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An Analysis on Landscape Structure and Biodiversity of the Bokha Stream as a Model to Restore the Degraded Urban Stream

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ABSTRACT: Landscape structure, habitat types, vegetation structure and biodiversity in the Bokha stream chosen as a reference stream were investigated to get ecological information necessary for restoration of urban stream degraded by excessive artificial interference. Landscape structure showed a slight change between before and after flooding. Habitat types of nine sorts were identified based on ecological information obtained from field survey such as micro-topography, hydrological characteristics, disturbance regime, and so on. Each habitat holds specific organisms to each site. Consequently, the number of plant communities, and species of benthos and fish increased as the kinds of habitat type increase. Ordination of habitat types based on vegetation, benthos, and fish data reorganized them into three groups of pool types of two kinds depending on whether they are connected to the water course or not and riffle one. Vegetation showed different stratification and species composition depending on topographical position in relation to disturbance cycle. Based on the results from this study, relationship between environmental heterogeneity and biodiversity was discussed and a restoration plan was suggested in a viewpoint of vegetation.

Key words: Biodiversity, Ecological restoration, Habitat types, Reference stream, Urban stream

INTRODUCTION

The rivers and/or streams are of great importance for plants, invertebrates, fishes, birds and mammals (including humans) but the diversity of their habitats has declined particularly over recent years. Floodplains have often been disconnected from their rivers and/or streams, reducing their flood-storage function and hence the range of low floodplain and marsh areas required to sustain diverse birds and mammals. Similarly, aquatic plants have been affected by eutrophication, whereas intervention such as channelisation, dredging, draining and vegetation removal have all been instrumental in degrading our river and/or stream systems. Likewise, fish habitats have been destroyed by these measures and the construction of dams and water pollution including eutrophication has meant that many native species are now threatened with decline or localized extinction. Today any Korean rivers and/or streams except for ones in DMZ(Demilitarized Zone) or CCZ(Civil Control Zone) cannot be truly defined as natural and this has serious implications for the associated ecosystems.

Natural river and/or stream flow is a key element in sustaining a healthy river and/or stream system, including absorbing pollutants, decomposing wastes, producing fresh water and habitat replenishment during floods (Postel and Richter 2003). There is therefore a huge potential resource that could be restored to increase and improve diversity of habitat. One of the objectives of river and/or stream restoration is to promote activities that initiate or accelerate recovery of degraded ecosystems.

Habitat restoration is currently a major focus in the field of environmental science and generally refers to the reestablishment of processes and functions of biological, chemical, and physical linkages between aquatic, riparian, and associated terrestrial ecosystems (Kaffman et al. 1997). Restoration is the process of returning a river and/or stream (or assisting its recovery) to a condition in which it can function ecologically in a self-sustaining way, more nearly resembling its former function prior to human-induced disturbance (Cairns 1989, Bisson et al. 1992, Sear 1994). Taking a dynamic, co-evolutionary view of rivers and/or streams, restoration can be defined as the act of relaxing human constraints on the development of natural patterns of diversity (Frissell and Bayles 1996, Eber-

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sole et al. 1997). In this view, a restored ecosystem does not necessarily return to a single ideal and stable state (i.e. pristine) but is free to express a range of natural successional trajectories and states, as constrained by the historical biological and physical characteristics of the river and/or stream and its natural disturbance regime (Frissell and Ralph 1998). That is, restoration measures should not focus on directly recreating natural structures or stages, but on identifying and reestablishing the conditions under which natural states create themselves.

In Asian countries where people depend on rice as a food source, most floodplains of rivers and/or streams were transformed in the past to rice fields, and high banks were constructed along waterways to prevent flooding. Consequently, the widths of most rivers and/or streams were reduced sharply. More recently, many rice fields were transformed to urban areas, and naturally meandering and complex channels were forced into straight and monotonous lines in. In such continuing transformation processes, riverside communities have degenerated greatly or been destroyed by tree cutting, the introduction of exotic species, the diversion and channeling of water for agriculture, and the use of riverbeds and shores for cultivation or roads. Therefore, riparian landscapes, including a river and/or stream ecosystem and its surrounding environment, hardly maintain original features. Riparian landscapes have been managed usually in terms of use and disaster protection to date. But today the importance of a natural environment is being reevaluated.

In order to restore the degraded ecosystem like this, we have to get information from various scientific principles because holistic and synthetic measures have to be prepared (Aber 1987). First of all, we have to prepare such plans by obtaining diverse ecological information including physical factors as well as biological factors of a habitat, which we try to restore (Aber 1987, MacMahon 1987). In particular, we have to get plentiful field information on an area to be restored because restoration efforts have to be practiced in the field (Hough 1984).

This study ultimately aims to restore structure and functions of urban river and/or stream, which were lost due to excessive artificial interference. In order to arrive at this goal, firstly, we investigated habitat types in the stream environment, which is in heterogeneous and dynamic state with reference to disturbance regime. Secondly, we explored distribution and structure of vegetation in a stream, which is located on the rural area and the internal space left in natural process except for the surrounding area. Finally, we discussed relationship between heterogeneity of environment and biodiversity.

METHODS

Study Area

Most rivers and/or streams in oriental countries including Korea experienced extensive transforming processes in spatial dimension as well as structure from the past. In particular, urban rivers and/or streams were severely transformed in a degree that we can never find out the original feature. Therefore, we need a reference river and/or stream with an integrate structure and function in order to restore such degraded urban river and/or stream.

We decided the Bokha stream, a tributary of the Namhan River, which is located in a rural area of central Korea as the reference stream (Fig. 1). Although this stream has the bank artificially constructed to prevent flooding damage on the surrounding rice fields, space within the bank remains natural state. This stream not only maintains natural flow but also contains floodplain. The natural flow created meandering water course and heterogeneous micro-topography. That is, this stream resembled the natural stream within the bank.

Catchment area, length, and mean slope of riverbed of the Bokha stream were 838.2 km^2, 116 km and 1/800, respectively. Width of this stream is about 200 m and that at low water level is about 50 cm (KICT 2002). Substrate on the riverbed is composed of sand and thereby riverbed shows severer variation compared with the gravel river. Field survey to obtain the ecological information was carried out in a reach throughout about 1 km range centering on the Heungcheon Bridge.

In addition, the Suip stream in CCZ and a partial reach of the Namhan River were chosen in sites in order to obtain information on vegetation to be introduced at restoration practice (Fig. 1).

Methods

Habitat types were divided on the bases of information on micro-topography, hydrological characteristics, disturbance regime and so on obtained from field survey. Monochrome aerial photographs (1:20,000 scale), taken in 2001, were used to identify micro-topography of the

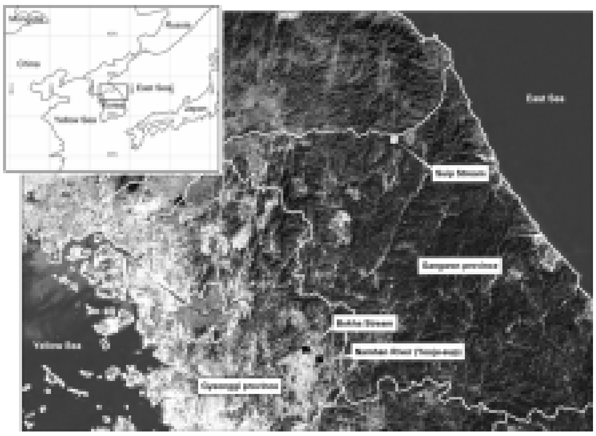

Fig. 1. A map showing locations of study areas.

stream. The boundaries of vegetation units were identified by field check on the bases of the micro-topography and were overlapped on the topographical maps of 1:5,000 scale. Patches smaller than $25m^2$ were excluded from this study due to uncertainty of their size and shapes on 1:5,000 maps (Küchler and Zonneveld 1988). Vegetation map was constructed with ArcView GIS (ESRI 1996). Field survey was carried out in 2001 (before flooding) and 2002 (after flooding).

Vegetation survey was carried out by Braun-Blanquet (1964) method. Each ordinal scale was converted to the median value of percent cover range in each cover class (Braun-Blanquet 1964). Importance value of each species was then determined by multiplying 100 to the fraction of each species cover to the summed cover of all species in each plot. Importance values of benthos and fish were obtained from density data by applying the same procedure. A matrix of importance values for all species in all plots were constructed and fed to Detrended Correspondence Analysis (DCA) for ordination (Hill 1979).

Vegetation stratification was made by describing distribution range and height of plant communities appearing in transect installed cross the stream studied. Benthos was investigated by identifying samples collected qualitatively as well as quantitatively. Suber net (25 × 25 cm; mesh size 0.5 mm) was used for quantitative sampling. Fish was investigated by identifying samples collected by field survey. Casting net (mesh size 8 × 8 mm, 10 × 10 mm) and fishing net (mesh size 3 × 3 cm, 4 × 4 cm) was used for sampling.

Cumulative curve of the number of plant communities, and species of benthos and fish was prepared by adding the number of communities and species appearing newly in the new habitat type.

RESULTS

Landscape Structure

Landscape structure of the Bokha stream was shown in Table 1. Dominant elements before flooding (before) were *Phragmites communis* community, bare sandbar, water course, *Robinia pseudoacacia* plantation, subordinate water course, *Humulus japonicus* community, and so on and those after flooding (after) were bare sandbar, *P. communis* community, water course, subordinate water course, *Robinia pseudoacacia* plantation, *Humulus japonicus* community, and so on. Although the area of bare sandbar increased slightly, change of landscape structure was not significant.

Habitat Types Formed in Natural Waterway

Habitats in a natural channel were identified into nine types by micro-topographical characteristics as the follows (Figs. 2 and 3)

1. Straight Watercourse (abbreviated as SW hereafter)

There is no any riffle or pool in this habitat. Vegetation of this site shows a difference in both sides. Sandbar without vegetation covers the one side, whereas *Phragmites japonica* community, *Humulus japonicus* community, and *Miscanthus sacchariflorus* community distribute in zonal pattern of the mentioned order as receded from waterway in the other side. This difference in vegetation reflects a difference of disturbance in both riversides. Substrate of this site was composed of sand and current velocity and water depth were 15 cm/s and 10 cm, respectively.

2. Bay (abbreviated as B hereafter)

In this habitat type, water flow is stopped away the main watercourse and hollowed landward. This site not only plays a crucial role as a remarkable habitat of fry but also can contribute to improve water quality when plants including emerged ones are established there. *P. japonica* community develops around this site. Substrate of this site was composed of sand and clay and current velocity and water depth were 10 cm/s and 70 cm, respectively.

3. Stepping Stone Type Riffle (abbreviated as SR hereafter)

If stones transported by water flow are arranged in stepping stone pattern, waterway breadth decreased and thereby current velocity increased. Such serial processes create swift riffle. Lack of vegetation on sandbar established downward this habitat reflects such habitat characteristics. Substrate of SR was composed of pebble and sand and current velocity and water depth were 35 cm/s and 20 cm, respectively.

4. Meandering Riffle (abbreviated as MR hereafter)

This habitat was occurred from meandering water flow. When riffles are classified into swift and normal types depending on current velocity, this habitat corresponds to the latter. Vegetation of this site is composed of *Rorripa islandica* community and *P. japonica* community. This site is disturbed frequently a little, *R. islandica* community reflects the fact as it is the typical pioneer vegetation in the river and/or stream ecosystem. Substrate of this site was composed of sand and pebble and current velocity and water depth were 75 cm/s and 15 cm, respectively.

5. Side Stream (abbreviated as SS hereafter)

This habitat is subordinate watercourse formed separately beyond main course of channel. This side channel can act as natural interceptors for surface and subsurface runoff from surrounding areas when it is formed on floodplain. Therefore, it can be exploited, perhaps by dredging to create wetland areas for diffuse source pollution control and conservation in the rehabilitation project of river

Table 1. Changes of landscape structure between before and after flooding in the Bokha stream

Landscape element	Before		After	
	Area (ha)	(%)	Area (ha)	(%)
Phragmites communis community	1.7730	5.1	1.8253	5.2
Phalaris arundinacea community	0.13861	0.4		
Salix gracilistyla community	0.42152	1.2	0.15786	0.5
Phragmites japonica community	5.70351	16.4	4.88717	14.0
Salix gracilistyla - Miscanthus sacchariflours community			1.56858	4.5
Salix gracilistyla - Humulus japonicus community			1.55008	4.4
Miscanthus sacchariflours community	2.21692	6.4	1.73682	5.0
Salix koreensis community			0.18131	0.5
Rubus crataegifolius community	0.18776	0.5	0.20216	0.6
Rorippa islandica community	0.76979	2.2	0.11898	0.3
Artemisia princeps var. *orientalis* community	0.51162	1.5	0.06662	0.2
Robinia pseudo-acacia community	2.91851	8.4	2.42137	6.9
Poa pratensis community	0.71223	2.0	0.63852	1.8
Zizania latifolia community			0.01894	0.1
Persicaria nodosa community	0.36043	1.0	0.63793	1.8
Humulus japonicus community	4.31706	12.4	2.40175	6.9
Cultivated land	1.45340	4.2	1.29250	3.7
Pool	0.04506	0.1	0.04506	0.1
Subordinate watercourse	2.63601	7.6	2.51823	7.2
Watercourse	4.72911	13.6	4.70974	13.5
Sandbar	5.48855	15.8	5.83751	16.7
Unpaved road			0.13068	0.4
Parking lot	0.12161	0.3	0.12161	0.3
Dredging lot			1.53133	4.4
Bridge	0.26005	0.7	0.26005	0.7
Total	34.7647	100	34.8601	100

margins (Large and Petts 1992). *P. japonica* community covers surrounding area of this site. Substrate of this site was composed of pebble and sand and current velocity and water depth were 25 cm/s and 20 cm, respectively.

6. Sandbar Tail (abbreviated as ST hereafter)

This habitat was formed by sand accumulated due to watercourse expansion or diversion and reduction of current velocity in the downward edge of sandbar. Size of sandbar increase and become higher with accumulation of sand in the direction of water flow (Tsujimoto 1999). But the size is sometimes reduced by erosion if the size is beyond a given one as well. *Persicaria nodosa* community is established in the edge of sandbar but the vegetation changes to *P. japonica* community as moves towards interior of sandbar. Further, *Salix gracilistyla* community and *S. koreensis* community also appear as the height of sandbar increased (KICT 2003). Substrate of this site was composed of sand and current velocity and water depth were 20 cm/s and 10 cm, respectively.

7. Pool around Rock (abbreviated as RP hereafter)

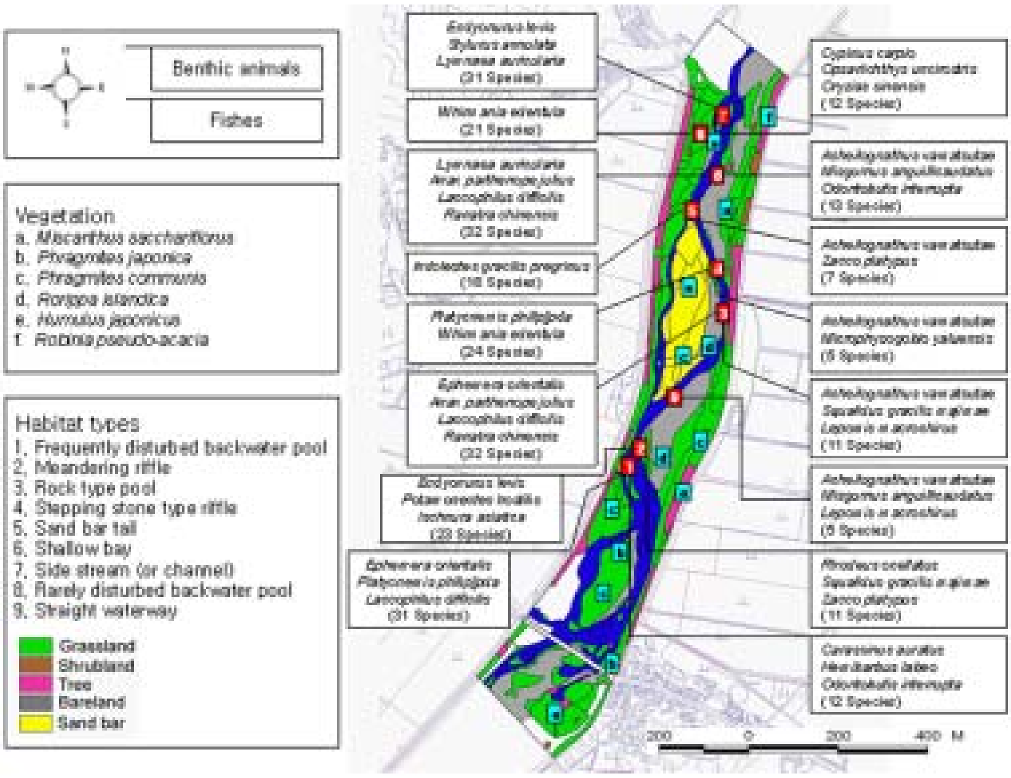

Fig. 2. A map showing habitat types identified in the Bokha Stream, a reference river. Habitat types were expressed by numbers on the simplified vegetation map of the river. Dominant species and the number of species of benthos and fish in each habitat type were shown in box.

This habitat is a pool formed by excavation around rock. Habitat of this type is often formed either in concave part on bedrock or around convex part. Vegetation of the site is composed of *P. japonica* community. Surrounding of this site maintains somewhat stable vegetation due to secure waterside compared with MR mentioned above or FDBP to be referred later. Substrate of this site was composed of pebble, sand, and clay and current velocity and water depth were 25 cm/s and 60 cm, respectively.

8. Frequently Disturbed Backwater Pool (abbreviated as FDBP hereafter)

This habitat located on floodplain is either connected or disconnected to the main waterway depending on its current status as an aquatic area of pond type. It is usually disconnected to the main waterway but influenced strongly by flooding. This site not only can be a habitat of fries but also be a shelter of them at flooding. Vegetation of the site is composed of *P. nodosa* community and *P. japonica* community. The former community reflects the fact that this site is frequently disturbed as the typical pioneer vegetation in the river ecosystem. Substrate of this site was composed of sand and clay and current velocity and water depth were 0 cm/s and 80 cm, respectively.

9. Rarely Disturbed Backwater Pool (abbreviated as e RDBP hereafter)

This habitat, which is an aquatic area of pond type formed on the floodplain, is connected or disconnected to mainstream depending on position of main waterway. It is usually disconnected to the main stream and influenced occasionally by flooding. Standing crop of fish depends on frequency being connected to the mainstream and successional stage of this site. *P. japonica* community and *Miscanthus sacchariflorus* community develops around this site and diverse aquatic plants such as *Ceratophyllom demersum*, *Potamogeton crispus*, *Scirpus radicans*, and so on form a community within water body. Substrate of this site was composed of sand and clay and current velocity and water depth were 0 cm/s and 70 cm, respectively.

Spatial Distribution of Vegetation

Vegetation in Bokha stream is comprised of 16 communities including mixed communities that plant species more than one dominate, and terrestrial plant communities (Fig. 4). *P. japonica* community and *P. communis* community dominate most areas including central part of the stream. *P. nodosa* community and *R. islandica* community appear in the sites where is close to waterfront and thus exposed to disturbance frequently. *Zizania latifolia* forms a com-

Fig. 3. Habitat types identified in the Bokha Stream. SW: Straight watercourse, B: Bay, SR: Stepping stone type riffle, MR: Meandering riffle, SS: Side stream, ST: Sandbar tail, RP: Pool around Rock, FDBP: Frequently disturbed backwater pool, RDBP: Rarely disturbed backwater pool.

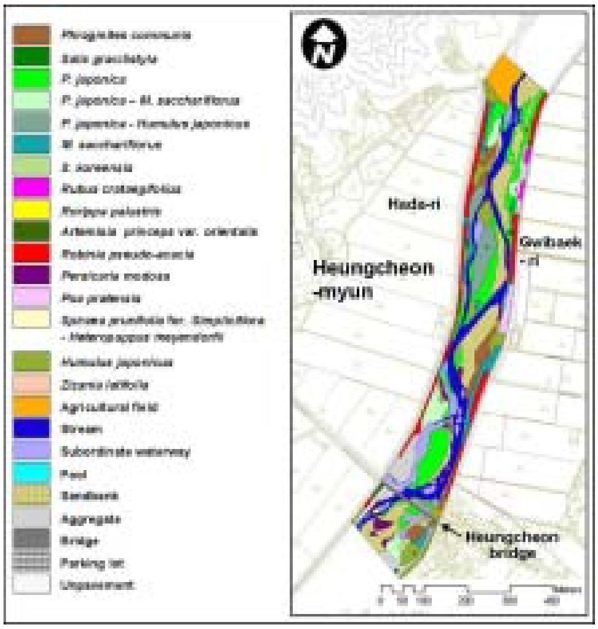

Fig. 4. A vegetation map of the Bokha Stream.

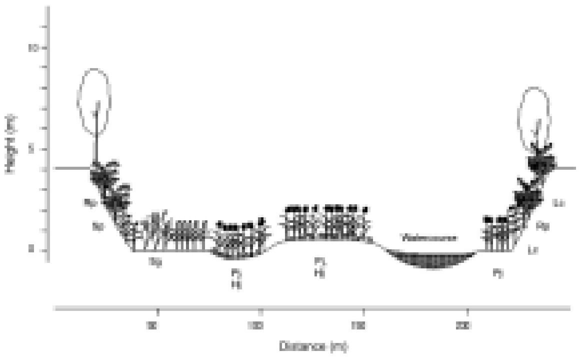

Fig. 5. A stand profile of vegetation established cross the Bokha Stream.

munity around pool where watercourse is wide and thereby current velocity is reduced. *M. sacchariflorus* community appears as recede from waterfront and approach to bank or on the bank. In the location similar to habitat of *M. sacchariflorus* community, *H. japonicus* community appears, organic debris, which was transported at flooding, are usually accumulated in this site. *S. gracilistyla* community and *S. koreensis* community appear rarely on sandbar with higher elevation compared with the surrounding area and floodplain with deep water table.

On the bank, black locust plantation introduced artificially, appear frequently and *P. communis*, *Spiraea prunifolia* var. *simpliciflora*, *Rubus crataegifolius*, *Poa pratensis* etc. form a community, respectively.

Vegetation Distribution Cross Waterway

Vegetation in waterway tend to distribute in the order of *M. sacchariflorus* community, *S. gracilistyla* community, *M. sacchariflorus* community, *P. japonica* – *H. japonicus* community, *P. japonica* community, *M. sacchariflorus* community from left to right sides. *Robinia pseudoacacia* – *Spiraea prunifolia* for. *simpliciflora* and *R. pseudoacacia* – *Lespedez cyrtobotrya* communities appeared on the dike of left and right sides, respectively (Fig. 5).

In addition, as was already mentioned *P. nodosa* community and *R. islandica* community appeared in the sites to be disturbed frequently as the fringe of sandbar and emerged plant community appeared in the RDBP. But they were omitted in this stand profile because they were located beyond the belt transect that we installed.

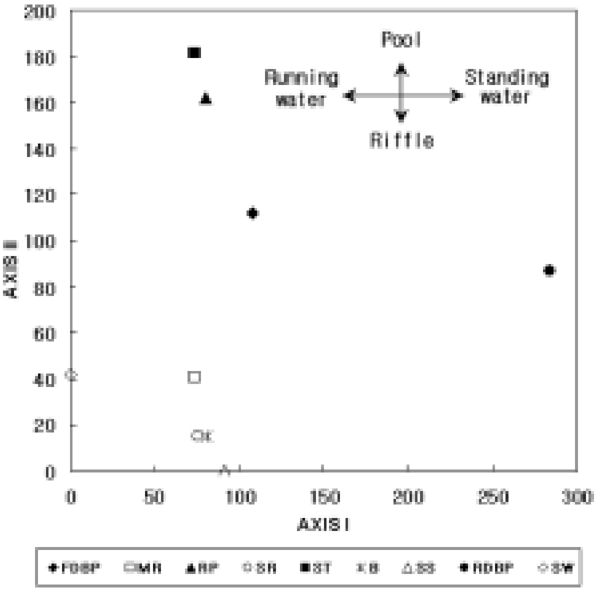

Fig. 6. Ordination of habitat types from the Bokha Stream based on vegetation, benthos, and fish data. SW: Straight watercourse, B: Bay, SR: Stepping stone type riffle, MR: Meandering riffle, SS: Side stream, ST: Sandbar tail, RP: Pool around Rock, FDBP: Frequently disturbed backwater pool, RDBP: Rarely disturbed backwater pool.

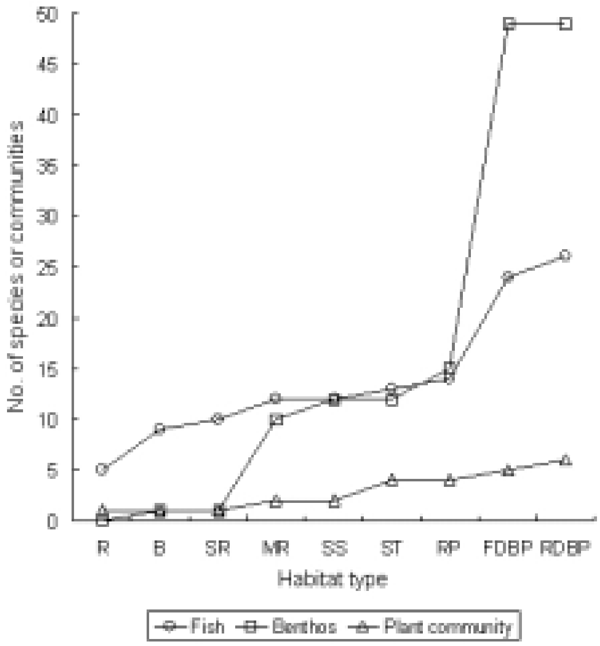

Fig. 7. Cumulative curve of the number of plant communities (lower) and species of benthos (middle) and fish (upper) appeared with the increase of kinds of habitat types.

Ordination of Habitat Types

Ordination of habitat types based on multiple data that vegetation, benthos, and fish data are synthesized, reorganized nine habitat types into three groups (Fig. 6). RDBP was isolated from the other habitat types on the Axis I. RDBP maintains standing-water as a lentic zone, which is disconnected to the main water course, whereas the other habitat types do running water. ST-RP-FDBP group and SW-SS-MR-SR-B group were divided on the Axis Ⅱ. The former and the latter groups represented pool and riffle, respectively. Riffle usually maintains rapid current velocity and shallow water depth, whereas pool does slow current velocity and deep water depth. Such hydrological characteristics determine substrate of each site and consequently influence species composition of each habitat type. The result of this ordination suggests that current velocity, water depth, substrate and so on are major factors determining species composition of each habitat type.

Relationship between Habitat Types and Biological Diversity

The number of plant communities and species of benthos and fish increased with the increase of the number of habitat types (Fig. 7). These results imply that biological diversity depends on heterogeneity (or diversity) of habitats (Forman 1995). In this respect, habitat restoration could be preferential requisite to restore ecological functions of urban river and/or stream, which is monotonous in structure and unstable in function (Bettress 1994).

The number of species of benthos increased strikingly in MR and FDBP and that of fish did in B and FDBP. The result means that such habitat types play important roles for sustaining biodiversity.

Vegetation Distribution in the Natural River and/or Stream

A feature of relatively integrate floodplain found in upper stream of the Namhan River was depicted in Fig. 8. *P. japonica* community dominates waterfront. *S. gracilistylla* dominates the first floodplain and *S. koreensis*, *Alnus japonica*, *Prunus padus* and so on including *Acer ginnala* together form a community on the second floodplain. Stand profiles of the Suip stream in CCZ were shown in Fig. 9. *P. japonica*, *Impatiens* spp., *Persicaria thunbergii* and so on domi--nated waterfront. *Alnus japonica* stunted due to frequent disturbance, *Rosa multiflora*, *S. gracilistylla*, and *S. purpurea* var. *japonica* dominated the first floodplain and *A. japonica*, *Acer ginnala*, *S. koreensis* and so on dominated the second floodplain.

DISCUSSION

Establishment and Roles of Micro-topography as a Basis of Bbiodiversity

The river and/or stream carries out three actions: erosion, transport, and deposition. Erosion creates pool, and the eroded soil parti-

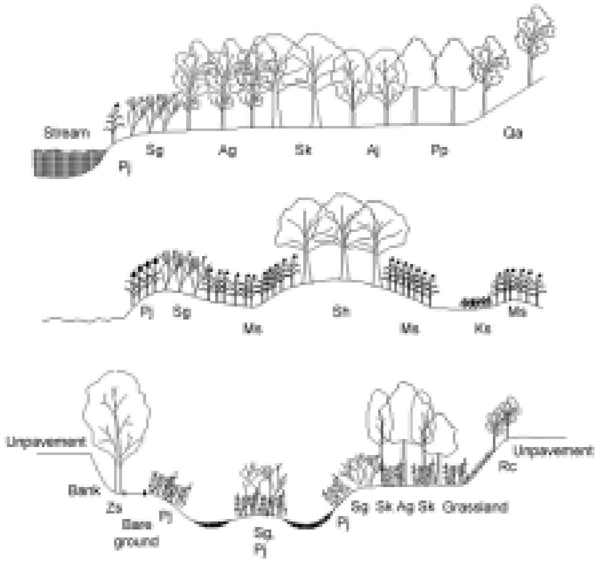

Fig. 8. A stand profile of vegetation established cross the Namhan River, the second reference river. Sg: *Salix gracilistyla*, Ag: *Acer ginnala*, Sk: *Salix koreensis*, Aj: *Alnus japonica*, Pj: *Phragmites japonica*, Qa: *Quercus aliena*, Pp: *Prunus padus*, Sh: *Salix hulteni*, Ms: *Miscanthus sacchariflorus*, Ks: *Kummerowia stipulacea*, Zs: *Zelkova serrata*, Rc: *Rhus chinensis*.

cles are transported and deposited downstream. Deposited parts become riffles, and current velocity increased here and thereby induces further erosion. Those processes create riffles and pools continued longitudinally on the riverbed. Flowing water usually runs meanderingly in the river and/or stream. Such meandering rivers and/or streams are also due to the result of these three actions. In waterways of the meandering river and/or stream, the repeated erosion and deposition form sandbars and pools and thereby creates an uneven micro-topography on the riverbed. Uneven topography induces a difference in water depth; different water depths create variations in water temperature, which leads to diversity in microhabitats. Furthermore, the concave-convex topography on the riverbed controls water flow and determines species composition in a given site (Fig. 6; Malanson1993, Lee et al. 1999, Lee et al. 2003). In fact, species composition of vegetation and benthos and fish fauna depended on habitat types identified by microtopographic condition (Fig. 6).

Current velocity, flow pattern of water, substrate, and so on dominate habitat environment of most aquatic organisms. For example, most of aquatic insects are influenced greatly by flow velocity and substrate. Fish requires not only different habitats and current velocities depending on growth stages but also different water depths to escape predation. Further, even in daily life cycle, changes of current velocity, water depth, and so on are required for activity, rest, and sleep. Considered diverse environmental conditions for life

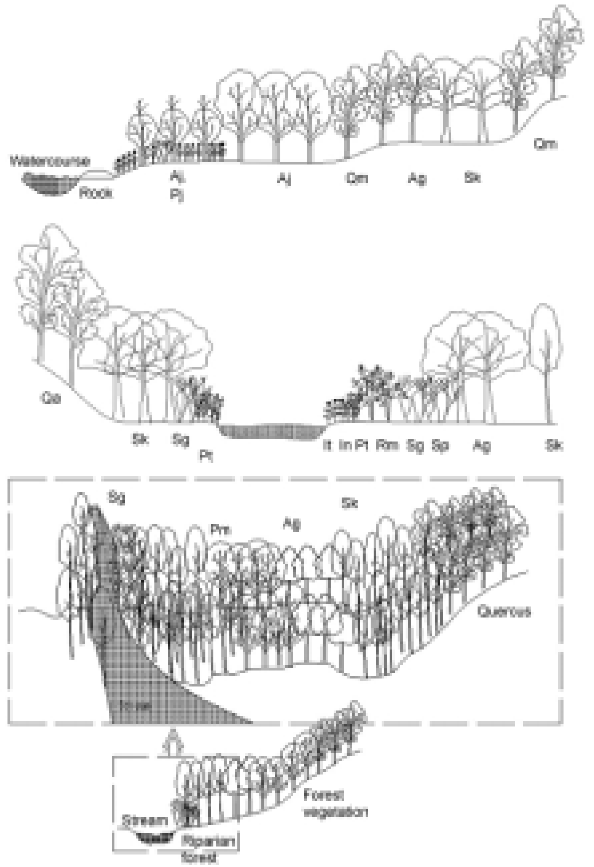

Fig. 9. A stand profile of vegetation established cross the Suip Stream located in CCZ, the third reference river. Sg: *Salix gracilistyla*, Pm: *Populus maximowiczii*, Ag: *Acer ginnala*, Sk: *Salix koreensis*, Aj: *Alnus japonica*, Pj: *Phragmites japonica*, Qm: *Quercus mongolica*, Pt: *Persicaria thunbergii*, It: *Impatiens textori*, In: *Impatiens noli-tangere*, Rm: *Rosa multiflora*, Sp: *Salix purpurea* var. *japonica*.

cycle and behavior of various organisms, diversity of river and/or stream morphology is very crucial and required also necessarily in river and/or stream restoration of the degraded river and/or stream (Hershey and Lamberti 1998, Benda et al. 1998, Lee et al. 1999).

Environmental Heterogeneity and Biodiversity

Biodiversity means "the wealth of life on earth, the millions of plants, animals, and microorganisms, the genes they contain, and the intricate ecosystems they help build into the living environment" (Worldwide Fund for Nature 1989). The importance of biodiversity is based on its diverse values that include various ecological functions, which lead to environmental stability (Naess 1989).

Biodiversity is based on heterogeneity of habitat, or ecodiversity (Romme 1982, Haber 1990, Naveh 1994). High biodiversity also derives from integrity of the environment, a healthy environment equipped with all its components (Primack 1995, Meffe and Carroll 1997).

In this study, the number of vegetation units and species of benthos and fishes increased as the habitat types increase (Fig. 7). The result means that heterogeneous micro-topography creates biodiversity. In fact, the streams in the Korean DMZ, which has left in a natural process for about 50 years since the Korean war, recovered diverse micro-topography and the result was shown in high biodiversity (Lee et al. 2006). On the other hand, the stream with micro-topography simplified due to excessive human impact imposed to recover the flood damage showed low biodiversity (Lee et al. 2006). From this viewpoint, we recommend recovering diversity in the structural frame, including micro-topography of the river and/or stream as a starting point to restore the degraded riverine ecosystem.

Biodiversity is directly related to habitat unit feature. There are two primary types of habitat units in the river and/or stream: riffles, which are topographic high points in the bed profile and are composed of coarser sediments, and pools which are low points with finer substrate (Richards 1982, O'Neill and Abrahams 1987). At base flows, riffles are shallow and have a steep water-surface gradient with rapid flow. In contrast, pools are deeper and generally have a gentle surface slope with slower flow (O'Neill and Abrahams 1987, Richards 1978).

Within a habitat unit, structural features, substrate, flow velocity, and pool depth influence biotic diversity (Sheldon 1968, Evans and Noble 1979, Angermeier 1987). Increased complexity resulting from the combination of these factors creates a greater array of microhabitats. Complexity can mediate competition between species. Structural complexity provides protection from predators, alters foraging efficiency (Wilzbach 1985), and influences social interactions (Fausch and White 1981, Glova 1986). Lonzarich and Quinn (1995) observed a general increase in species diversity with increasing complexity of pools and different responses of species to habitat features.

Complexity within habitat units also influences the diversity of fish assemblage (Gorman and Karr 1978, Schlosser 1982, Angermeier and Karr 1984). Communities in streams with reduced habitat complexity are less diverse than those with higher habitat complexity. In addition, interactions between coho salmon and steelhead and cutthroat trout may be altered as a result of habitat simplification. Further, changes in microhabitat features favor some species but decrease suitability for others (Dolloff 1986, Elliott 1986, Berkman and Rabeni 1987).

Many aspects of the physical stream environment affect the composition and abundance of stream macroinvertebrates. At the local scale, substratum and current velocity are probably the most important factors determining the types of macroinvertebrate taxa present (Hershey and Lamberti 1998).

Recommendation for Restoration

Core subject in river and/or stream restoration is in how to we treat vegetation. Sorts and spatial arrangement of vegetation to be introduced for restoration are important as such. Although characteristics of riverine environment are determined by morphology of river and/or stream created by water flow and vegetation, vegetation also participate in controlling river and/or stream morphology. Riparian vegetation detains erosion materials, thus decreasing the amount of solids in suspension in the watercourses and improving the quality of the water (Howard-Williams et al. 1986, Cooke and Cooper 1988, Pinay and Decamps 1988, Fustec et al. 1991, Haycock and Burt 1990, 1991). Vegetation slows the flow of torrential rains and collects material, reducing the effects downstream. Furthermore, highly developed root systems reinforce the banks of streams (Salinas and Guirado 2002).

These advantages, together with the considerable enhancement of the landscape that this vegetation affords, justify considering riparian vegetation of primary importance (Salinas and Guirado 2002). The maintenance and/or restoration of this vegetation thus deserve priority in land management projects.

Ecological information from the natural or the semi-natural rivers and/or streams showed three different micro-topographies and vege-

Table 2. A list of plant species to be introduced in each zone where is different in ecological characteristics including disturbance regime to restore the degraded urban river and/or stream

Herb dominated zone (Waterfront)	Shrub dominated zone (Low floodplain)	Tree and sub-tree dominated zone (High floodplain through dike)
Phragmites communis	*Salix gracilistyla*	*Alnus japonica*
P. japonica	*S. purpurea* var. *japonica*	*S. koreensis*
Persicaria thunbergii	*S. graciliglans*	*Acer ginnala*
etc.	*Miscanthus sacchariflorus*	*Spiraea prunifolia* for.
	Impatiens textori	*Simpliciflora*
	Astilbe chinensis var. *davidii*	*Staphylea bumalda*
	etc.	*Rosa multiflora*
		Viola verecunda
		Sanguisorba tenuifloia var. *alba*
		Impatiens noli-tangere
		etc.

tation types depending on the distance from the watercourse: waterfront (herb dominated zone), low floodplain (shrub dominated zone), and high floodplain (sub-tree and tree dominated zone). Such a topographic sequence and arrangement of vegetation responded on the bed could be a model for restoration of the degraded urban river and/or stream (Table 2). Plant species recommended to herb, shrub, and tree and subtree dominated zones were prepared hypothesizing stand profiles of single, two, and three layers, respectively based on the results from field survey.

Furthermore, creation of diverse micro-topography through natural process and/or human aid is also required to ensure more improved biodiversity in the riverine environment (Benda et al. 1998).

CONCLUSION

In urban river and/or stream where not only topography is monotonous, but also species composition is simple, we should create habitats of diverse organisms to restore natural ecosystem with diversity as well as stability. This river and/or stream restoration can contribute to recovering environmental health in the corresponding urban area as well by various ecological functions that the restored river and/or stream offers (Lee 2002). Attempts to create natural rivers and/or streams by applying techniques of ecological engineering frequently appear in various regions of Korea since the mid-1990s (KICT 2002). In such projects, restoration has usually been focused on the waterfront of the rivers and/or streams. But true effects of restoration could be displayed when the spatial range of the restoration is expanded to floodplain or dike and further to their surrounding environment (Frissell and Ralph 1998). In fact, an exam ple in Europe seeks to a restoration, which expanding the width of river and/or stream and then recovers the nature of river and/or stream by leaving it natural processes (Hey 1995). Most Asian countries, which have carried out excessive land use around river and/or stream compared with European countries, should indeed pursue such a restoration. Moreover, in these days differently from the past when the rice production had not been enough, such a restoration could be realized, in particular, in rural areas of the developed Asian countries, such as Korea and Japan where the rice production is sufficient.

On the other hand, we also need to understand physical processes controlling channel shape and dimensions to confront flexibly with dynamic changes that the natural rivers and/or streams show (Bettress 1994). Moreover, most restoration efforts to date have focused on the alteration of physical habitat characteristics at small spatial scales, most often the placement of logs, rocks, or wire gabions in a channel to create pool or riffle. The effect of such efforts on the survival and the growth of the target organisms are uncertain (Frissell and Ralph 1998). Therefore, development of more diverse habitats is required in order to create more stable biological environment. Kinds of habitats in river and/or stream clarified from this study and information on their formation background could contribute to realize such project significantly.

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