Annual Journal of Hydraulic Engineering, JSCE, Vol.51, 2007, February

EXAMINATION OF RIFFLE BEDS AND THEIR RELATIONSHIP TO THE NET-SPINNING CADDISFLY (*STENOPSYCHE MARMORATA*)

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The objective of the study is to improve the understanding of relationships between multiple spatial scales and the development of micro-habitat as well as its co-dependence with the net-spinning caddisfly (*Stenopsyche mamorada*). In this study, two target riffles located in the Asa River basin were investigated during the spring of 2006. Three major findings of this research were that; 1. the target specie seems to prefer substrate with median diameters between 3-13 cm because they need medium-sized gravel to create their nests, 2. the abundance of medium-sized gravel in the loose surface layer of riffle bed was observed to be related to the normal flow unit-width discharge because the finer bed material on the surface is washed out during normal flow condition and loose layer is developed, and 3. despite the unstable nature of braided morphology the target specie population was more prevalent and stable because the rough terrain reduce the local shear stress on the riffle bed during small floods.

Key Words **:** *Benthic Macro-invertebrate, Normal flow Unit-Discharge, Reach-scale morphology, Surface layer condition and stability of riffle bed*

1. INTRODUCTION

(1) Background

Japanese rivers, particularly those in the Kanto region have a long history of alterations for human benefits. The river works which had been intended to improve the flood safety for urban dwellers have left nearly all rivers in some way, dam regulated, hardened, and or straightened. River environments in terms of both water quality as well as physical habitat were in poor condition. In 1997 the new river law stipulated that river ecology be included as one of the key management goals along with flood control and water supply. Initial efforts to restore the physical environment of rivers were conducted by trying to reconstruct the desired morphology either by concrete structures intended to mimic nature or excavating natural material. Many of the early attempts at restoration failed to reach their objectives because they did not account for the cyclical nature of riparian ecosystem or the dynamics responsible for shaping it. Prior to any restorations, it is necessary to understand multiple spatial and temporal scale forces which shape the current physical environment.

(2) Objectives

The specific target of this study is to examine the effect of multiple spatial and temporal scale forces on the characteristics of benthic condition within a riffle unit. Particular focus was placed on the heterogeneity and stability of gravel structure. The roles of hydrological and hydraulic parameters including normal flow discharge, hydraulic conditions during a small flood and several scale physical factors were examined. Finally the target specie *Stenopsyche marmorata* (Higenagakawa-tobikera in Japanese) was examined in order to understand the bio-physical relationship among gravel structure, flow regime, and benthic habitat. *Stenopsyche marmorata* was selected as a biological indicator because it is widely acknowledged as a generalist specie in Japanese rivers[1)]. *Stenopsyche marmorata,* as it is commonly referred to, has been shown to be sensitive to substrate stability but fairly insensitive to water quality. Many past studies have identified *Stenopsyche marmorata* as a re-enforcer of substrate and clarified the effect of their activity on riverbed stability. But, in this study, we supposed

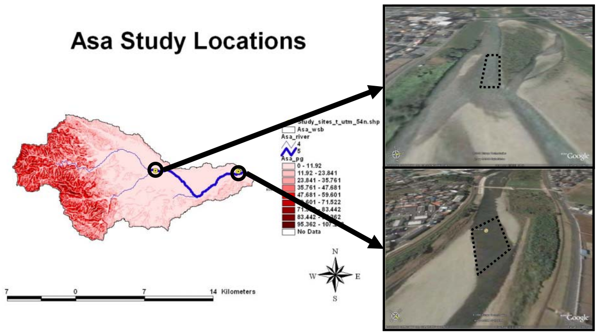

Fig.1 Map of the Asa River Basin with gradients displayed in progressive shades. Locations of study sites are accompanied by oblique aerial images.

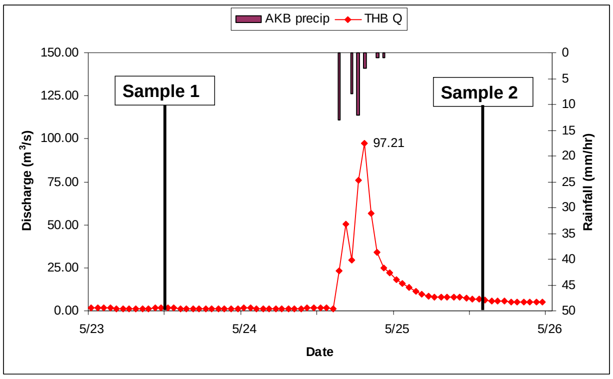

Fig.2 Hydrograph near the AFB site. Pre- and post-flood observation times are also shown.

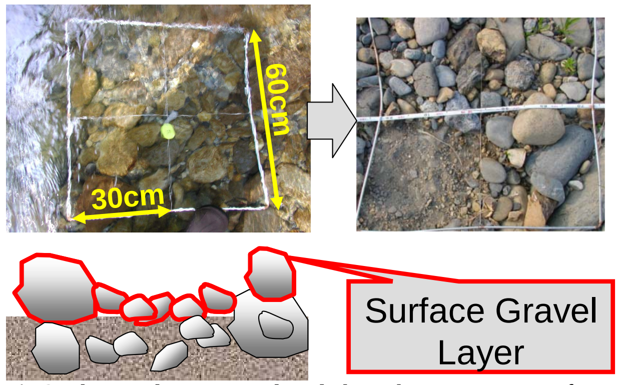

Fig.3 The quadrat we used and the schematic image of surface gravel layer

that the original benthic characteristics that are the heterogeneity and stability of gravel affected the initial colonization of the target specie, and focused on the original gravel structure rather than the enforcement by the insects.[2)3)4)].

2. FIELD MEASUREMENTS

(1) SITE SELECTION

Selected parameters for determining study sites were that the riffles had to be long-type planar shape[5)] and had to have mean thalweg gradients between 1/60 and 1/90.

The Asa Ogiwara Bashi (AOB) site was located near river km 12 in a braided reach and the Asa Fureai Bashi (AFB) site located near river km 2 within an alternate bar reach **(Fig.1)**. The observed thalweg bed slopes were actually 1/59 in the AOB site and 1/76 in the AFB site. Both sites were selected within 500 meters of a river gauging station.

(2) Dates of Field Measurements and Discharge

The first round of the field measurements for topography and velocity was conducted at both sites on April 29th of 2006.

The second round of the field measurement for substrate and macro-invertebrate was conducted on May 23rd. Unfortunately, the upper transect of the AOB site could not be measured on the 23rd due to a time limitation. A small flood occurred on the 24th and substrate condition was altered. The flood event of May 24th was estimated to have a discharge of 97.21 m^3/s at the gauge near AFB. The discharge on the 23rd during the second round of the observation had been 1.36 m^3/s.

On May 25th, the macro-invertebrate was sampled again from the middle cross-sections of both sites. The discharge at the gauge was 6.87 m^3/s during the sampling **(Fig.2**).

(3) Topography and Velocity Measurements

Vertical and horizontal surveys were conducted during the first round of observation to retrieve the morphology of the riffle unit as well as to document adjacent features on the bars. The topographic survey established three transects with three in-channel sampling points within each of the study riffles for velocity measurements and later benthic sampling. Velocity measurements were taken from each of the in-stream sampling points with an electronic meter at 60% depth.

(4) Survey of Substrate

Gravel sampling was conducted at each sampling point in each of the three transects within the AFB site and from the lower and middle transects within the AOB site using a 60x60cm frame with 30x30cm grids (see **Fig.3**). All medium-sized gravel whose medium diameter is from 3 to 13cm were taken from the quarter quadrat and brought to shore to be massed and photographed with a scale bar. In this sampling, only surface gravel which were less than half buried and could be dislodged with one hand was focused on. Digital photography was selected as an efficient method of measuring medium diameters of individual gravel. Gravel which was larger than 13 cm was taken from whole quadrat then carried back to the shore for measurement and weighed individually [5)].

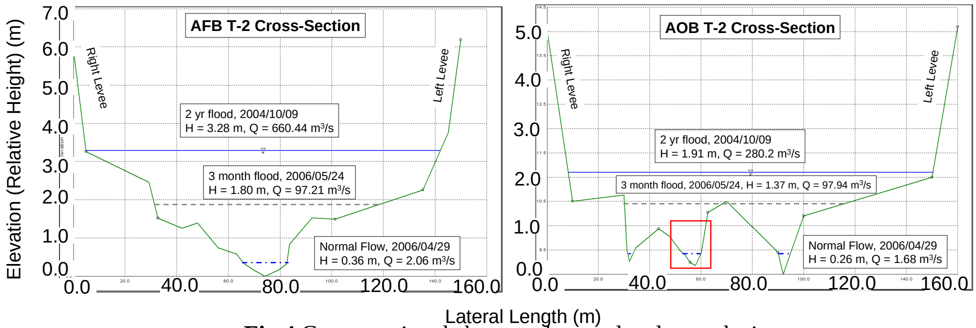

Fig.4 Cross-sectional shape and water level at each site

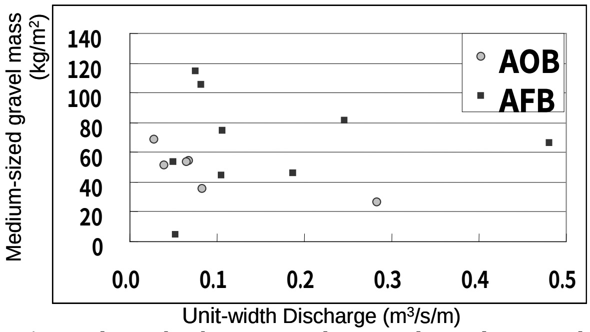

Fig.5 Relationship between medium sized gravel mass and unit-width discharge

(5) Insect Sampling

A Surber net (250μm mesh) was held in place on the downstream side of the 30cm x 30cm grid and as gravel was removed it was washed into the net. Onshore the contents of the net were emptied and rinsed into a 500 ml container, filled with 90% Ethanol and sealed.

Collected *Stenopsyche marmorata* were separated from other insects and then their body lengths were measured. As with the gravel samples, number of individuals were converted from the sampling unit area of 30 cm^2 to 1 m^2.

The transect-average densities of the target specie on 23rd and 25th were compared in order to examine the effect of the event flow on the abundance in each riffle. Combined size distributions from pre- and post-flood surveys were examined in order to check if there was a difference in sensitivity to flood.

3. RESULTS

(a) Topography

The middle cross-sectional profiles of both sites are shown in **Fig.4**. The flow in AOB was divided between channels during normal flow condition as well as the peak discharge of the May 24th. No significant change on the topography was found at either of the study sites after the event.

(b) Unit-width discharge during normal flow

Unit-width discharge at each of the sampling points was calculated as local depth multiplied by velocity respectively. The values within AFB for unit-width discharge ranged from 0.03 $m^3/s/m$ at both sides of the upstream transect to 0.48 $m^3/s/m$ in the thalweg of the downstream transect. On the other hand, there was very little variability in the unit-width discharge among sample points of the AOB site. The range of observed unit-width discharge was between 0.03 $m^3/s/m$ in the right side of the upstream transect and 0.28 $m^3/s/m$ on the thalweg of the downstream one. The cut-bank in both study riffles was located on the river left bank.

The values increased with downstream distance and laterally towards the thalweg in both sites due to the concentration of flow.

(b) Medium-sized gravel mass

Medium-sized gravel mass per square meter within both sites followed nearly inverse of the trend for unit-width discharge **(Fig.5)**. The large unit-width discharge around the thalweg is thought to flush the medium-sized gravel leaving only large substrate.

The largest values of medium-sized gravel mass within the AFB site were observed on the right and left banks of the middle cross section. The maximum mass of medium-sized gravel from the middle right sampling point was 114.44 kg/m^2 while only 81.22 kg/m^2 were observed on the thalweg of the same transect. The minimum observed mass 17.89kg/m^2 was found at the upper right sample point. Within AOB site, the minimum observed mass 26.11 kg/m^2 was observed on the thalweg of downstream transect. The largest gravel mass was 68.33 kg/m^2 which was observed at the downstream right sample point.

The observations of this research agree with previous studies showing that the thickness of surface layer is usually thin at the upstream side and thick at the downstream side of a riffle, and the medium-sized gravel mass is abundant at both sides of riffles and less on the thalweg[5)6)]. The characteristics of the distribution are similar between two sites, but the overall mass in AFB is much larger than that in AOB.

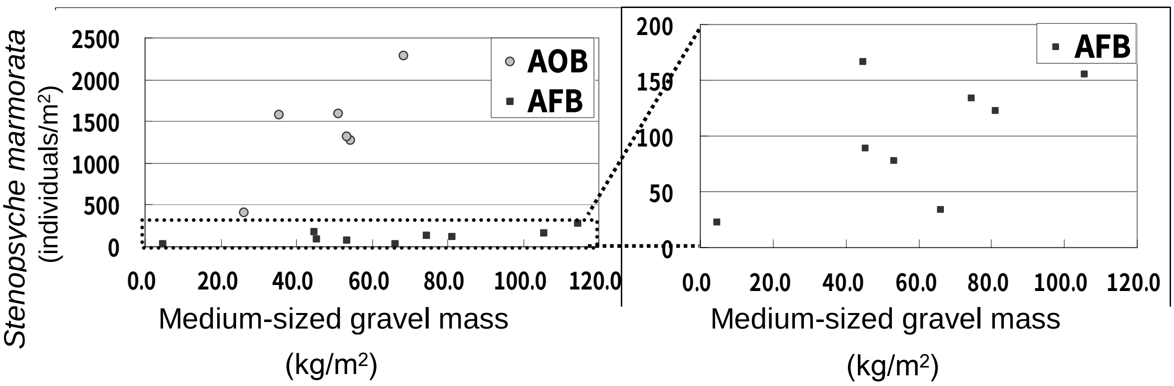

Fig.7 Relationship between medium-sized gravel mass and the concentration of the target specie

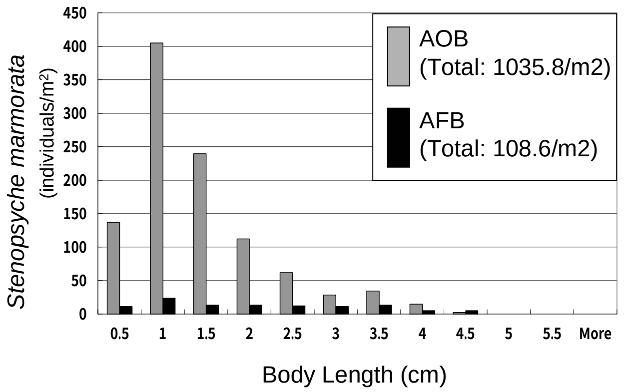

Fig.6 Size distribution of *Stenopsyche marmorata* that is collected from all sampling points at both sites

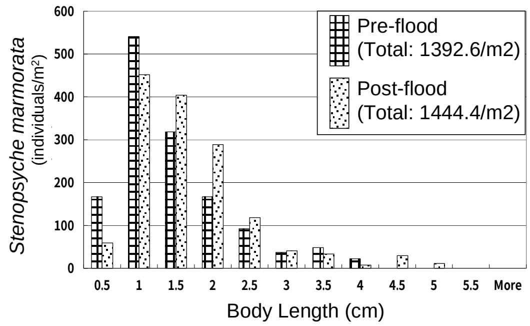

Fig.8 Comparison of *Stenopsyche marmorata* that was collected from the middle cross section of AOB

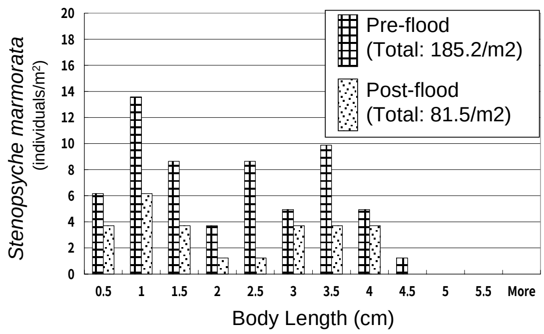

Fig.9 Comparison of *Stenopsyche marmorata* that was collected from the middle cross section of AFB

(c) Insect sampling before the flood of May 24th

Fig.6 shows the size distribution of the target specie *Stenopsyche marmorata* that was collected from all sampling points at both sites. The data collected before the flood was utilized, but unfortunately the upstream cross-section of AOB was not investigated. Therefore it was assumed that the population in upstream cross-section of AOB was not changed by the flood because upstream cross-section has the mildest slope that corresponds to the lowest shear stress. *Stenopsyche marmorata* were ten times more prevalent in the AOB riffle than in the alternate bar AFB riffle (see **Fig.8** & **Fig.9** explained later).

Based on the size distribution, the target specie in AOB is mainly composed of the individuals whose body length is about 1cm, however in AFB there are two peaks around 1cm and 3.5cm. Mainly the population of new generation is different between two sites.

In terms of the preference for micro habitat, a similar trend was found at two sites. In AFB, two of the three highest concentrations of *Stenopsyche marmorata* were located near the banks of the middle transect. A density of 278individuals/m^2 was observed from the right sample point and 156individuals/m^2 was found on the left side. Minimum values of 22individuals/m^2 and 33individuals/m^2 were observed at the upper and lower left sampling points where medium gravel masses were also low.

The highest and lowest densities within the AOB site were found at the downstream right with 2,289individuals/m^2 and downstream left with 400individuals/m^2. The target specie within AOB also concentrated the area where medium gravel mass was large **(Fig.7)**.

Within each site, the population of the target specie appears to increase with increasing mass of medium gravel. The overall population between two sites, however, is quite different in contradiction to the overall medium-sized gravel mass in a riffle. The reason will be discussed later.

(d) Insect sampling after the flood of May 24th

Fig.8 and **9** show the size distribution of the target specie pre and post flood of May 24th in each site. The density of *Stenopsyche marmorata* within the

AOB site remained in the range of 1,300-1,400individuals/m^2 after the flood, but the population of *Stenopsyche marmorata* within the AFB site was reduced by half and was less than 100individuals/m^2. It is not clear whether the cause of the increased density in some sampling points in AOB is sampling error or other factors. But in AFB, the density at all sampling points decreased remarkably, and the clear difference was found. The stability of benthos seems to be affected by the local shear stress on the bed during flood as well as by stabilization due to the net spinning of the target specie. The difference of stability of the population is considered to be a reflection of the difference in the original population densities of *Stenopsyche marmorata.*

4. DISCUSSION

(1) The suitable micro-habitat condition for *Stenopsyche marmorata* (Sub-unit scale analysis)

The target specie was observed to prefer areas with more medium gravel mass that appeared to be related to the normal flow unit-width discharge. The target specie is a net-spinner on the riffle bed, so the large unit-width discharge seems to be preferable in terms of the efficiency of the foraging activity. But the presence of a large unit-width discharge also affects the stability of medium gravel mass even under normal flow conditions in a riffle. *Stenopsyche marmorata* usually bind the medium gravel to larger cobble in order to create their nest. Little medium-sized gravel is available in the vicinity of the thalweg where unit-width discharge is high and the stability of the bed is poor.

The medium-sized gravel is abundant at both sides of a riffle, but the thickness of surface layer is thin at the upstream side of a riffle. The target specie is therefore considered to concentrate along the shore side of middle or downstream cross-section of riffles where the mass of medium-sized gravel is greatest.

(2) Relationship between overall medium-sized gravel mass and riffle condition (Unit scale analysis)

It was clarified that the mass of medium-sized gravel is usually lower around the thalweg and greater around the shore. The overall medium-sized gravel mass in a riffle is quite different between AOB and AFB. The relationship between averaged unit-width discharge in a riffle and averaged medium-sized gravel mass on the surface layer was examined in order to understand the mechanism which shapes the difference in bed condition between riffles. Data from eight additional long type

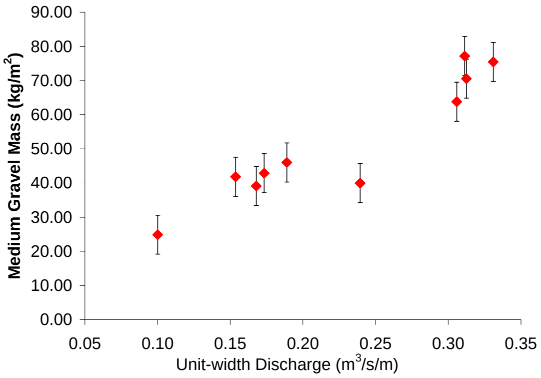

Fig.10 Relationship between averaged unit-width discharge and averaged medium-sized gravel mass in ten riffles around the target sites in this study

riffles where surface medium gravel mass had been previously investigated were included in the analysis of unit-width discharge and medium-sized gravel. **Fig.10** shows that higher average unit-width discharges were correlated to higher average masses of medium gravel. Local distributions of medium-sized gravel mass by contrast were inversely related to local unit-width discharge. The apparent conflict between the results for the local and unit scales could be explained by considering the two processes how medium gravel accumulates at the surface.

The medium gravel cannot be exposed on the surface near the shore of riffles where the unit-width discharge is small, because the fine materials among gravel cannot be washed out. The fine material can be removed and medium-sized gravel can be exposed only around the thalweg in such riffles. Moreover, a riffle with a small unit-width discharge cannot create clear thalweg, so it is difficult to create the thick surface layer. The riffle with large unit-width discharge by contrast, can scour a part of riffle bed and create clear thalweg. Medium-sized gravel can exist on top of the bed near the shore even if the thalweg is covered only with larger gravel.

Based on this consideration, side of riffles that have sufficient unit-width discharge have abundant medium-sized gravel and provide suitable habitat for *Stenopsyche marmorata*. The AFB site seems to be preferable for the target specie when considering the overall medium gravel mass, however the observed target densities were quite low. Many *Stenopsyche marmorata* utilize the side of AOB site where the amount of medium gravel is relatively large.

(3) Stability of riffle beds (Reach scale analysis)

The stability of riffle beds is another important factor in habitat suitability. As the comparison between pre and post flood shows, abundant target specie lived in AOB and the population density was not reduced by the flood of May 24th. The stability of riverbed in AOB seems to be due to the net spinning activity by the target species, but the original bed condition has to be different between the two sites. The local shear stress on the riverbed should be examined in order to better understand the substrate stability limitation of *Stenopsyche marmorata* in AFB.

AOB and AFB have similar unit-width discharges during normal flow conditions and similar riverbed slope. The shear stress on the bed during normal flow should therefore also be similar. During flood periods reach-scale morphology (i.e. braided or alternate bar) and the vertical undulation between riffles and pools receive the majority of the bed shear and may have the effect of shielding the benthos at the local scale. During periods of low flow a majority of resistance to flow comes from either small morphological features such as bed roughness and small obstacles. **Fig. 4** shows that braided reaches have greater wetted perimeters and more vertical relief than single row bar channels do especially in the case of May 24th flood. Tockner et.al.[7] and others have suggested that braided channels are much less stable than single channels as more energy is directed to the banks around riffle. In the case of small event like a May 24th flood, the topography was not altered, but the cumulative resistance to flow resulting from the many isolated bars in a braided channel is relatively high. If the large scale resistance to flow is high, then it seems reasonable that less energy will be available for the disturbance on the local riverbed condition. The combination of flood intensity and reach scale resistance helps to determine the stability of the benthos. Micro-habitat conditions can be said to be a function of local stability as well as availability of medium-sized gravel at the surface.

Many past studies have focused on the relevance of the *Stenopsyche marmorata* as an eco-system engineer or stabilizer of the benthic substrate.[3)4)] The *Stenopsyche marmorata* did seem to have a noticeable impact on benthic stability which was evident when removing surface gravel or with the lack of mobile fine martial however we also observed that the target specie population was dependant on the stability of the benthos (similar to observations of Houghten et.al[2)]).

Actually, the overall mass of medium-sized gravel was reduced by nearly 60% in AFB, but remained nearly constant in AOB. As this result shows, the substrate condition was altered in AFB site, but not in AOB. The surface layer in AFB will be gradually developed by flushing the fine materials after the event, and the target specie should be expected to require a long time in order to colonize.

5. CONCLUSIONS

Various spatial and temporal factors work in combination to determine the character and stability of micro habitat in riffle. Hydro-response is a function of basin condition. Hydro-response and channel shape determine the bar type. The bar type determines the resistance to flow during the flood event. The ratio between reach-scale resistance and local bed roughness in particular depends on the bar type. The unit shape and hydro-response determine unit-width discharge during normal or base flow conditions.

During the course of this research, a relationship between normal flow unit discharge and the mass of medium sized gravel (3-13cm) available in the benthic surface layer could be observed. And also the relationship between macro invertebrate and microhabitat condition was examined.

ACKNOWLEDGEMENT: We would like to extend thanks to the Ministry of Land, Infrastructure and Transport (MLIT) for providing discharge and precipitation data as well as granting research permits for observations in the Asa River.

REFERENCES

1) Dudgeon David: *Tropical Asian Streams: Zoobethos, Ecology and Conservation*, Hong Kong University Press, pp.389-392, 1999.
2) Houghton, David C.: Utility of Caddisflies (Insecta: Trichoptera) as Indicators of Habitat Disturbance in Minnesota, *Journal of Freshwater Ecology*, *Vol.19 (1),* pp.97-108, 2004.
3) Cardinale, B. J., Gelmann, E. R., and Palmer, M.: Net spinning caddisflies as stream ecosystem engineers: the influence of Hydropsyche on benthic substrate stability, *Functional Ecology*, *Vol.18*, pp.381-387, 2004.
4) Akira Takao, Junjiro N. Negishi, Masanori Nunokawa, Takashi Gomi, and Osamu Nakahara: Potential influences of a net-spinning caddisfly (Trichoptera: *Stenopsyche Marmorata)* on stream substratum stability in heterogeneous field environments, *Journal of the North American Benthological Society, Vol. 25 (3),* pp.545-555, 2006.
5) Takeyoshi CHIBANA, Tetsuro TSUJIMOTO, Motofumi MIYAKE, Gaku SASAKI, Hidehito IWAMOTO: Hierarchical Analysis of Physical Environment in Riffles, *KSCE Journal of Civil Engineering, Vol.9 No.1,* pp.1-6, 2005.
6) Motofumi MIYAKE, Takeyoshi CHIBANA and Tetsuro TSUJIMOTO: CLASSIFICATION OF SORTING STRUCTURE IN RIFFLES, *Advances in River Engineering Vol.10,* pp.399-404, 2004. [in Japanese]
7) Tockner, Klement., Paeltzold, Achim., Karaus, Ute., Claret, Cecile, Claret., and Zettel, Jurg.: *ECOLOGY OF BRAIDED RIVERS*, IAS Special Publication, 2004.

(Received September 30, 2006)