sediment flux contribution at 20km from the river mouth.

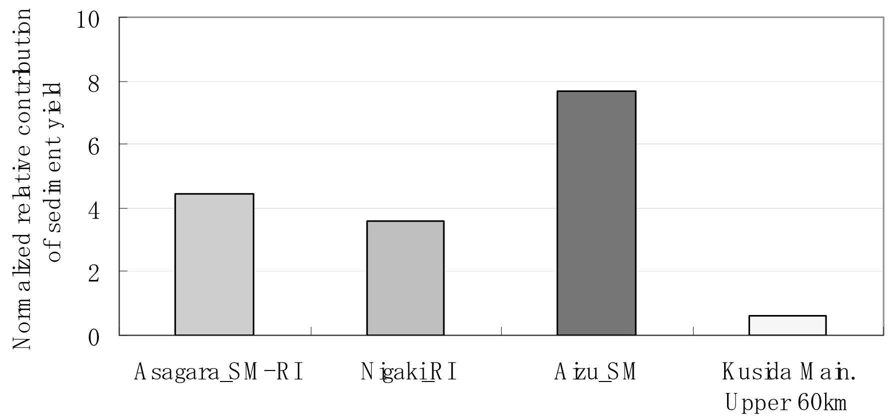

Fig. 6. Contributions of sediment flux from the different tributary watersheds for the region located from 20 km to 60 km in the Kushida river system.

Abrasion-mixer Experiment

Figure 7 shows the temporal decreases in relative mass of the tested cobbles due to the experiment with abrasion-mixer. We remarkably examined that the igneous rocks collected in the Nigaki river were relatively much tolerant than the other rocks. On the other hand, Figure 8 shows the grain size distribution for tested sediments before and after the 180 minute abrasion-mixer experiments. The produced materials were quite different in the total mass and in the size composition in these experiments, which were dependent on friability of the each cobble. Consequently, it was suggested that metamorphic rocks tended to be crushed, cracked and ground with fine products, and whereas sedimentary rocks were easy be split and chipped with relative coarse products according to the arrangement of abrasion mechanisms by Frings (2008).

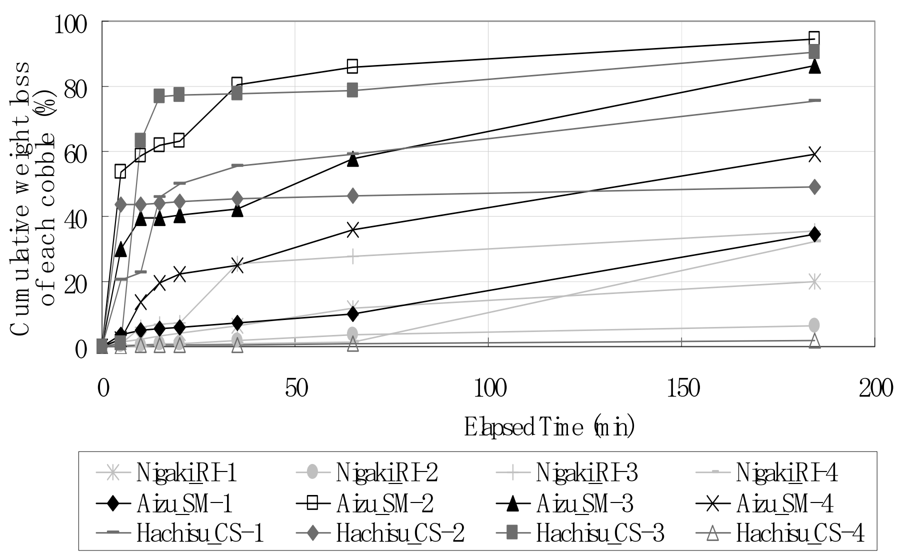

Fig. 7. Weight loss of the each cobble in experiments with abrasion-mixer.

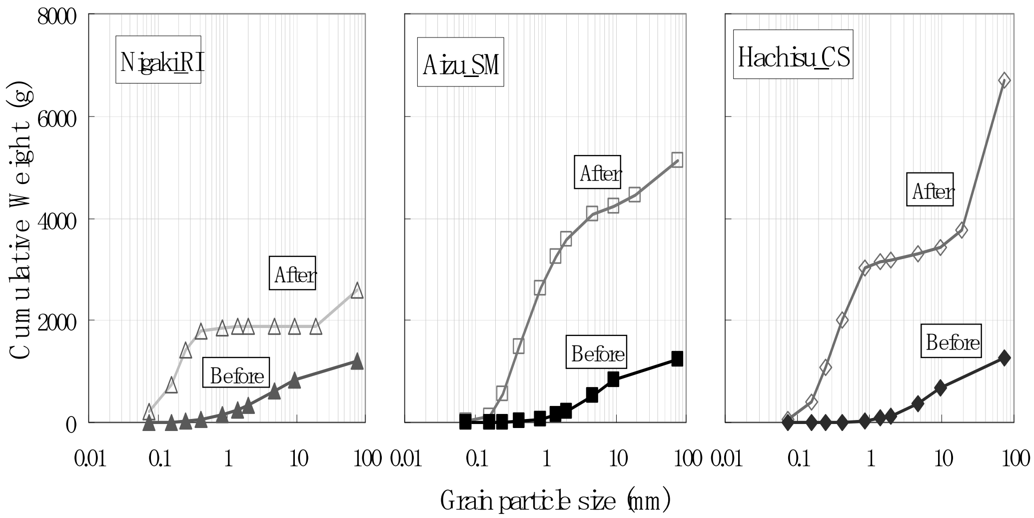

Fig. 8. Grain size distributions of the tested sediments before and after the 180 minute abrasion-mixer experiments.

Macroinvertebrate Community

As a result of the species identification of macroinvertebrates, we could clarify the characteristics of benthic macroinverterate community in the each site. Table 2 shows the dominant species (> 15% in the percentage of individuals) in pool sediments of tributary stations. Since remarkable difference of each index of water quality could not be observed, the controlling factors were considered to be mainly in physical aspects of habitat condition. As typical species reflected physical habitat environments, two species of mayfly larvae: *Ephemera japonica* and *Ecdyonurus bajkovae* were selected in this study. The both of mayfly larvae indicated sandy substrate which was familiar in the Ryoke igneous terrain (RI), the former one prefers these condition, and whereas the latter one avoids these condition (e.g. Kawai and Tanida, 2005). By combining these results with the sediment size distributions, we could examine that the benthic macroinvertebrate community reflected the size distribution of sediment in the each reach related to the geology of its watershed.

Table 2. Dominant species (> 15% in the percentage of individuals) in pool sediments of tributary stations. Latin and Japanese names were described.

Tributary	Geological unit	UR		MR		LR	
Nigaki	RI	*Geothelphusa dehaani*	サワガニ	*Semisulcospira libertina*	カワニナ	*Potamanthus formosus*	キイロカワカゲロウ
		Ephemera japonica	フタスジモンカゲロウ				
Tsukide	RI-SM	*Ephemera japonica*	フタスジモンカゲロウ	*Ecdyonurus bajkovae*	オニヒメタニガワカゲロウ	*Ecdyonurus bajkovae*	オニヒメタニガワカゲロウ
				Elminae	ヒメドロムシ亜科	Elminae	ヒメドロムシ亜科
Aizu	SM	*Ephemera japonica*	フタスジモンカゲロウ	Naidinae	ミズミミズ亜科	*Ecdyonurus bajkovae*	オニヒメタニガワカゲロウ
		DIPTERA	ハエ目			Leuctridae	ホソカワゲラ科
Asagara	SM-RI	*Gumaga orientalis*	ケトビケラ科の一種	*Thraulus* sp.	トゲエラカゲロウ属	*Neoperla* sp.	フタツメカワゲラ属
		Elminae	ヒメドロムシ亜科				
Aota	SM-CS	Chloroperlidae	ミドリカワゲラ科	*Erioptera* sp.	ガガンボ科の一種	*Ecdyonurus bajkovae*	オニヒメタニガワカゲロウ
Hachisu	CS	*Paraleptophlebia* sp.	トビイロカゲロウ属	*Micrasema quadriloba*	マルツツトビケラ	*Torleya japonica*	エラブタマダラカゲロウ
		Chloroperlidae	ミドリカワゲラ科				

CONCLUSIONS

Physicochemical characteristics of stream bed materials in the river basin system were clarified by analyzing field measurement of their topography and grain size distribution in pool sediments. Two kinds of laboratory experiments for these sediments were conducted by employing the X-ray fluorescence (XRF) spectrometer and the abrasion-mixer. The XRF spectrometer examined that characteristics of sediment element distribution partly corresponded to the geological distribution. Also, we could relatively evaluate the relative contribution of sediment flux from each tributary watershed with the element proportion of sediment. And the abrasion-mixer experiment clarified the differences in decreasing mass of tested cobble and in size distribution of produced sediment, and hence suggested that the splitting, chipping, crushing, cracking and chipping process were caused by the each sample friability related to the geological characteristics. Furthermore, the species identification of macroinvertebrates could clarify the characteristics of benthic macroinverterate community in the each site. Consequently, by combining these results in the present study, we could examine that source and flux of sediment and these effects on benthic macroinvertebrate community in a river basin system with heterogenic topography, geology and lithology, from the viewpoint of grain size distribution with downstream fining process.

ACKNOWLEDGEMENTS
The authors are thankful for the technical supports given by Prof. Kenji Suzuki (Eco Topia Science Institute, Nagoya University) in the x-ray fluorescence analysis and Dr. Keisuke Sato (Ritsumeikan Univeristy) in the analysis with geographical information system. This study was performed through Special Coordination Funds for Promoting Science and Technology from the Ministry of Education, Culture, Sports, Science and Technology of the Japanese Government.

REFERENCES

Brune, G.M. 1953. Trap efficiency of reservoirs. *Tans. AGU*, 34(3), 407-418.

Enomoto, M., Sato, A., Yamamoto, K. and Okada, K. 1967. Grouping analysis of sand and gravel pile in the Jintsu river basin (1st report): One method for calculation of sand gravel discharge from each branch. *J. Erosion-Control Engineering Society*, 67, 9-20. (in Japanese)

Frings, R.M. 2008. Downstream fining in large sand-bed rivers. *Earth Science Reviews*, 87, 39-60.

Hasegawa, K., Wakamatsu, K. and Matsuoka, M. 2005. Mapping of potential erosion-rate evaluated from reservoir sedimentation in Japan. *J. Japan Society for Natural Disaster Science*, 24(3), 287-301. (in Japanese)

Hirabayashi, K. 2000. Estimation of sediment supply from each sub-catchment of the Fuefuki river by analyzing longitudinal change in lithologic composition of river bed material.

Annual Journal of Hydraulic Engineering, 44, 723-728. (in Japanese)

Inoue, D., Kakuda, T., Kawamura, K. and Tomori, M. 1992. An examination of slope failure characteristics and their relationships with geology and reservoir sedimentation in Japan Part 1: relationship between slope failure characteristics and geology, J. Japan Society of Engineering Geology, 33(3), 1-10. (in Japanese)

Kawai, T. and Tanida, K. 2005. Aquatic Insects of Japan: Manuals with Keys and Illustration. Tokai University Press, Kanagawa. (in Japanese)

Kodama, Y. 1994a. Downstream changes in the lithology and grain size of fluvial gravels, the Watarase river, Japan: Evidence of the role of abrasion in downstream fining. *J. Sedimentary Res.*, A64(1), 68-75.

Kodama, Y. 1994b. Experimental study of abrasion and its role in producing downstream fining in gravel-bed rivers. *J. Sedimentary Res.*, A64(1), 76-85.

Lavorel, S. , Mcintyre, S., Landsberg, J. and Forbes, TDA . 1997. Plant functional classifications: from general groups to specific groups based on response to disturbance. *Trends Ecol. Evol.*, 12(12), 474-478.

Nakajo, T. 2004. Geomorphology and sedimentation of microtidal flat in the Kushida river estuary, Ise bay, central Japan. *Bulletin of the Osaka museum of Natural history*, 58, 69-78. (in Japanese)

Ortiz, E. and Roser, B. 2006. Geochemistry of stream sediments from the Hino river, SW Japan: Source rock signatures, downstream compositional variations, and influence of sorting and weathering, *Earth Science*, 60, 131-146.

Parker, G. 1991. Selective sorting and abrasion of river gravel. I: Theory. *J. Hydraulic Engineering*, 117(2), 131-148.

Shimatani, Y., Nomura, K. and Kawaguchi, Y. 2006. Longitudinal distribution of sediment composition in the Kita river, *Advances in River Engineering*, 12, 305-310. (in Japanese)

Tashiro, T., Noboritate, K. and Tsujimoto, T. 2008. Effects of geological heterogeneity in watershed area on tributary sediment flux with size and element distribution of sediment in rier system. *Advances in River Engineering*, 14, 121-126. (in Japanese)

Yamamoto, K., Sugisaki, R. and Arai, F. 1986. Chemical aspects of alteration of acidic tuffs and their application to siliceous deposits. *Chemical Geology*, 55, 61-76.

Wallbrink, P.J., Murray, A.S. and Olley, J.M. 1998. Determining source and transit times of suspended sediment in the Murrumbidgee river, New South Wales, Australia, using fallout ^{137}Cs and ^{210}Pb. *Water Resources Res.*, 34(3), 879-887.