INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

An Attempt to Assess the Environmental Change in Downstream River of Dams by Benthic Macroinvertebrate Community

Kunihiko Amano, Yoichi Iwami & Maremi Endoh
National Institute for Land and Infrastructure Management, Tsukuba, Japan
amano-k92ta@nilim.go.jp

Munehiro Igarashi
Ministry of Land, Infrastructure, Transport and Tourism, Japan

Akio Shirai & Satoshi Kashiwabara
Water Resources Environment Technology Center, Japan

ABSTRACT:
Dam construction can significantly alter sediment transport and flow regime at the downstream river. These alterations will induce channel degradation and/or bed material change, leading to a change in benthic macroinvertebrate community. We have attempted to assess the impact of dam on downstream ecosystems by comparing benthic macroinvertebrate species found at upstream and downstream of dams, assuming that those at downstream would have been similar to those at upstream without a dam.
For this purpose, we have analysed benthic macroinvertebrate species data obtained at 42 dams nationwide. Macroinvertebrates were classified into 166 taxonomic units. TWINSPAN analysis was applied to these assembled data to classify sampling stations according to the resemblance of the macroinvertebrate communities. The tendency of listed taxon is not similar at upstream and downstream of dams; implying dams have affected benthic macroinvertebrate community downstream.
Taxa such as *Capniidae*, *Drunella*, *Epeorus* and *Glossosoma* were typically found at upstream sites, whereas taxa such as *Asellidae* and *Macrostemum* were typically found at downstream sites. We have deduced that these biases are led by the downstream environment that is characterized by the lack of sand and fine gravel in riverbed, relatively stable and slower current, and abundant organic matter.

Keywords: Benthic macroinvertebrate, environmental impact, flow regime, sediment

1. INTRODUCTION

Construction of dams usually induces enormous alteration on ambient environment. Fulfilment of the Environmental Impact Assessment (EIA) was mandated for dam construction in Japan in 1997. Avoidance, reduction, or compensation measures for presumed environmental impact may be necessary depending on the result of EIA. Both the accuracy of the EIA and effectiveness of above mentioned measures are critically important for the success of remedy of environmental impact caused by dam constructions.

Aquatic ecosystem is one of the most difficult items to assess in the EIA process since there are many causes by which it is affected. These causes include the fragmentation of streams by dam structure, flow regime shift, water quality change and sediment transport change. While the fragmentation of streams affects both on up and downstream of a river on which dam is constructed, flow regime shift, water quality change and sediment transport change mainly happen at the downstream of a dam. The fragmentation of streams by dam hinders the migration of aquatic organisms including fishes. Since such hindrance is thorough, the consequence is relatively easy to predict (i.e. without remedial measures, migratory fishes obviously can no longer migrate over a point where dam will be constructed and their habitat will be shrunk). However; the influences on aquatic ecosystems caused by the flow regime shift, water quality change or sediment transport change cannot be so clearly predicted because these changes are different in magnitude and character among dams and mechanisms through which their influences propagate on aquatic ecosystems are not clearly understood.

We have compared benthic macroinvertebrate species found at upstream and downstream of dams to investigate if there is a significant difference. Benthic macroinvertebrates seem to represent local environment of a stream since their mobility is limited and depend on river bed condition which is formulated by water flow, water quality and sediment transport.

2. METHOD

2.1. Survey Data

The National Survey for River and Riparian Ecosystems has been conducted since 1990, aiming to collect the list of species found in river system nationwide periodically and continuously by the unified formats in Japan. We have checked these data and picked up dams where benthic macroinvertebrates have been surveyed at both upstream and downstream ambient of them.

Such datasets were available at 42 dams nationwide from the data of the National Survey for River and Riparian Ecosystems which were obtained from 1996 to 2002. Macroinvertebrate data which were collected simultaneously at upstream and downstream of a dam in winter were chosen for analysis, since benthic macroinvertebrates are usually abundant during winter. Since some dams have data pairs of up and downstream for more than two years, total number of chosen dataset pairs is 56 out of 42 dams.

Macroinvertebrates were classified into 166 taxonomic units. Mayflies, stoneflies and caddisflies were classified into a genus or family level and others were classified above a family level. It was difficult to classify these macroinvertebrate data into species level because of the limitation of information.

2.2. Data Analysis

A divisive classification method named TWINSPAN (Two-way Indicator Species Analysis) is employed to classify data samples and macroinvertebrate taxa. TWINSPAN is a program to classify species and samples, producing an ordered two-way table of their occurrence (Hill 1979, Kobayashi 1995). The process of classification is hierarchical. Analysed samples are successively divided into categories, and taxa are then divided into categories on the basis of the sample classification (McCune and Mefford 1999). Division was conducted four times (Levels); classifying samples and taxa into 16 categories for each of 56 pairs of dataset independently (i.e. 112 samples).

Dams of which up and downstream samples are divided at the first division (Level 1) can be considered to have significantly different benthic macroinvertebrate community at up and downstream of them. On the contrary, dams of which up and downstream samples are not divided even at the fourth division (Level 4) can be considered to have similar benthic macroinvertebrate community at up and downstream of them (Fig. 1). Such two groups of dams are extracted and compared with the flow regime change at downstream of them.

2.3. Classification of Flow Regime Change by Dams

Flow regime change caused by dams is various depending of the operation of dams. We have categorized flow regime change by dams into three patterns (Fig. 2). First pattern is characterized by the decrease of ordinary flow which is often found in dams of which main purpose is power generation. Second pattern is characterized by the significant decrease of the peak of flood discharge which is found in large dams with large flood control capacity. Third pattern is characterized by the small flow regime change found in smaller dams. Our classification method for flow regime change is qualitative. Patterns of flow regime change at the downstream of dams are classified by method above and compared with the implied environmental change by index macroinvertebrate taxa to check the conformity.

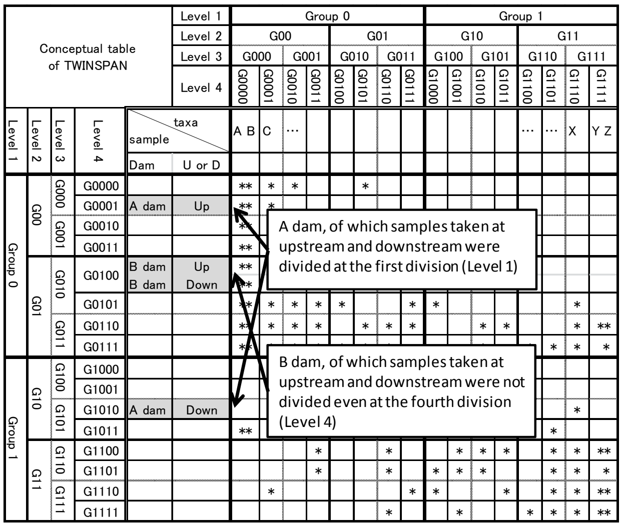


Figure 1. Conceptual Table of TWINSPAN analysis

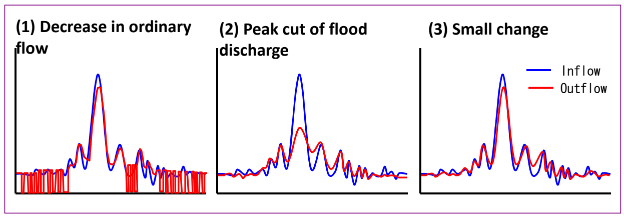


Figure 2. Three Categorized Patterns of Flow Regime Change by dams

2.4. Environmental Comparison by Index Taxa

Classification results by TWINSPAN analysis show just an array of dataset ordered by similarity of the list of taxa found in samples and they do not explain the environmental character of sampling stations. Thus; we have chosen several index taxa of which habitat preference is clear to explain environmental character of sampling stations. Index taxa we have chosen are as follows;

a) Taxa representing very slow flow; *Asellidae*, *Speridae*, *Lymnaeidae*, *Ephacerella*, *Tubificina* and *Uracanthella*,

b) Net spinning caddisflies representing stable river bed; *Macrostemum, Stenospyche, Hydropsyche and Chaumatopsyche,*

c) Taxa representing the abundance of sand; *Ephemera, Glossosoma*, *Lepidostoma*, *Goera* and *Hydroptila.*

The logarithm of the number of index taxon per 1 square meter is ranked following a criterion in Table 1. The rank of each index taxon is evaluated both at upstream sample and downstream sample of each dams. Then, the rank of upstream sample and downstream sample are summed to

Table 1. An example of the check of Bias in the Emergence of Index Taxa of Macroinvertebrate for a dam

Taxon	Rank of number: Upstream	Rank of number: Downstream	Rank of number: Total	Ratio in upstream in total rank
Epeorus	7	0	7	100%
Rhithrogena	5	0	5	100%
Capniidae	5	0	5	100%
Chloroperlidae	5	0	5	100%
Caroperla	5	0	5	100%
Hydroptila ***	5	0	5	100%
Cinygmula	5	0	5	100%
Cincticostella	5	0	5	100%
Perlodidae	3	0	3	100%
Goera ***	3	0	3	100%
Simuliidae	3	0	3	100%
Apsilochorema	2	0	2	100%
Lepidostoma ***	1	0	1	100%
Paraleptophlebia	1	0	1	100%
Amphinemura	1	0	1	100%
Glossosoma ***	1	0	1	100%
Chironomidae	7	4	11	64%
Tipulidae	8	7	15	53%
Cheumatopsyche **	9	8	17	53%
Hydropsyche **	8	8	16	50%
Rhyacophila	4	4	8	50%
Stenopsyche **	2	2	4	50%
Corydalidae	5	6	11	45%
Gibosia	7	9	16	44%
Ceratopogonidae	5	7	12	42%
Athericidae	1	4	5	20%
Uracanthella *	1	6	7	14%
Diptera	0	1	1	0%
Crambidae	0	1	1	0%
Kamimurai	0	2	2	0%
Lymnaeidae *	0	3	3	0%
Pleuroceridae	0	3	3	0%
Asellidae *	0	3	3	0%
Ephacerella *	0	3	3	0%
Ephemera ***	0	4	4	0%
Baetiella	0	5	5	0%
Psephenidae	0	5	5	0%
Lumbriculidae	0	6	6	0%
Macrostemum **	0	7	7	0%
Turbellaria	0	8	8	0%
Spheridae *	0	8	8	0%

← Upstream biased (Epeorus – Chironomidae) → ← No bias (Tipulidae – Ceratopogonidae) → ← Downstream biased (Athericidae – Spheridae) →

* Taxon representing very slow flow

** Net spinning caddisfly to represent stable river bed

*** Taxon represening the existence of sand

The logarithm of the number of individuals per 1 square meter is ranked by following threshold.

0 :	=	0	5 :	>	54.6
1 :	>	0	6 :	>	148.41
2 :	>	2.72	7 :	>	403.43
3 :	>	7.39	8 :	>	1096.63
4 :	>	20.09	9 :	>	2980.96

Group of Taxa		Number of Taxa: Upstream biased (a)	Number of Taxa: No bias (b)	Number of Taxa: Downstream biased (c)	Evaluation of bias (d)	Evaluation Equation	Criterion for Judgment
*	Slow flow	0	0	5	∞	d=c/(a+b)	Slow flow at downstream if d>2
**	Stable bed	0	3	1	0.33	d=c/(a+b)	Stable bed at downstream if d>2
***	Sand	4	0	1	4.00	d=a/(b+c)	Less sand at downstream if d>2

obtain total rank of numbers for each taxon. The ratio of the rank at upstream to the total rank is calculated and if this ratio is more than 60%, then this taxon is considered to be biased to emerge at upstream. If this ratio is between 40 to 60%, this taxon is considered not to be biased. If this is less than 40%, then this taxon is considered to be biased to emerge at downstream (Table 1).

The number of taxa which are considered to be upstream biased, no biased, and downstream biased is summarized and the bias is evaluated by evaluation equation which is shown in Table 1. The evaluation of the bias is referred to the criterion for judgment for three index taxon groups and the implied environmental difference between upstream and downstream of each dam by the bias of the emergence of index macroinvertebrate taxa is evaluated.

2.5. Extraction of Biased Taxa by IndVal Method

Macroinvertebrate taxa sampled at dams of which up and downstream samples are divided at the first division in TWINSPAN analysis (Level 1) are analyzed by IndVal method to extract indicator taxa. IndVal is a method to find indicator taxa and taxa assemblages characterizing groups of samples (Dufrêne and Legendre 1997). For each taxon i in each site group j, we computed the product of A_{ij}, the mean abundance of taxon i in group j compared to the mean abundance of taxon i in all groups in the study, by B_{ij}, the relative frequency of occurrence of taxon i in group j, as follows:

$$A_{ij} = \text{Nindividuals}_{ij} \ / \ \text{Nindividuals}_{i} \quad (1)$$
$$B_{ij} = \text{Nsites}_{ij} \ / \ \text{Nsites}_{j} \quad (2)$$
$$\text{IndVal}_{ij} = A_{ij} \times B_{ij} \times 100 \quad (3)$$

IndVal values for upstream and downstream are calculated for each taxon and if there is a significant difference from these values with randomly arranged sites, such taxon is extracted as an indicator taxon.

3. RESULTS

3.1. Classification by TWINSPAN

There was a bias in the emergence of taxa depending on whether the sample was obtained at upstream or downstream of dams. All samples were divided to Group 0 or Group 1 at the first division. 47 samples out of 69 samples which are divided to Group 0 are from upstream sites. 34 samples out of 43 samples which are divided to Group 1 are from downstream sites (Table 2). These results imply that the tendency of the emergence of benthic macroinvertebrate taxa is different between sites at upstream and downstream of dams.

Taxa such as *Capniidae*, *Drunella*, *Epeorus* and *Glossosoma* were typically found at upstream sites, whereas taxa such as *Asellidae* and *Macrostemum* were typically found at downstream sites. We have deduced that these biases are led by the downstream environment that is characterized by the lack of sand and fine gravel in riverbed, relatively stable and slower current, and abundant organic matter.

There are 12 dams with 17 datasets of which samples taken at upstream and downstream were divided at the first division (Level 1). Macroinvertebrates communities at the upstream and downstream of these dams are differently composed. The number of dams of which samples taken at upstream and downstream were not divided even at the fourth division is 6 with 7 datasets.

Table 2. Number of samples at the first division by TWINSPAN

	Upstream	Downstream	Total
Group 0	47	22	69
Group 1	9	34	43
Total	56	56	112

3.2. Classification of Flow Regime Change by Dams

12 dams with 17 datasets of which samples taken at upstream and downstream were divided at the first division (Level 1) are classified into “decrease in ordinary flow”, “peak cut of flood discharge”, and “small change” patterns in terms of flow regime change by 5, 5, and 7 datasets, respectively. 6 dams with 7 datasets of which samples taken at upstream and downstream were not divided even at the fourth division (Level 4) are classified into “decrease in ordinary flow”, “peak cut of flood discharge”, and “small change” patterns in terms of flow regime change by 1, 2, and 4 datasets, respectively.

3.3. Environmental Comparison by Index Taxa

Environmental change at the downstream for 12 dams with 17 datasets of which samples taken at upstream and downstream were divided at the first division (Level 1) in TWINSPAN analysis is presumed by the evaluation procedure in Table 1. The number of datasets which are suggested to have slow flow at the downstream is 4, 3, and 4 for flow regime change patterns of (1) decrease in ordinary flow, (2) peak cut of flood discharge, and (3) small change, respectively (Table 3, Fig. 3). The number of datasets which are suggested to have stable river bed at the downstream is 0, 3, and 1 for flow regime change patterns of (1), (2) and (3), respectively (Table 3, Fig. 3). The number of datasets which are suggested to have sand shortage at downstream is 2, 1, and 4 for flow regime change patterns of (1), (2) and (3), respectively (Table 3, Fig. 3).
Percentage of datasets which are implied to have slow flow at downstream by biased emergence of taxa such as *Asellidae*, shellfish, *Tubificina* and *Uracanthella* is high in dams of which flow regime change pattern is classified to “decrease of ordinary flow”. Dams of which flow regime change pattern is classified to “significant

decrease of the peak of flood discharge” occupy most of datasets which are implied to have stable riverbed by biased emergence of net spinning caddisfly such as *Macrostemum* and *Stenospyche* at downstream. Ratio of datasets which are implied to have less sand in downstream riverbed by biased emergence of taxon *Ephemera* and *Glossosoma* at upstream is high in dams of which flow regime change pattern is classified as “small change”.

Table 3. Number of datasets for flow regime change patterns

Environment implied by taxa	Number of Datasets		
	(1)	(2)	(3)
a) Slow flow	4	3	4
b) Stable bed	0	3	1
c) Sand	2	1	4
Total	5	5	7

(1) decrease in ordinary flow, (2) peak cut of flood discharge, and (3) small change, respectively

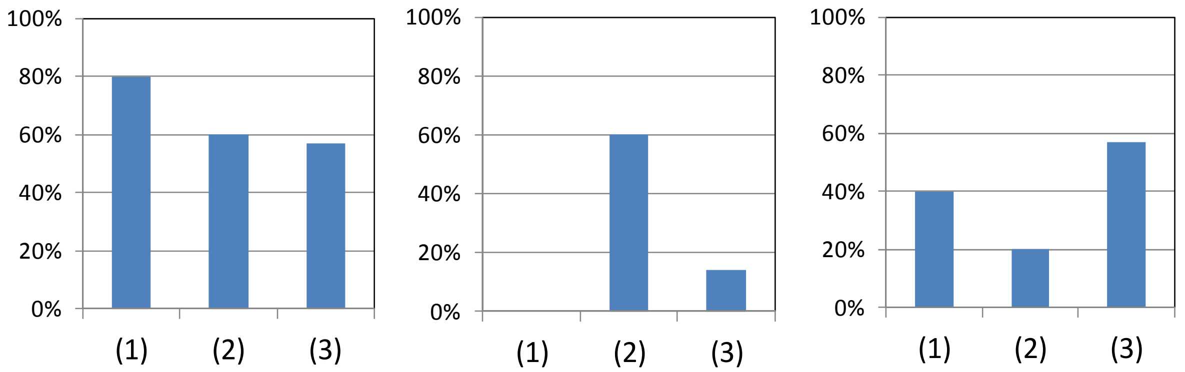
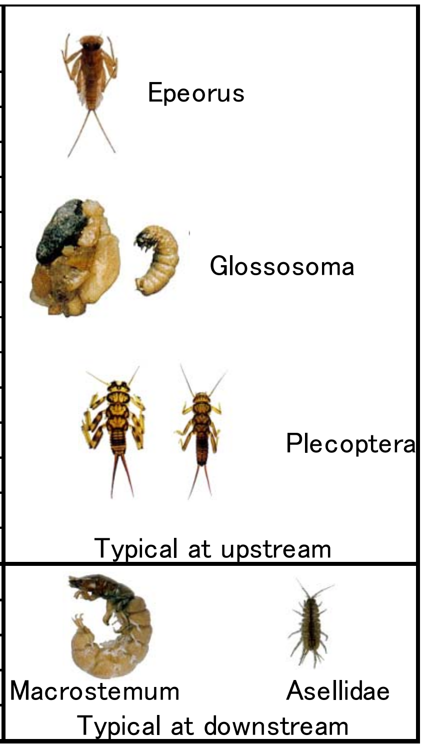


Figure 3. Correspondence to Implied Environmental Change by Index Taxa among dams with different flow regime change pattern (Left: Percentage of datasets which are implied to have slow flow at downstream, Middle: Percentage of datasets which are implied to have stable riverbed at downstream, Right: Percentage of datasets which are implied shortage of sand at downstream. Circled digit represents group of different flow regime change pattern at downstream. (1) Decrease of ordinary flow, (2) Significant decrease of the peak of flood discharge, (3) Small change.)

Taxon	IndVal value	upstream	downstream	significance (p≦0.01)
Drunella	91.64	1330./ 16	36./ 1	**
Cincticostella	84.5	3947./ 17	724./ 8	**
Glossosoma	78.38	1026./ 14	52./ 4	**
Epeorus	77.17	5346./ 16	1174./ 7	**
Chloroperlidae	76.47	463./ 13	0./ 0	**
Rhithrogena	64.64	1905./ 11	2./ 1	**
Perlodidae	61.56	1228./ 12	180./ 4	**
Capniidae	58.67	1534./ 10	4./ 2	**
Taeniopterygidae	58.13	1857./ 10	22./ 2	**
Paraleptophlebia	49.26	1178./ 9	88./ 3	*
Blephariceridae	40.56	265. /7	4./ 2	*
Lepidostoma	39.77	282./ 7	10./ 1	*
Cinygmula	35.29	1924./ 6	0./ 0	*
Perlodidae	29.41	78./ 5	0./ 0	*
Asellidae	64.71	0./ 0	498./ 11	**
Macrostemum	58.45	50./ 1	7828./ 10	**
Lumbriculidae	35.29	0./ 0	324./ 6	*
Ceraclea	23.53	0./ 0	26./ 4	*
Ameletus	5.79	84./ 6	5310. /1	*



A./ B A: Toal number of individuals

B: Total of points of emergence (max. 17)

Significance **: Significant for both A and B

*: significant for either A or B

Figure 4. Indictor taxa emerging biased at upstream or downstream

3.3. Extraction of Biased Taxa by IndVal Method

Indicator taxa which can be considered to emerge at upstream or downstream are listed in Fig. 4. These taxa are similar to presumed index taxa, suggesting that our presumed index taxa can imply representing environment such as slow flow, stable riverbed, or abundance of sand.

4. DISCUSSION

While Tanida and Takemon (1999) summarized the presumed mechanisms by which dams affect on benthic macroinvertebrates at downstream of them as changes of flow regime, river morphology, water temperature, turbidity, and organic matter flux and fragmentation of stream continuity, we have compared benthic macroinvertebrates with only flow regime change. Flow regime change is one of the important factors which affect physical environment of rivers. Since three patterns of flow regime change we have classified seem to have their typical effects on macroinvertebrates through different environmental impact, effective remedial measures should be also different. Increase of discharge variation to cause appropriate disturbance can be effective for dams with low ordinary flow discharge and/or high peak cut of flood. If the flow regime is not modified largely, supply of fine sediment like sand may be effective.

5. CONCLUSION

We have shown several macroinvertebrate index taxa which represent typical environmental changes caused by flow regime change at the downstream of dams. Comparison of macroinvertebrate community at upstream and downstream of dams can be used to plan effective remedial measures for the impact of dams.

REFERENCES

Dufrêne, M. and Legendre, P. (1997): Species assemblages and indicator species: the need for a flexible asymmetrical approach, Ecological Monographs, 67, pp. 345-366.

Hill, M. O. (1979): TWINSPAN: A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes, Department of Ecology and Systematics, Cornell University, Ithaca, NY.

Kobayashi, S. (1995): Multi-variate analysis of biological groups, Aoki Shobo, Tokyo (in Japanese).

McCune, B. and Mefford, M.J. (1999): PC-ORD. Multivariate Analysis of Ecological Data. Version 4.25. MjM Software, Gleneden Beach, Oregon, USA.

Tanida, K and Takemon, Y. (1999): Effects of dams on benthic animals in streams and rivers, Ecology and Civil Engineering, 2(2), pp. 153-164 (in Japanese with English abstract).