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Effects of Partial Habitat Restoration by a Method Suitable for Riverine Environments in Korea

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ABSTRACT: Korean rivers and their surrounding environments have been used excessively for rice production in the past and more recently for construction of urban areas to accomodate the rapidly increasing population. Affected Korean rivers experience dramatic fluctuations in their water levels and have faster currents compared with those in other countries. In order to restore more natural conditions in rivers experiencing such conditions, we employed a partial restoration method, which is designed to achieve physical and biological stability simultaneously. Concrete blocks were introduced to increase the river's physical stability during floods, and terra cottem, a soil enhancer, was used to reduce water loss due to intense heat. These interventions increased the river's ability to hold water and thereby promoted plant growth. This restoration method increased vegetation coverage and species diversity in treated areas, and changed the species composition in treated areas to more closely approximate that of the control site. These results suggest that this method is effective in restoring damaged habitats to more natural conditions.

Key words: Korean rivers, Partial restoration, Species composition, Species diversity, Terra cottem, Vegetation coverage, Water-holding capacity

INTRODUCTION

Habitat restoration is currently a major focus of the field of environmental science. The term of restoration refers to practices designed to reestablish naturally occurring processes and biological, chemical, and physical linkages between aquatic, riparian, and associated terrestrial ecosystems (Kaffman et al. 1997). Restoration is the process of returning a river 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, Ebersole et al. 1997). Therefore, 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 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 fact, European countries pursue restoration by extending the width of rivers, and then leaving them to recover via their own natural processes (Hey 1995).

Riparian landscapes include river ecosystems and their surrounding environments. These landscapes are easily damaged by excessive use, resulting in dramatic alteration of habitat structure and functioning. Riparian landscapes have been usually been managed to promote human use and prevent disasters. However, more recently the importance of riverine environments as natural environments has been given increasing recognition (Petts and Calow 1995).

Riparian ecosystems are spatially and temporally dynamic and are shaped by fluvial geomorphic processes. Therefore, there are physical and biological connections among terrestrial and aquatic environments, and these environments represent biotopes in which animals may seek refuge and food, while enriching the soil (Gregory et al. 1991). Riparian ecosystems usually support higher species richness and densities of wildlife than do other nearby ecosystems (Johnson and Simpson 1971, Carothers et al. 1974). Riparian vegetation prevents erosion, thus decreasing the quantity of suspended sediments and improving water quality (Howard-Williams et al. 1986, Cooke and Cooper 1988, Pinay and Decamps 1988, Fustec et al. 1991, Haycock and Burt 1990, 1991). Vegetation also slows the flow of runoff from torrential rains, reducing the effects downstream. Furthermore, the highly developed root systems reinforce the riverbanks (Salinas and Guirado 2002). All of these

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advantages, together with the considerable enhancement of the landscape that riparian vegetation affords, justify considering this type of vegetation as being of primary importance (Salinas and Guirado 2002). Land management projects should therefore place a high priority on the maintenance or restoration of riparian vegetation.

In Asian countries where rice is a staple food, humans have transformed most floodplains of rivers and streams to rice fields and constructed dikes near affected waterways to prevent flood damage. Therefore, the widths of most rivers and streams have been sharply reduced. Many of these rice fields were subsequently absorbed into urbanized areas, and meandering and complex channels were artificially straightened in urban areas. As a result, riverine plant and animal communities have been damaged or destroyed by deforestation, the introduction of exotic species, the diversion and channeling of water for agriculture, and the use of river beds and shores for cultivation or even roads (Lee and You 2001, Lee and Woo 2006).

Since the 1990's, land managers have been using ecological engineering methods to attempt to restore natural ecosystem communities and processes (KICT 2002). Such restoration projects have usually focused on the waterfront. However, restoration efforts will be more effective when the spatial range is expanded to include floodplains, weirs, and the surrounding environments (Frissell and Ralph 1998). Therefore, extension of the spatial range for restoration projects would result in more effective land management. However, Korean rivers experience severe fluctuation of water levels as a result of local climatic conditions. Moreover, the topographical characteristics of the landscape, in which 65% of the land surface consists of steep slopes, lead to particularly rapid water flow (Lee 2004). Those natural characteristics and the heavy human use of riverside land make effective restoration of Korean rivers hard to achieve (Lee and Woo 2006). This study aims to evaluate the effectiveness of a restoration technique which seeks to achieve both physical and biological stability of riparian habitats in a Korean river.

METHODS

Laboratory experiments were conducted from February to April, 2003 in a greenhouse. A concrete wall with holes 10 cm in diameter was used as model of artificial waterfront protection facilities. When artificial floodwalls are exposed to sunlight in the summer, their temperature increases greatly, resulting in the loss of water due to evaporation. In this study we evaluated the effects of a material called as "Terra cottem (hereafter TC)" in the prevention of water loss. TC is a soil ameliorator, which is believed to promote water and nutrient retention. We employed the model habitat to evaluate the effects of four different TC treatments (control, 1～3%) and three water supply intervals (1～3 weeks). Each treatment had three replicates. The effects of TC were evaluated by examining the growth responses (leaf area and branch length) of sample plants, including *Salix gracilistyla*, *S. koreensis* and *Spiraea prunifolia* var. *simplicifolia*). Sample plants of *Salix gracilistyla* and *S. koreensis* were prepared by cutting grafts into 20 cm sections. Samples of *Spiraea prunifolia* var. *simplicifolia* was prepared by cutting sample plants dug out in field into 20 cm sections. Information on the spatial distribution of sample plants was obtained from natural or semi-natural stretches of several rivers or streams such as the Suip stream, the Seom river, and the Namhan river. *Salix gracilistyla* grows on waterfronts or floodplains close to waterways and *S. koreensis* and *Spiraea prunifolia* var. *simplicifolia* grow in floodplains at a greater distance from the waterway. They should therefore respond differently to environmental conditions, such as soil moisture content and disturbance regime, which vary according to distance from the waterway. Leaf area was calculated by measuring leaf length and breadth using calipers with 0.05 mm precision and then calculating the area of an ellipse of the same dimensions. Total leaf area was obtained by multiplying the number of leaves by the mean leaf area. Branch length was measured using a measuring tape with 0.1 cm precision. Growth indices were obtained from coefficients of regression equation, which expresses accumulative growths of leaf and branch plotted against cultivation time. Cultivation of sample plants was progressed for 12 weeks from February to April and measurement of growth was carried out for six weeks from mid-March to April. The water content of soils was estimated using the weight loss of fresh soil dried at 105℃ in a dry oven.

The differences among plots in plant growth and water content were examined using ANOVA and HSD at $\alpha = 0.05$ (SAS, 2001). Regression equations, which express the growth processes of sample plants, were derived using Microsoft Excel.

Field experiments were carried out from March to September, 2004 in the Dongmun stream located in Munsan-eub, Paju-si, Gyunggi province in central western Korea. "Eub" and "Si" are administrative units, which correspond to town and city, respectively. Sample plants cultivated in textile pots (10 cm diameter, 15 cm height,) with different TC contents were planted in holes placed on a concrete wall used for waterfront protection. Plant growth was determined by measuring branch lengths using the same method as the laboratory experiment. The bank of the Dongmun stream was covered with concrete blocks to maintain the physical stability of the river, and restored by introducing plants in holes in the concrete blocks to promote ecological stability. The Siup stream, located in Bangsan-myun, Yanggu-gun, Gangwon province in eastern Korea (in the "Myun" (rural areas) and "gun" (county) administrative units) was selected as a reference stream, as the stream was left to follow natural processes for approximately 50 years after the Korean War.

We conducted vegetation surveys by recording the cover class of plants in randomly placed 2 m × 2 m quadrats using methods described by Braun-Blanquet (1964). Vegetation survey was carried out in August of both years, 2003 and 2004. The ordinal cover derived using the Braun-Blanquet method was then converted to the median value of percentage cover for each cover class and then subjected to Detrended Correspondence Analysis (DCA; Hill 1979). Species diversity was compared using rank-abundance curves, which graphically depict patterns of species diversity and dominance, and the Shannon Wiever Diversity Index (H') (Magurran 2004).

RESULTS

Laboratory Experiments

Growth coefficients obtained from the growth curves of sample plants were used to compare plant growth among plots with different TC contents and water supply intervals. In all sample pots, higher TC contents corresponded with larger growth coefficients (Table 1). Moreover, in pots with longer water supply intervals, the relative growth coefficients in pots with higher TC contents were generally higher. That is, TC played a more important role as the water supply intervals become longer, although this result was not completely consistent across all conditions.

Table 1. Branch growth coefficients (GC) and the relative index (RI) to the control plot of sample plants in each treatment. Sg: *S. gracilistyla*, Sk: *S. koreensis*, Sp: *Spiraea prunifolia* var. *simplicifolia*

Water supply interval	Terra cottem content	Sg		Sk		Sp	
		GC	RI	GC	RI	GC	RI
1 week	Control	4.0	100.0	18.7	100.0	16.8	100.0
	1.0%	5.5	136.0	21.0	112.0	18.3	109.2
	2.0%	6.5	160.9	21.8	116.4	24.5	145.9
	3.0%	7.7	190.1	31.5	168.2	35.7	212.7
2 week	Control	2.6	100.0	10.2	100.0	13.3	100.0
	1.0%	3.2	125.1	12.6	123.8	20.5	154.3
	2.0%	4.7	182.2	15.9	156.2	21.8	163.7
	3.0%	6.5	249.0	22.0	215.7	34.2	257.3
3 week	Control	3.0	100.0	6.1	100.0	18.8	100.0
	1.0%	4.9	162.4	12.3	202.0	24.1	128.2
	2.0%	5.6	183.2	17.4	285.5	27.2	144.4
	3.0%	9.5	314.2	26.9	442.6	54.1	287.8

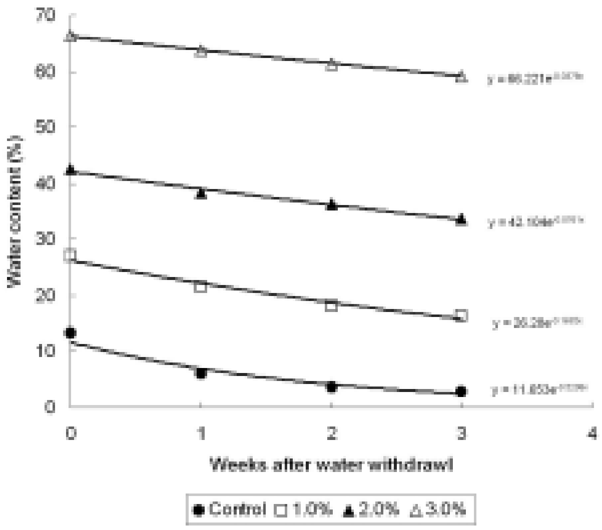

Fig. 1. Water content of soils with different Terra cottem contents plotted against time since water withdrawal. Equations on the graph are regression equations for water content curves. The larger the regression coefficient, the faster the reduction in water contents after water is withdrawn.

The effectiveness of TC in promoting moisture retention was evaluated by comparing the water content of soils with different TC content after water withdrawal. In samples with higher TC content, the loss of water was lower (Fig. 1), which suggests that TC is effective in promoting water retention by soils.

Field Experiments

In samples with higher TC content,, the growth of sample plants was greater, which is consistent with the results of the laboratory experiments (Fig. 1). Soil water content was also higher in samples with higher TC content (Fig. 3).

Restoration Effects

Restored stands exhibited characteristics that differed from untreated stands of the same rivers, and the characteristics of restored stands approached those of stands at the control site (Fig. 4). Specifically, the species composition of the restored stands was more similar to that of control sites than to untreated stands of the same river.

The vegetation coverage index was calculated by adding the coverage of all plant species that appeared in a quadrat. The index was higher in the restored plots than in those not receiving any restorative treatment although the difference did not reach statistical significance (Fig. 5).

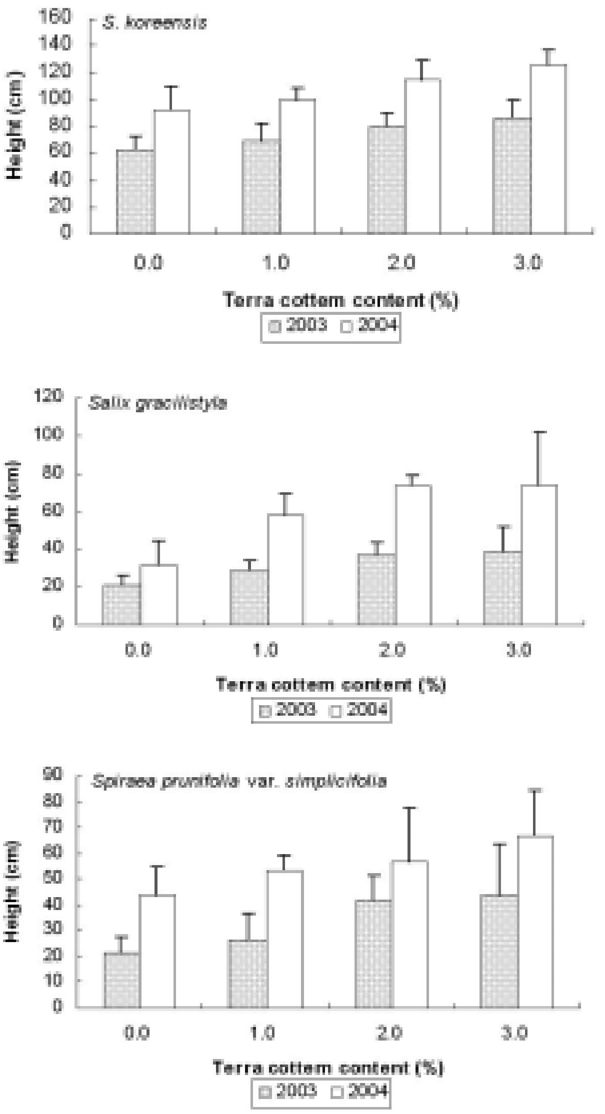

Fig. 2. Comparison of branch growth of sample plants in field experimental plots with different Terra cottem contents. Branch growth tended to increase as Terra cottem contents increased but differences among treatment plots were not significant.

Rank-abundance curves showed that species richness was higher in the restored plot (Fig. 6). The Shannon Wiener Diversity Index (H') was also higher in the restored plots than in the untreated plots. In the second year after restorative treatment, 2004, the diversity of both restored and non-restored plots increased, but the difference between the two remained.

DISCUSSION

Evaluation of Restoration Effects

The trajectory of a restoration project may be viewed in terms

Table 2. Leaf growth coefficients (GC) and the relative index (RI) to the control plot of sample plants in each treatment. Sg: *S. gracilistyla*, Sk: *S. koreensis*, Sp: *Spiraea prunifolia* var. *simplicifolia*

Water supply Interval	Terra cottem content	Sg		Sk		Sp	
		GC	RI	GC	RI	GC	RI
1 week	Control	39.2	100.0	55.4	100.0	11.0	100.0
	1.0%	42.2	107.7	63.6	114.8	15.4	140.0
	2.0%	47.3	120.7	72.5	130.9	20.0	181.8
	3.0%	54.7	139.5	95.5	172.4	24,2	220.0
2 week	Control	52.3	100.0	25.9	100.0	12.7	100.0
	1.0%	66.7	127.5	29.8	115.1	18.7	147.2
	2.0%	74.0	141.5	40.9	157.9	25.2	198.4
	3.0%	95.9	183.4	61.7	238.2	35.6	280.3
3 week	Control	17.8	100.0	13.5	100.0	9.08	100.0
	1.0%	24.1	135.4	17.4	128.9	12.9	143.3
	2.0%	28.3	159.0	21.2	157.0	16.5	184.4
	3.0%	39.8	223.6	28.6	211.9	24.5	272.2

of ecosystem structure and functioning. A change in both dimensions occurs when habitat is degraded. The fundamental goal of restoration is to return a habitat or ecosystem to a condition as close as possible to its pre-degraded state. Complete restoration would involve a return or a partial return to the original state, whereas other trajectories would result in rehabilitation of the system, 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 this norm. 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 evaluate the integrity of a stream, ecological attributes of the stream are compared with those of an "undisturbed" reference. In our study, we compared the species composition and biodiversity of a) restored streams, b) streams not receiving any restorative treatment, and c) natural reference streams.

The species composition of restored streams resembled those of reference streams (Fig. 4) and the species diversity was higher in

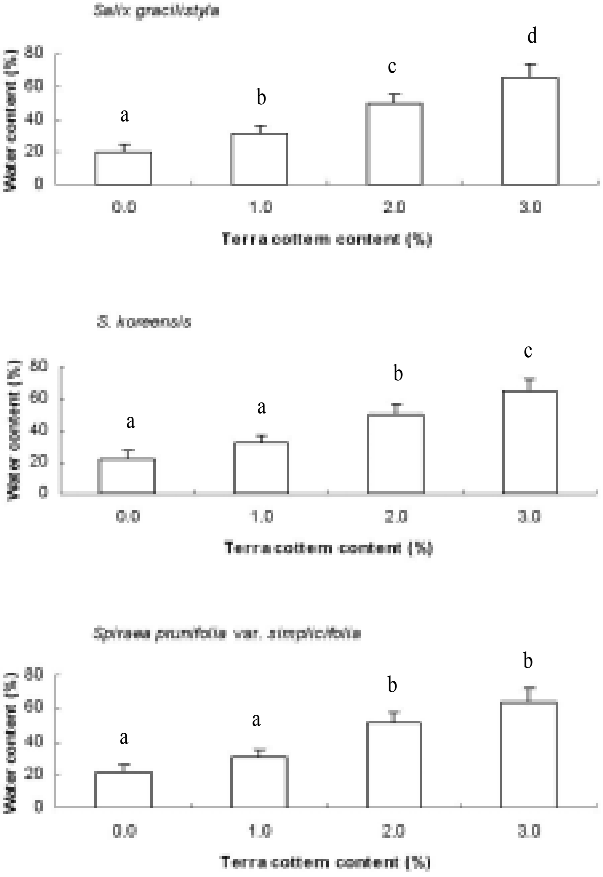

Fig. 3. Comparison of the water contents of soils in plots with different Terra cottem contents in field experimental plots containing three different sample plants.

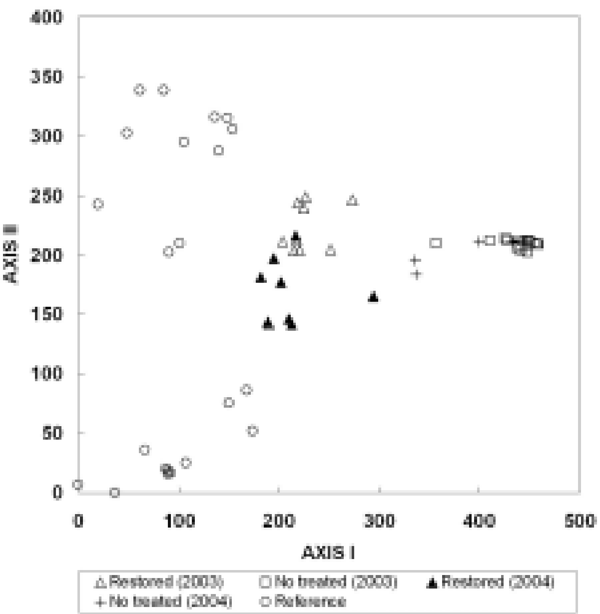

Fig. 4. Stand ordination of restored, untreated, and control sites.

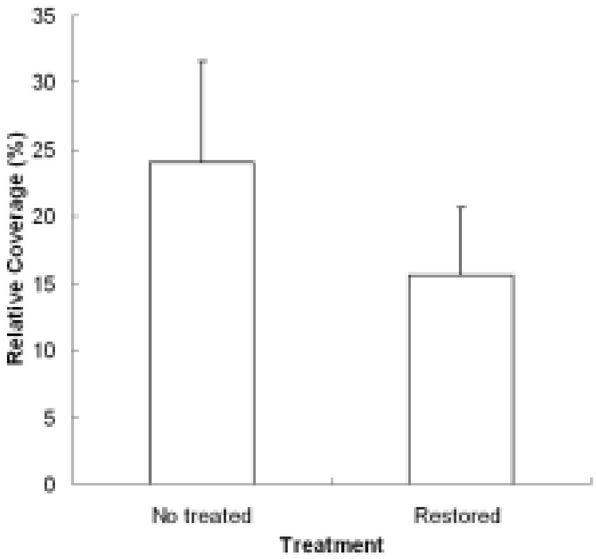

Fig. 5. Comparison of the relative coverage of exotic plants in restored and untreated plots.

restored streams than untreated streams (Fig. 6). Therefore, the restorative treatment was effective in increasing the biological integrity and ecological stability of the treated streams.

Exotic Species and Restoration

Many species have been introduced, deliberately and accidentally, into areas where they are not native (Grove and Burdon 1986, Hedgpeth 1993). Often these exotic species subsequently expand their ranges beyond the place of initial establishment because of advantageous life history strategies (Meffe et al. 1997). Disturbed lands often provide favorable microhabitats 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). Accordingly, 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, Lee and Lee 2006). Our data showed that restorative treatment reduced relative coverage of exotic plants (Fig. 5), which implies that restoration practices can contribute to conserving and restoring the biological integrity of damaged riverine ecosystems (Ewell 1987, Karr 1996).

CONCLUSION

TC increased the water holding capacity of soils, and thereby promoted plant growth. These results suggest that TC can make an important contribution to restoration efforts in riverine habitats.

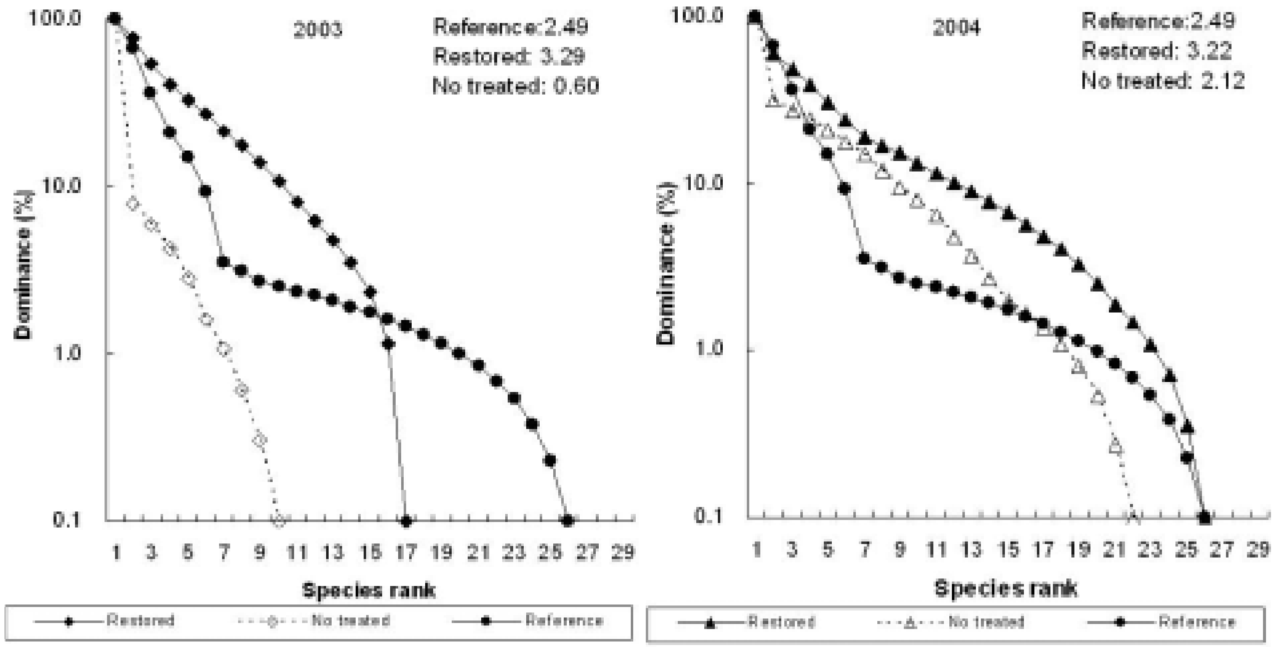

Fig. 6. Comparison of species rank-dominance curves of restored and untreated sites in the first (2003) and the second (2004) years after treatment.

Field experiments using TC demonstrated that treated sites display higher vegetation coverage and species diversity, lower coverage of exotic plants, and more similar species composition to control site than to untreated sites. These results implied re-vegetation efforts relied on soil amelioration by applying TC can be effective in promoting the physical stability and biological integrity of damaged Korean rivers.

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