ECOLOGICAL RESPONSE OF STREAMS IN KOREA UNDER DIFFERENT MANAGEMENT REGIMES

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Abstract: Today, a trend that tries to return the artificial space of a river to a natural one is expanding. But in Korea, which lies in the monsoon climate zone, rivers endure flood damage every year. Moreover, climatic change from global warming causes severe variations in precipitation patterns. Until recently, river restoration practices in Korea have followed partial restoration. These restorative treatments transformed artificial structures of the stream to natural ones and introduced natural vegetation by imitating natural or semi-natural streams. Treatment transformed the riparian structure and increased the diversity of micro-topography and vegetation. Furthermore, restoration recovered species composition, increased species diversity, and inhibited the establishment of exotic species. In particular, the Suip stream, which was left to its natural process for approximately 50 years, recovered its natural features almost completely through passive restoration. An urban stream, the Yangjae, and a rural stream, the Dongmoon, were restored partially by applying ecological principles. On the contrary, technological treatment applied to recover flood damage induced species composition far from the natural vegetation and decreased species diversity. Additionally, this treatment increased exotic species. The same results were found also in benthic invertebrate and fish fauna. The above-mentioned results reflect the importance of ecological considerations in river management.

Keywords: Biological integrity; Ecological response; Ecological stability; Restoration; Restorative treatment; River; Stream

1. INTRODUCTION

Riparian ecosystems are spatially and temporally dynamic and are shaped by fluvial geomorphic processes. There are, therefore, physical and biological links between terrestrial and aquatic environments (Gregory et al. 1991) and biotopes in which animals may seek refuge and food, while enriching the soil with detritus. Riparian ecosystems usually support higher species richness and densities of wildlife than other nearby ecosystems (Johnson and Simpson 1971, Carothers et al. 1974). 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.

Rivers, together with their marginal ecotonal systems, are corridors through the landscape; their margins provide buffers between a watercourse and the variety of land uses within a catchment. This intimate relationship between land and water, however, has been interrupted, degraded, and, in extreme cases, destroyed by human activity (Bravard et al. 1986, Petts et al. 1989, Dister et al. 1990, Petts 1990).

River systems have been dramatically altered by dams and reservoirs, channelization, and land-use development (Petts et al. 1989). Some species of flora and fauna have disappeared; exotic species have invaded; the functional characteristics of river systems have been disrupted; and there has been a reduction in landscape quality and a loss of wilderness areas. The need to develop rivers and their water resources continues to intensify, especially in developing countries because of needs for hydro-electric energy and irrigation, the increasing demands of rapidly growing populations, and the likely increase in per capita resource demands. A strong concern is arising for ecosystem sustainability in the face of both socio-economic development and climatic change. Over the past two decades, attempts have been made to restore damaged systems (Gore 1985, NRC 1992) and to improve watershed management (Naiman 1992).

Increasingly, efforts have been directed toward the application of scientific principles to the development of environmentally sensitive approaches for river management. The restoration of rivers degraded by past urban, industrial, and agricultural impact is now a priority for developed nations.

In Asian countries where people depend on rice as a food source, most floodplains of rivers were transformed in the past to rice fields, and high banks were constructed along waterways to prevent flooding. Consequently, the widths of most rivers 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 river beds and shores for cultivation or roads. Therefore, riparian landscapes, including a river 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.

This study aims to clarify the ecological response of rivers to treatment under different management regimes. Rivers for this study were chosen in one urban and three rural areas in Korea. Management regimes were divided into three types: natural recovery, partial restoration from an ecological viewpoint, and technological rehabilitation to recover flood damage. Ecological responses were analyzed based on changes in species composition, biodiversity and naturalness.

2. STUDY AREAS

The Yangjae, Dongmun, Suip, Yudong and Gyu streams, all located in Korea, were chosen for this study. The Yangjae stream is an urban stream, and the Dongmun, Suip, Yudong and Gyu streams are rural ones. In the Yangjae stream, the bank is covered with concrete block, which is very common in urban streams in Korea. The restoration approach to this stream was ecological. In the Dongmun stream, the bank was covered with concrete block and was restored by introducing plants to the perforated holes in the concrete block to maintain both physical and ecological stability. The Yudong and Gyu streams are close to each other as tributaries of the Seom River. Although the Yudong stream remains in its natural state, the Gyu stream was treated excessively to rehabilitate flood damage. During construction, iron nets with stones were introduced to stabilize the riverbed and bank. Irrigation for agricultural use is practiced in a section of the Suip stream, but another reach was kept natural for approximately 50 years after the Korean War.

3. METHODS

Streams were evaluated based on criteria that distinguished naturalness in terms of transformation of the riparian structure and diversity of micro-topography and vegetation (Table 1; transformed from Lee and You 2001). Diversity of vegetation was evaluated by life form and endemism of component plants.

Riparian vegetation tends to appear in the order of grassland, shrubland, and forest as recede from the waterfront. The distance from the waterfront to each vegetation type reflected disturbance frequency in each site. A vegetation survey was carried out by dividing grassland, shrubland, and forest. Quadrats of 1, 4, and $100m^2$ in size were used to survey grassland, shrubland, and forest, respectively. The vegetation survey was completed by recording the cover class of plant species in quadrats installed randomly (Mueller-Dombois and Ellenberg, 1974). Plant cover was recorded by applying the Braun-Blanquet (1964) scale. Ordinal cover of Braun-Blanquet was converted to the median value of percent cover range in each cover class and then subjected to Detrended Correspondence Analysis (DCA; Hill 1979). Species diversities were compared by rank-abundance curves, which graphically depict patterns of species diversity and dominance (Magurran 1988; Kent and Cocker

Table 1. A criterion evaluating the degree of naturalness of the riparian ecosystem (modified from Lee and You 2002)

Degree	Structural frame	Vegetation structure	Surrounding landscape	Remarks
1	Waterfront, floodplain, and bank are not only covered with artificial material, but also managed artificially.	Herb (usually annual) Herb (usually perennial)	Urban	Vegetation covers less than 50% of the soil surface and is usually composed of annuals.
2	Waterfront and bank (but not floodplain) are covered with artificial material but management is still artificial.	Herb and shrub	Urban and rural	Vegetation covers more than 50% of the land and is usually dominated by perennials.
3	Only waterfront is covered with artificial material and management depends partially on artificial management.	Herb, shrub and tree (usually exotic)	Urban and rural	
4	All zones of the river are covered with natural material, and artificial management remains.	Herb, shrub and tree (usually endemic)	Rural	Vegetation stratification composed of herb and shrub layers appears.
5	All zones of the river are covered with natural material, and management remains natural.		Rural and natural	Vegetation stratification composed of herb, shrub, and tree layers appear, but trees are exotic or unfamiliar species with the ecological conditions in a given region. Vegetation stratification composed of herb, shrub, and tree layers appear, and trees are not only endemic but also familiar species with the ecological conditions in a given region.

1992). The percentage of exotic species was obtained from the ratio of the number of exotic species to the total species.

Benthos and fish were investigated by identifying samples collected by suber net (25 x 25 cm; mesh size 0.5 mm), and casting net (mesh size 8 x 8 mm, 10 x 10 mm) and fishing net (mesh size 3 x 3 cm, 4 x 4 cm), respectively.

4. RESULTS

4.1 Naturalness degree

With a naturalness scale that ranges from 1 to 5, with 5 being the most natural, the naturalness degree of UY, UYR, UYF, CBD, RD, YD, GY, RS and NS was recorded as 2, 4, 2, 2, 3, 4, 3, 3 and 5, respectively. In sum, urban and rural streams showed a degree or 2 or 3, and semi-natural and natural streams showed a degree of 4 and 5 in naturalness, respectively. Restoration practice based on ecological principle in both urban and rural streams improved naturalness, but technological treatment applied to recover flood damage deteriorated it.

4.2 Species composition

Treatment in the urban stream, the Yangjae, was practiced in terms of ecological restoration. In order to evaluate the treatment effect in species composition, DCA ordination (Hill 1979) was applied. As a result of stand ordination based on species composition, stands established on streams with banks paved by concrete block failed in restoration. The restored and reference streams tended to be arranged in the previously mentioned order (Fig. 1).

The Dongmun stream located in a rural area, has banks paved by concrete block to prepare for flood season. Treatment in this stream was

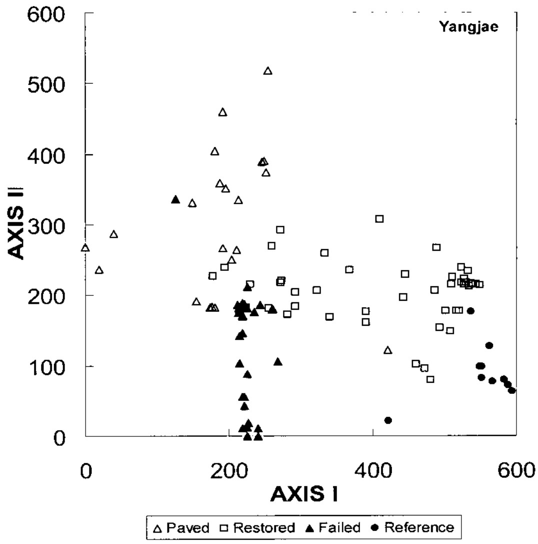

Fig. 1. Ordination of stands different in treatment methods in an urban stream, the Yangjae stream and reference stands sampled in the natural stream. Restored: the reach restored based on ecological principle, Failed: the reach failed in ecological restoration, Paved: the typical urban stream that stream bank is covered with concrete block

carried out in from an ecological restoration viewpoint. As a result of stand ordination, treated areas were arranged between both stands left without any treatment and reference streams, which were left to natural processes (Fig. 2).

As a result of stand ordination, stands of the Yudong and Gyu streams overlapped in part, but most stands were arranged in different locations (Fig. 3). That is to say, the species composition of both streams, which are situated near each other, shared both similarities and differences. The similarities stem from the shared geographic positions, and the differences lie in the flood protection that was done to the Gyu stream. The results of ordination of benthic invertebrate and fish samples also showed differences between the Yudong and Gyu streams

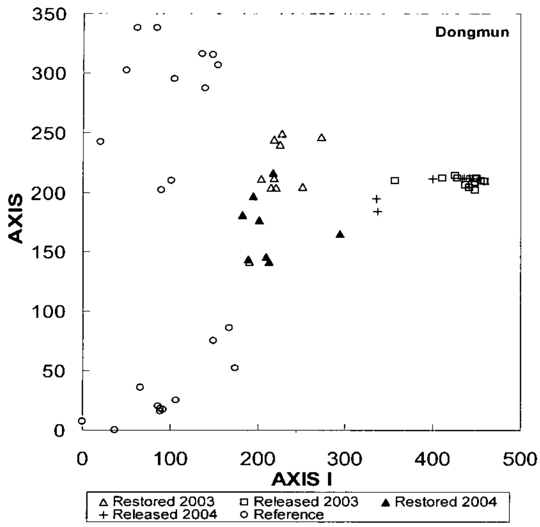

Fig. 2. Ordination of stands different in treatment methods in the Dongmun stream, a rural stream, and reference stands sampled in the natural stream. Restored 2003: the restored reach investigated in 2003, Released 2003: the released reach without any restoration practice investigated in 2003, Restored 2004: the restored reach investigated in 2004, Released 2004: the released reach without any restoration practice investigated in 2004

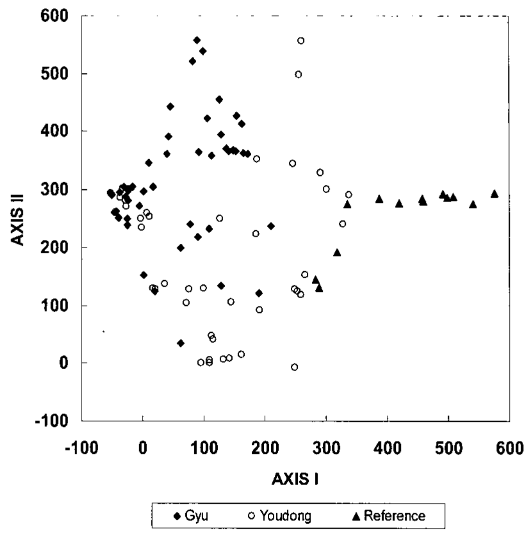

Fig. 3. Stand ordination of the Gyu and Yudong streams, and reference streams based on vegetation data

(Fig. 4). In particular, stand ordination based on fish fauna showed that the Yudong samples were closer to the reference streams than the Gyu ones.

4.3 Ordination of riparian vegetation left to a natural process

Ordination of stands established in natural and rural reaches, where agriculture is still practiced, did not divide stands of both reaches. Stands in the natural reach were scattered widely, while those in the rural reach were restricted in the narrow part and thereby tended to be embedded among stands from the natural reach. The result was that the natural stands hold diverse species composition, whereas the rural ones contain simple species composition (Fig. 5).

Ordination of riparian vegetation with different stratification established in the natural reach of the Suip stream tended to be arranged in the order of grassland, shrubland, and forest, which indicates arrangement with distance from the waterway, except for grasslands established on the site with shallow soil depth on the Axis I (Fig. 6). Those stands were close to alder stands, and the result would be because of the moisture gradient due to the alders (Malanson 1995).

4.4 Response of biodiversity

Biodiversity was discussed in regard to plants, benthic invertebrates, fish species, and vegetation, which are referred to as landscape elements henceforth. Rank-abundance relationships (Fig. 7) revealed two trends of net increases in species diversity. First, species richness generally increased in response to the restorative treatment, but decreased with human

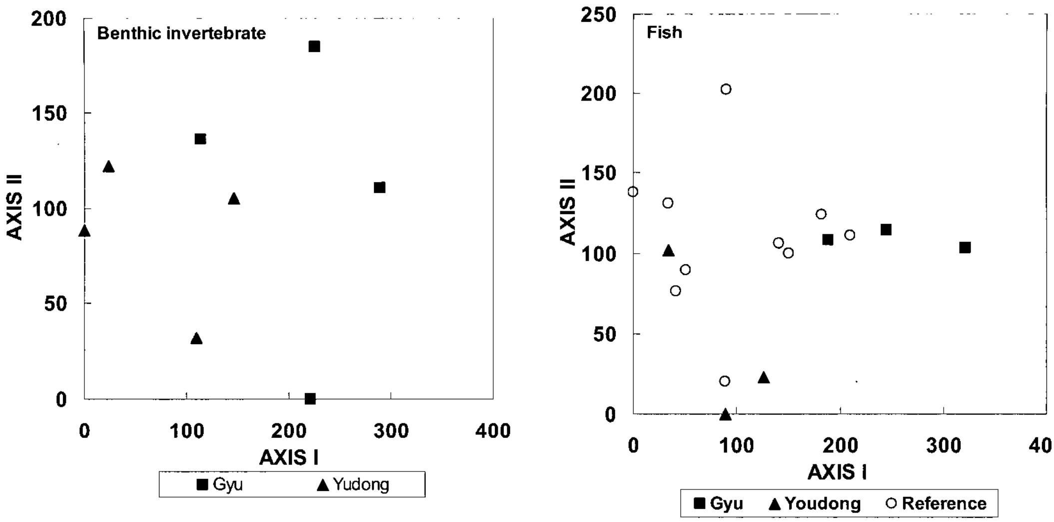

Fig. 4. Stand ordination of the Gyu, Yudong, and reference streams based on benthic invertebrate (upper) and fish (lower) fauna

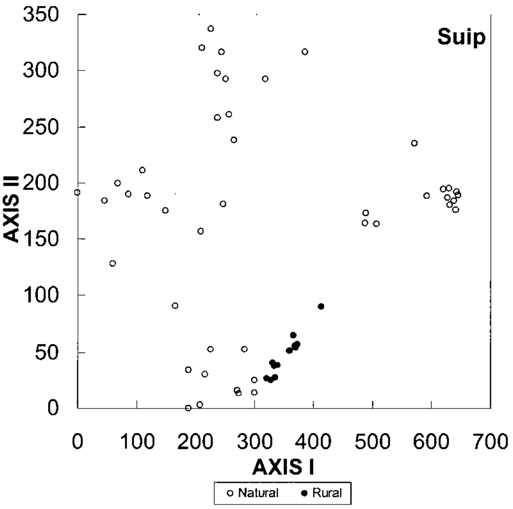

Fig. 5. Ordination of stands sampled in the Suip stream. Natural: the natural reach of the Suip stream, Rural: the rural reach of the Suip stream

influence. Second, the degree of dominance, determined by the steepness of the curves, declined in response to the restorative treatment, but ascended with human influence. In response to restorative treatment, the relative abundance of an average species was higher, indicating a

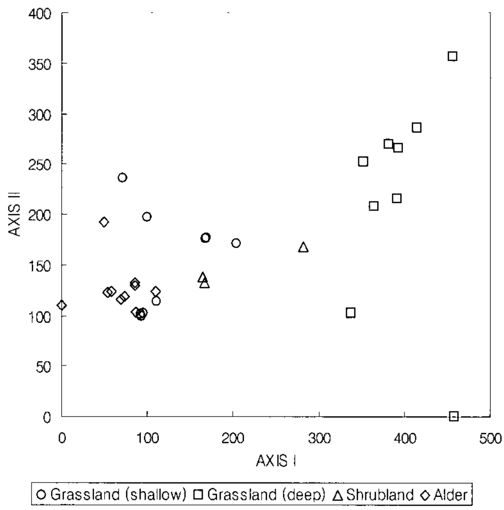

Fig. 6. Ordination of stands sampled in the natural reach of the Suip stream. Grassland established in the sites with shallow soil depth, Grassland established in the sites with deep soil depth, Shrubland: stands dominated by shrubs, Alder: alder stand

more even distribution of space occupancy.

The rank-abundance relationship based on the benthic invertebrates, fish, and landscape elements

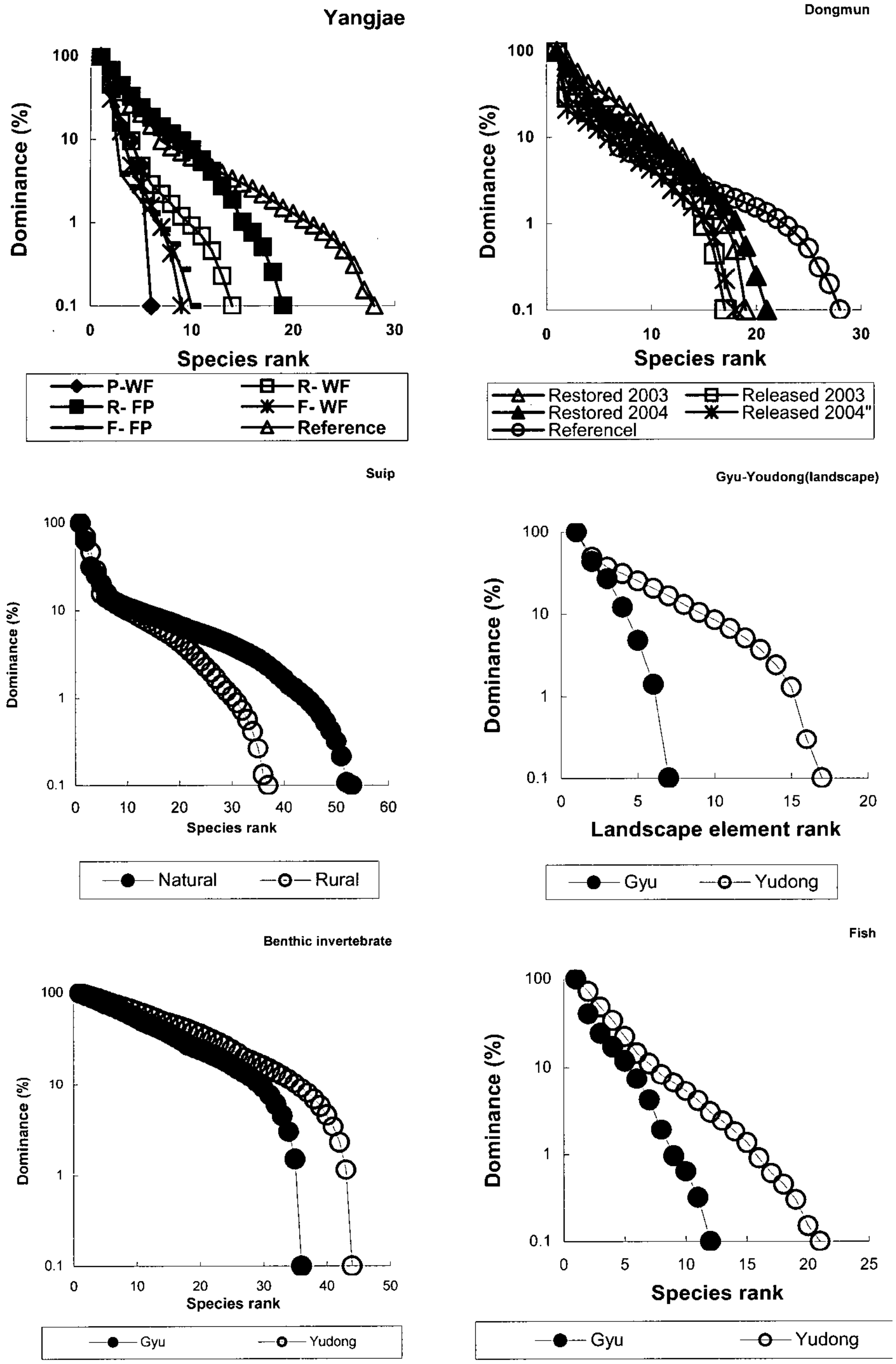

Fig. 7. Rank-abundance curves of plant and animal (benthic invertebrate and fish) species grouped by sites different in treatment methods. R: the reach restored based on ecological principle, F: the reach failed in ecological restoration, P: the typical urban stream where the bank is paved with concrete block, WF: water front, FP: floodplain, B: bank

showed similar trends to plant species. These results are due to the interrelationship among them. Terrestrial invertebrate inputs increased from the restorative treatment applied on the riparian zone and increased fish abundance in streams (Kawaguchi et al. 2003).

4.5 Dynamics of the riparian forest in the stream left to natural processes

Vegetation dynamics were analyzed in stands of three types established in the natural reach of the Suip stream: stands dominated by black locust, willow, and maple (Fig. 8). The black locust and willow stands are dominated by mature trees of their respective species names, which consist of the overstory with maple as young trees in the under-story. These stands might be succeeded by maple over time. Dead trees also appear among these two stands, reflecting that they are in the degenerate stage. The maple-dominated stands show no such degeneration.

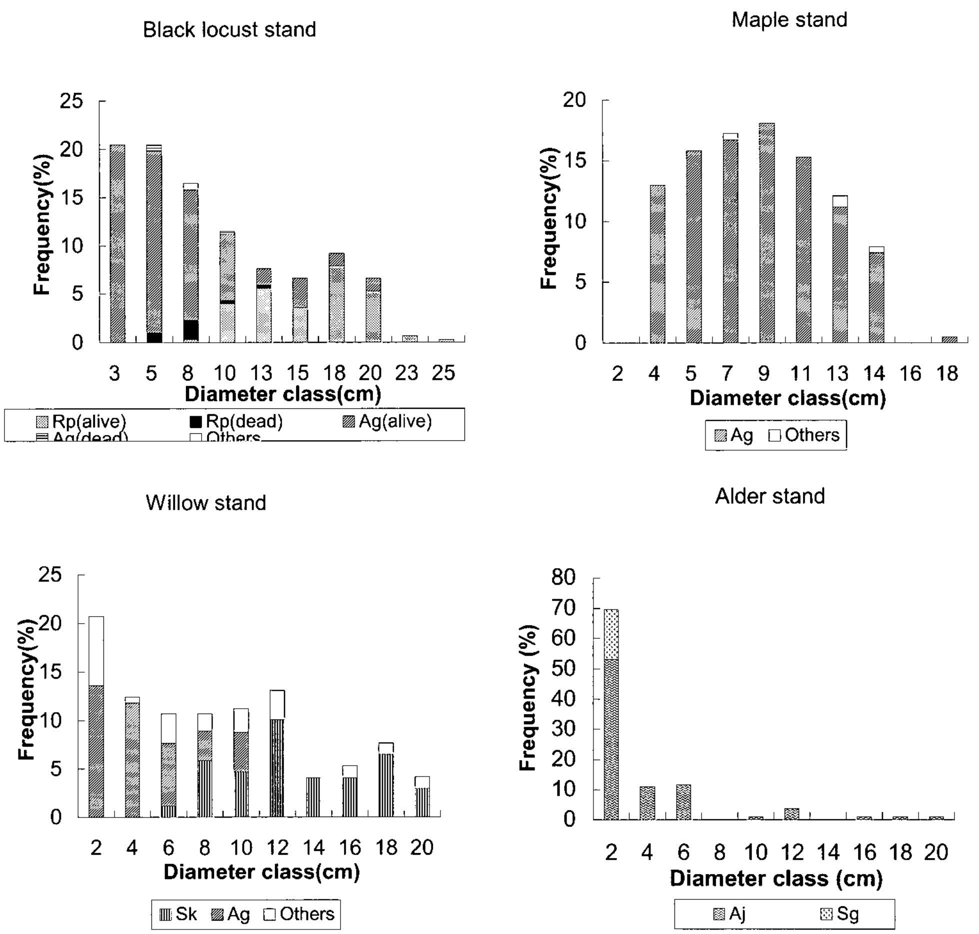

Fig. 8. Frequency distribution diagrams of diameter class (D30) of the major woody species that compose the riparian forest of the Suip stream. Lower, middle, and upper diagrams shows the results obtained from the southern tip, middle part, and northern tip in the civilian control zone of the Suip stream, respectively. Ag: *Acer ginnala*, Rp: *Robinia pseudoacacia*, Pp: *Prunus padus*, Sk: *Salix koreensis*

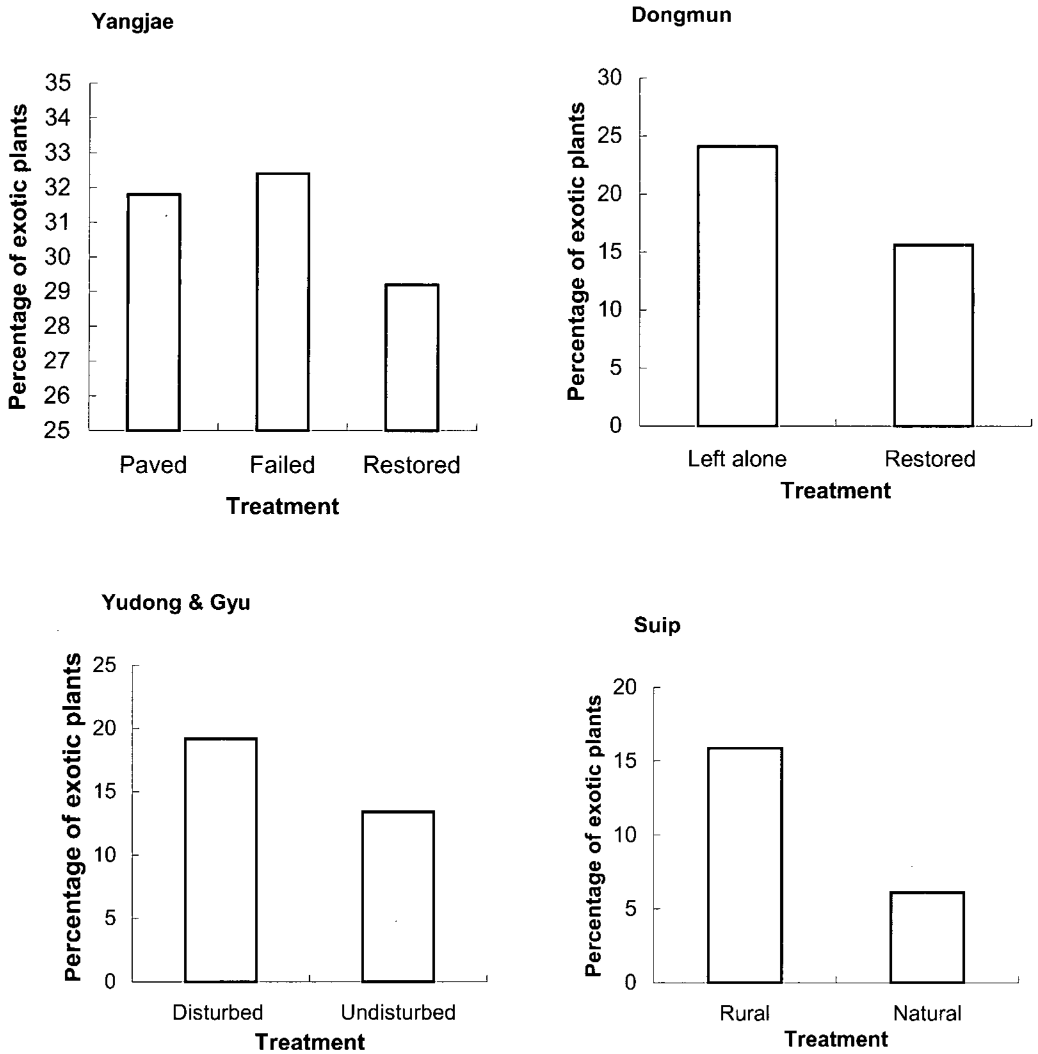

Fig. 9. A comparison of the percentage of exotic plants between or among sites with different treatment methods

4.6 Exotic species

The percentage of the exotic species was lower in the restored parts of each stream than in sections without any restorative treatment (Fig. 9). On the other hand, the stream disturbed by excessive human interference, showed a higher percentage of exotic species than the undisturbed stream. Active restoration based on ecological principles and a passive approach achieved through natural process reduced the percentage of exotic plants, whereas nonecological human impact showed the opposite effect.

5. DISCUSSION

5.1 Evaluation on the effects of treatment under different management regimes

River floodplains and riparian forests throughout the world have been modified by human development, causing losses of biological diversity and ecological function and increasing the probability of loss of human life and property during floods (Naiman et al. 1988, Naiman and Decamps 1990, Petts 1990, NRC 1992, Gregory and Bisson 1996).

Environmental change is reality, and it is continuous. In the past, changes on Earth were driven by wind and water; geological forces; astronomical events; and the work of microorganisms, plants, and animals. During the past two centuries, human activities have become the principal driver of change on Earth. Human influences are massive; they are incessant; and they are global. For the first time, a biological agent – a single species – rivals geophysical forces in shaping the surface of the Earth.

Human-caused change may be positive, neutral, or negative. The challenge faced by environmental scientists is to distinguish among these three alternatives by detecting and interpreting the causes and consequences of change, especially those that alter living systems. Resource and environmental managers want to detect and treat changes that have negative consequences; at the same time, they want to avoid wasting resources – treating changes that do not have negative consequences (Karr 1998).

Management regimes change over time. Management for these rivers had focused on use and protection for disaster in the past, whereas present restoration concentrated on improving structure and function of the stream in its natural environment. Management regime depends on landscape or region. Landscape is shaped by a combination of climate, landforms, soils, vegetation and land uses. The dominant factor today is land use (Karr 1996). In fact, management is a sort of restoration, which is different in the final goal (MacMahon 1997). The trajectory of a restoration project may be viewed in terms of ecosystem structure and function. A change in both dimensions occurs upon degradation. The fundamental goal of restoration is to return a particular habitat or ecosystem to a condition as close as possible to its pre-degraded state. Complete restoration would involve a return to that state, a partial return, or other trajectories would result in rehabilitation or replacement by a different system (Bradshaw 1984).

To effectively restore degraded areas, or to protect existing high-quality areas, we must be able to define the attributes of "normal" and undegraded, or "healthy," habitats as a model. One way of setting a baseline and measuring restoration success is to define the normal "biological integrity" of a system and then measure deviations from there. Integrity implies an unimpaired condition, or the quality or state of being complete or undivided. Biological integrity is defined as "the ability to support and maintain a balanced, integrated, adaptive biological system having the full range of elements and processes expected in the natural habitat of a region" (Karr 1996). To practice evaluation on a stream, ecological attributes of the stream are compared with those of an "undisturbed" reference. In our study, we compared species composition and biodiversity among streams with different management regimes. In particular, we compared species composition and diversity of streams in urban and rural areas, which historically had been managed in terms of use and disaster protection and were treated from a viewpoint of ecological restoration only in recent years. We also evaluated the effect of civil engineering applied to reclaim flood damage without any ecological consideration.

Species composition of streams dominated by a restorative treatment resembled the reference stream and diversity increased. In contrast, nonecological treatment not only created different species composition from the reference stream but also lessened biodiversity. Therefore, the restorative treatment functioned toward increasing both biological integrity and ecological stability and thereby gained access toward the restoration goal. On the other hand, nonecological treatment created a system farther from the restoration goal.

As is shown in the results of stand ordination (Figs. 1-5), restored streams showed species composition more similar to the reference stream than ones left without treatment. Treatment to rehabilitate flood damage led to the contrary. Flood-damage treatment deteriorated the degree of naturalness and reduced biodiversity. Such different species composition is the product of a different structural frame and artificial disturbance.

5.2 Necessity of ecological restoration in the degraded riparian ecosystem

Riparian ecosystems are the vegetation, habitats, and ecosystems associated with water bodies and are dependent on the existence of perennial, ephemeral, or intermittent surface or subsurface drainage. Riparian ecosystems are some of the most productive ecosystems. These ecosystems indirectly affect the stability and quality of surrounding ecosystems by reducing flood peaks, acting as sediment and nutrient sinks, controlling water temperature, and increasing ground water recharge (Schmidt 1987). Therefore, despite their relatively small expanse, riparian areas play a critical role in the life cycles of an inordinate number of wildlife species and provide important recreation opportunities for outdoor enthusiasts.

In Korea, most riparian ecosystems have disappeared already and the remaining ones are in decline. The rapid decline of these valuable ecosystems has made riparian conservation a focal issue in the public eye, but progress to check the decline has been marginal, which is partially because the science of repairing damaged riparian ecosystems is relatively young.

Riparian ecosystems are characterized by high diversity in both plant and wildlife species. The mesic nature of riparian areas permits the establishment and growth of many plant species not found on adjacent, more xeric uplands. Riparian ecosystems take on many forms and are characterized by a variety of plant communities. Riparian ecosystems can be narrow, with abrupt transitions between the riparian and upland plant communities, or broad, with the riparian zone extending for hundreds of meters from the stream channel.

Change in elevation (with its concomitant effects on frequency of inundation) appears to be the most significant factor associated with the distribution of riparian plant communities and their species composition (Szaro 1989). Passive restoration, achieved by leaving a stream to its natural processes for approximately 50 years, showed high biodiversity dependent on microtopography. Restoration practices carried out by imitating the riparian ecosystem caused a change of species composition similar to the reference stream, which holds an integrate ecosystem with high biodiversity. These results show that restored streams increased biological integrity and stability. Based on these results, we see the necessity of ecological restoration.

5.3 Restoration of microtopography as a basis of biodiversity

A river carries out three actions: erosion, transport, and deposition. Erosion creates small ponds, and the eroded soil particles are transported and deposited downstream. Deposits become riffles, and water flow velocity increases in these spots and induces more erosion. Those processes create riffles and ponds continued longitudinally on the riverbed. Flowing water runs meanderingly in a river. Such-snake shaped rivers are also to the result of these three actions.

In the waterways of a meandering river, small islands and ponds appear. The channeled river also creates an uneven micro-topography on the riverbed through repeated erosion and deposition. Uneven topography induces a difference of water depth; different water depths create variations in water temperature, which leads to diversity in microhabitats. Furthermore, the concave-convex topography of a riverbed controls water flow and determines species composition in a given area (Lee et al. 2003).

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, Hoover and Parker 1991, 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).

Alteration of habitats by human activity is the greatest threat to biodiversity. The most visible form of habitat alteration is direct habitat removal. If we view the broader landscape, however, often the most striking pattern we see is the fragmentation of a once-continuous natural landscape into bits and pieces (Wilcove et al. 1986, Shafer 1990). Fragmentation, which is the disruption of extensive habitats into isolated and small patches, produces two negative components for biota: loss of total habitat area and the creation of smaller, more isolated habitat patches. Consequently, fragmentation becomes a threat to biodiversity (Primack 1995, Meffe and Carroll 1997).

High biodiversity in a stream restored naturally is due to the recovery of the diverse microtopography on the floodplain left in a natural process and an integrate environment without human interference (Fig. 6). The stream where microtopography simplified because of excessive human impact imposed to recover the flood damage, the Gyu, showed low biodiversity (Fig. 6). From this viewpoint, we suggest recovering diversity in the structural frame, including micro-topography of the river as a starting point to restore the degraded riparian ecosystem.

On the other hand, the Suip stream, which was restored by a natural process, showed species diversity. The difference of species composition among sites in the natural stream reflected the natural condition of each site. Differences in species composition in the natural streams reflected also variation of the micro-topographies, such as the waterfront and flooding bed. Such differences reflect different disturbance regimes and determine vegetation to be established in a given area.

5.4 Exotic species and Restoration

In modern days, many species have been introduced, deliberately and accidentally, into areas where they are not native (Grove and Burdon, 1986; Hedgpeth, 1993). Oftentimes, these exotic species expand their range beyond the place of initial establishment because of advantageous life history strategies (Meffe et al., 1997). It is usually known that disturbed lands provide favorable microsites for exotic species equipped with opportunistic or ruderal life history strategies (Johnstone, 1986; Hobbs and Huenneke, 1992; Meffe et al., 1997, Lee et al. 2003). Rivers, where both artificial and natural disturbances are frequent, support many exotic species (NIER 1995, 1996).

Restoration practices are recommended as a measure to inhibit the invasion of exotic species (Lee et al. 2003, Lee et al. 2004). Our data shows that restorative treatment reduced exotic plants, whereas excessive artificial interference increased their presence. This result implies that restoration contributes to conserving biological integrity.

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