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RESEARCH

Evaluation of the effects of the river restoration in Hwangji Stream, the upstream reach of the Nakdong River

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Background: In Korea, riparian zones and some floodplains have been converted into agricultural fields and urban areas. However, there are essential for maintaining biodiversity, as they are important ecological spaces. There are also very important spaces for humanity, as they perform various ecosystem services in a changing environment including climate change. Due to the importance of rivers, river restoration projects have been promoted for a long time, but their achievement has been insignificant. Development should be pursued by thoroughly evaluating the success of the restoration project. Ecological restoration is to accelerate succession, a process that a disturbed ecosystem recovers itself, with human assistance. Ecological restoration can be a test bed for testing ecological theories in the field. In this respect, ecological restoration should go beyond a 'simple landscaping exercise' and apply ecological models and theories in restoration practice.
Results: The cross-section of the restored stream is far from natural rivers due to its steep slope and artificial material. The vegetation profiles of the restored streams did not reflect the flooding regime of the river. The species composition of the vegetation in the restored stream showed a significant difference from that of the reference stream, and was also different from that of an unrestored urban stream. Although species richness was high and the proportion of exotic species was low in the restored stream, the effect was offset by the high proportion of gardening and landscaping plants or obligate terrestrial plants.
Conclusions: Based on both the morphological and ecological characteristics of the river, the restoration effect in the restored stream was evaluated to be very low. In order to solve the problems, a systematic adaptive management plan is urgently required. Furthermore, it is necessary to institutionalize the evaluation of restoration effects for the development of river restoration projects in the future.

Keywords: adaptive management, evaluation, Hwangji Stream, restoration effect, river restoration

Introduction

In Korea, most floodplains of rivers were transformed to rice fields in the past, and high banks were constructed along waterways to prevent flooding, because people in the country depend on rice as a food source. Consequently, the widths of most rivers were greatly reduced. More recently, many rice fields were transformed into urban areas, and naturally meandering and complex channels were forced into straight and monotonous lines. In such continuing transformation processes, riparian vegetation has degenerated greatly or been destroyed by tree cutting, the introduction of exotic species, the diversion and channeling of waterways for agriculture, and the use of riverbeds and shores for cultivation or roads. The rapid decline of those valuable ecosystems has made riparian conservation a focal issue in the public eye, but progress to control the decline has been marginal, which is partially because the science of repairing damaged riparian ecosystems is relatively immature (Lee and Woo 2006; Lee and You 2001; Lim et al. 2021; Park et al. 2013).

Ecological restoration is an ecological technology that aims to restore disrupted ecological balance by healing the damage caused to nature and restoring its natural buffering function. One natural process through which a disturbed ecosystem recovers itself is succession. Ecological restoration is to promote succession with human assistance. Therefore, we need to imitate intact natural systems to lead this project to success (Aronson et al. 1993; Gann et al. 2019; McDonald et al. 2016). In fact, ecological restoration is a test bed for testing ecological theories in the field (Bradshaw 1984; Ewel 1987). In these respects, ecological restoration should move beyond a ‘simple landscape exercise’ and apply ecological models and theories to restoration practice (Bradshaw 1987; Lee et al. 2011).

Furthermore, ecological restoration should cope with changing environments such as climate change by preventing disasters caused by it or mitigating it by utilizing the ecological service functions displayed by the restored ecosystem (Greipsson 2011). Moreover, rivers with riparian vegetation can contribute to alleviating climate change (Kim et al. 2008; Lee et al. 2020). In this regard, securing the whole spatial range of the river, which includes the stream and riparian ecosystems, is the most urgent and necessary task for the ecological restoration of the river (Greipsson 2011; Jeong et al. 2011; Lee et al. 2011; Lee et al. 2020).

The process of ecological restoration involves several steps, including diagnostic evaluation, the collection of reference information, the preparation of a restoration plan based on this information, restoration practices, monitoring of the restoration process, analysis of monitoring results, adaptive management based on the findings, and an evaluation of the restoration effect (Gann et al. 2019; McDonald et al. 2016; Society for Ecological Restoration International Science & Policy Working Group 2004). The implementation of restoration is only one starting point, and thoroughly accepting and proceeding with these procedures can lead the restoration project to success and achieve development (Gann et al. 2019; Lim et al. 2021; McDonald et al. 2016). Despite numerous restoration projects, the evaluation of their effectiveness is often neglected (Kondolf et al. 2007; Palmer et al. 2007; Tischew et al. 2010). However, without a comprehensive evaluation of the project, science does not develop. Projects cannot move forward without help from past knowledge of what has been worked on, what has not been worked on, and how these achievements have differed depending on the project (Wilson et al. 2011).

This study aims to assess the ecological effects of river reconstruction executed aimed at improving the overall system functions of the upper reach of the Nakdong River, a waterway that ran under a concrete road surface for a long time, and returning it to a thriving, sustainable ecosystem. To arrive at this goal, we conducted a vegetation survey and compared the results with those from natural reference stream and non-restored urban stream. In addition, we evaluated the naturalness of the reconstructed stream reach based on morphological (e.g., watercourse sinuosity, diversity of watercourse breadth) and ecological (e.g., land use on floodplain, biodiversity) characteristics. Further, this study also has another purpose of preparing improvement measures to induce this reconstructed reach to successful ecological restoration.

Materials and Methods

Site description

The Nakdong River originates from the Neodeol spring of Mt. Cheoneui in Taebaek City and enters the South Sea via the mouth of the Nakdong River in Saha-gu, Busan. However, the origin of the Nakdong River is known to the public as Hwangji Pond, located in Hwangji-dong, Taebaek City. This study was carried out in a tributary section of Hwangji Stream, which starts from Hwangji Pond and joins Hwangji Stream. The reach had been covered for a long time, but was restored through a river restoration project, which is supported by the central government, the Ministry of Environment and practiced by the local governments (Fig. 1).

The reference stream was selected in the upstream section of Nakdong River between Taebaek, Gangwon-do and Bonghwa, Gyeongsangbuk-do (Table 1). This natural reach is located in remote areas which have escaped excessive artificial interferences, and thus retains relatively integrated

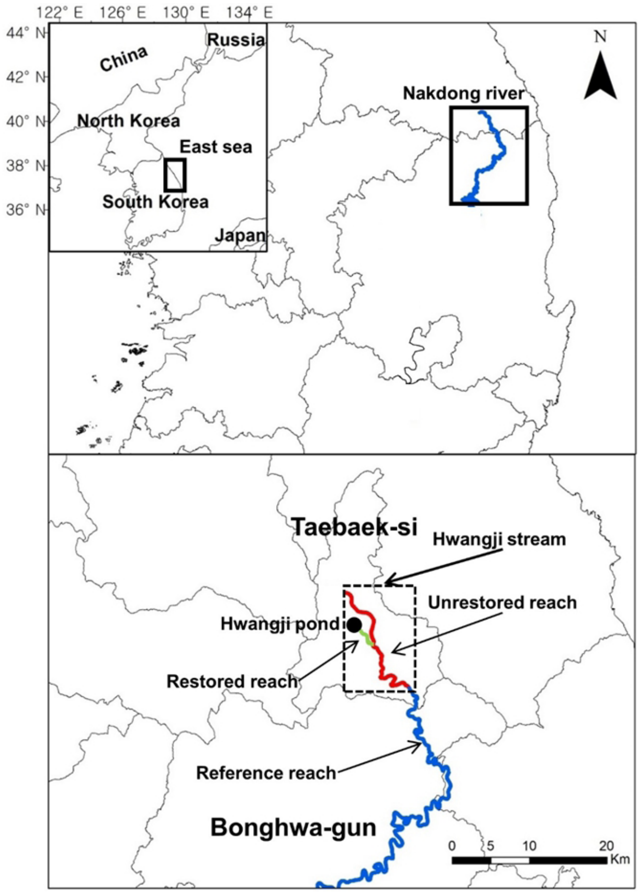

Fig. 1 A map showing the study areas. The restored reach is a tributary, which starts from the Hwangji Pond and joins into the Hwangji Stream. The reference river was selected in the upstream reach of the Nakdong River (blue colored reach), which runs from Taebaek, Gangwon-do to Bonghwa, Gyungsangbuk-do. In addition, the Taebaek City reach of the Hwangji Stream (red colored reach), as an unrestored urban river, was selected for comparing with the restored stream.

Table 1 Geographical position of the reaches in which the riparian vegetation was investigated in three groups selected for study

Reach type	Site no.	Stream	Latitude	Longitude	Stream width (m)
Reference reach	R1	Nakdong River	37° 03' 54.10" N	129° 02' 18.90" E	79
	R2		37° 00' 56.00" N	129° 04' 36.70" E	66
	R3		36° 59' 31.20" N	129° 05' 02.10" E	65
	R4		36° 57' 42.32" N	129° 05' 27.71" E	67
	R5		36° 51' 51.05" N	128° 54' 13.76" E	92
	R6		36° 46' 45.62" N	128° 53' 12.61" E	125
	R7		36° 44' 05.01" N	128° 52' 39.92" E	220
Unrestored reach	U1	Hwangji Stream (main channel)	37° 04' 49.53" N	129° 03' 18.68" E	56
Restored reach	R1	Hwangji Stream (tributary)	37° 10' 21.36" N	128° 59' 26.74" E	7

riparian vegetation, which appears in the order of grassland, shrubby forest, and tree forest, reflecting a flooding regime far from the waterway (Fig. S1). Therefore, it shows high naturalness compared to the other river sections in Korea (Fig. S2). On the other hand, the Taebaek City section of Hwangji Stream was also selected for comparison as the urban stream (Fig. S3).

Naturalness assessment

Naturalness was assessed based on the guidelines for the assessment of naturalness developed by synthesizing the morphological and ecological characteristics of a river (Table S1) (Ministry of Environment 2007). Naturalness was assessed once for one restored river, unrestored urban river, and natural reference river, respectively. We classified the traits of the restoration project into morphological and ecological characteristics of the river and subdivided each trait into five levels: 'very good (5)', 'good (4)', 'medium (3)', 'poor (2)', and 'very poor (1)'.

Vegetation survey

All plant species growing in each plot were identified, following Lee (1985), Park (1995), and the Korea National Arboretum (2018). The vegetation survey was carried out by recording the cover class of plant species appearing in quadrats of 2 × 2 m, 5 × 5 m, and 20 × 20 m size in grassland-, shrub-, and tree-dominated stands, respectively, installed randomly in the riparian zone of each stream reach selected for study (Mueller-Dombois and Ellenberg 1974). Study plots of 7, 10, and 19 were placed in the restored, urban, and reference streams, respectively. Plant cover was recorded applying the Braun-Blanquet (Braun-Blanquet 1964) scale.

Vegetation stratification was prepared by depicting the profile of stand spread in a belt transect of 10 m breadth across the stream reaches selected for survey. Four, three, and seven belt transects were installed to prepare the vegetation stratification diagrams in the restored, urban, and reference streams, respectively. In the vegetation stratification diagrams, the left and the right sides indicate the left and the right banks, respectively.

Reference information of vegetation was prepared by depicting the vegetation profile, including the spatial distribution of the riparian vegetation, and systematizing the information for species composition classified by the riparian zone based on vegetation data collected through field surveys. Reference information was constructed for three riparian zones of grassland, shrub-land, and tree forest by reflecting the flooding disturbance regime, which determines the spatial distribution of vegetation.

Statistical analyses

Ordination analyses were conducted using R (version 4.3.0) software 'vegan' package (Oksanen 2018). For ordination, each ordinal cover scale measured in the field was converted to the median value of percent cover range in each cover class. Relative coverage was determined by dividing the cover fraction of each species by the summed cover of all species in each plot and then multiplying 100 to the value. Relative coverage was regarded as the importance value of each species (Curtis and McIntosh 1951). A matrix of importance values for all species in all plots was constructed and it was subjected to Detrended Correspondence Analysis for ordination (Hill 1979). A similarity between communities was analyzed using the analysis of similarity (ANOSIM) test ($\alpha = 0.001$) (Clarke 1993).

We constructed rank–abundance curves following Magurran (2003) and Kent (2012), and calculated species diversity (H') following Shannon (1948).

One-way analysis of variance (ANOVA) was used to compare the difference in the percentage of the exotic plants among the plant communities: different ($\alpha = 0.05$). The difference in values among the sites was tested using Scheffe's test.

Results

Cross section of the stream

The cross section of the restored Hwangji Stream tributary is far from natural rivers due to its steep slope. The material of the waterfront is made up of materials that are very strong and struggle to accommodate changes caused by water flow. This cross-sectional structure of the stream was reflected in the results of the naturalness degree evaluation, and the naturalness degree based on the morphology of the stream was evaluated to be very low (Fig. S2 and Table 2).

Naturalness degree

With a naturalness scale ranging from 1 to 5, with 5 being the most natural, the naturalness degrees of the restored Hwangji Stream tributary based on the sinuosity of the watercourse, the number of sandbars, the diversity of flow, river profile, diversity of the water course breadth, naturalness of the waterfront protection material, artificial degree of bank, land use within the bank, floodplain use, transverse artificial facilities, and vegetation profile bank were recorded as 1, the lowest degree in all items (Table 2).

On the other hand, the naturalness degree of the unrestored urban stream varied from 1 to 4 and therefore showed rather higher naturalness than the restored Hwangji Stream (Table 2). The naturalness degree of the natural reference river was recorded as 4 or 5 in all items (Table 2).

Vegetation profile

The spatial extent of the restored Hwangji Stream tributary is defined by stacking stones instead of concrete walls (Fig. S4). Compared to the concrete walls, it is also possible to observe positive aspects such as gentle slopes and small gaps in these river sections, but still focusing on civil engineering rather than ecological restoration. The introduced vegetation is not only far from river vegetation, but also exotic species are introduced, which are also far from ecological restoration. The embankment was constructed by stacking stones from the bottom to the top, and *Lolium perenne*, *Sedum kamtschaticum*, *Thymus quinquecostatus*, *Hosta longipes,* and *Dianthus deltoides* were planted. *Pinus densiflora*, *Chionanthus retusus*, *Zelkova serrata*, etc., were planted like street trees next to the sidewalk on the top of the embankment. Except for *H. longipes* and *Z. serrata*, species that did not match the riparian zone were introduced (Fig. 2 and Fig. S4).

A willow tree was introduced at the center of the channel island and a variety of *Phragmites japonica*, *Potentilla fruticosa*, *D. deltoides*, *Hemerocallis fulva*, *Iris pseudacorus*, *Zoysia japonica*, *Rhododendron yedoense* for. *poukhanense*, *Euonymus japonicus*, and *P. densiflora* for. *multicaulis* were introduced on the slope of the channel island. Except for *P. japonica*, these were also species that did not fit at all with the riparian zone. But even *P. japonica* is a variety (Fig. 2 and Fig. S1).

Depending on the location, there are sections where *Prunella vulgaris* var. *lilacina*, *Poa* spp., *Festuca* spp., *Mukdenia rossii*, *Stachys japonica*, *Liriope platyphylla*, *Buxus koreana*, *Fraxinus sieboldiana*, etc., were introduced on the slope of the embankment, and there were sections where *Taxus cuspidata*, *Z. serrata*, *Acer palmatum*, *Quercus rubra*, etc., were introduced on the top of the embankment (Fig. 2 and Fig. S3).

Exotic species and species which do not match the riparian zone make up most of the plants introduced.

The Taebaek City reach of the Hwangji Stream, which was not treated as a restoration project, is a typical urban stream in Korea, and the spatial range of the river is limited by concrete walls (Fig. S3). However, vegetation established in the waterway reflect the natural disturbance regime caused by the flow of water. The spatial distribution of vegetation reflects the frequency and intensity of floods, and thus grasslands dominated by *Phalaris arundinacea* and *P. japonica* were established near the waterway, and as the distance from the waterway becomes farther away, shrubby willow including *Salix integra* dominating vegetation and *Salix koreensis* dominating vegetation appeared continuously (Fig. 2).

Stand profiles of riparian vegetation collected from seven upstream reaches of the Nakdong River, where the riparian vegetation is well conserved, are shown in Figure 2. Riparian vegetation appeared in the order of grassland, shrubland, and tree forest, as far away the distance from the waterway, and thus tended to reflect the flooding disturbance regime. The *P. japonica* community and mixed community of *P. japonica* and *Salix gracilistyla* dominated the grassland zone. The shrub zone was dominated by *S. gracilisty-*

Table 2 The naturalness degrees of restored, unrestored, and reference reaches in the Nakdong River

Metric	Restored reach	Unrestored reach	Reference reach
Sinuosity of watercourse	Very poor	Very poor	Very good
The number of sandbars	Very poor	Medium	Very good
Diversity of flow	Very poor	Medium	Very good
Naturalness of profile	Very poor	Very poor	Good
Diversity of water course along the cross section	Very poor	Poor	Good
Artificial degree of low-flow levee	Very poor	Good	Very good
Artificial degree of high-flow levee	Very poor	Very poor	Good
Land use within banks	Very poor	Very poor	Good
Land use outside banks	Very poor	Good	Good
Transverse artificial facilities	Very poor	Good	Good
Vegetation stratification	Very poor	Good	Very good

5: very good, 4: good, 3: medium, 2: poor, and 1: very poor.

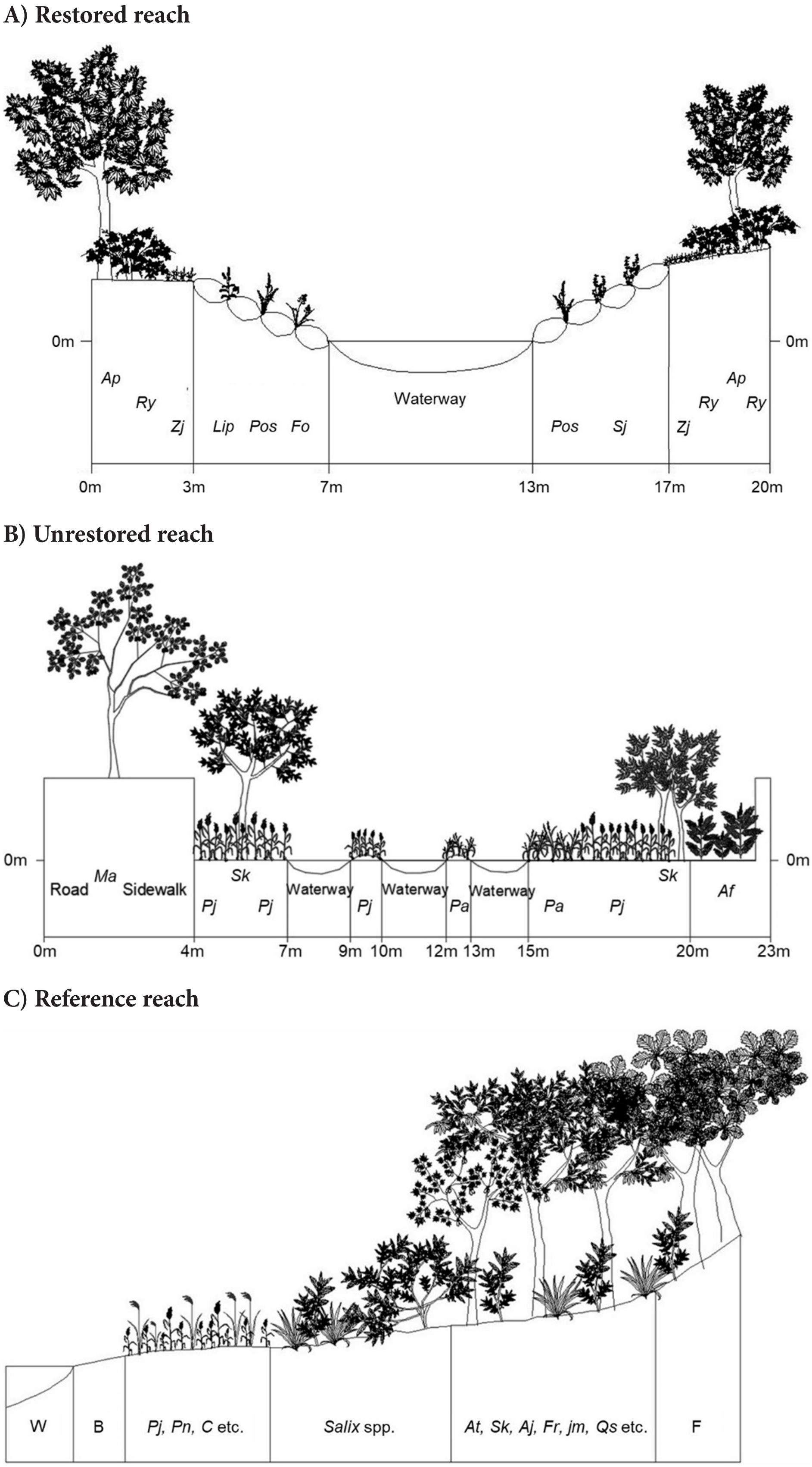

Fig. 2 A comparison of the representative stand profiles of riparian vegetation in the restored, unrestored, and reference natural reaches of the Nakdong River. Ap: *Acer palmatum*; Ry: *Rhododendron yedoense* for. *Poukhanense*; Zj: *Zoysia japonica*; Lip: *Liriope platyphylla*; Pos: *Poa sphondylodes*; Fo: *Festuca ovina*; Sj: *Stachys japonica*; Ma: *Morus alba*; Pj: *Phragmites japonica*; Sk: *Salix koreensis*; Pa: *Phalaris arundinacea*; Af: *Amorpha fruticose*; W: waterway; B: bare ground; Pn: *Persicaria nodosa*; C: *Carex* spp.; At: *Acer tataricum* subsp. *Ginnala*; Aj: *Alnus japonica*; Fr: *Fraxinus rhynchophylla*; Jm: *Juglans mandshurica*; Qs: *Quercus serrata*; F: upland forest.

la, *Carex dimorpholepis*, *Acer tataricum* subsp. *ginnala*, etc., and *S. koreensis*, *A. tataricum* subsp. *ginnala*, *Juglans mandshurica*, *Fraxinus rhynchophylla*, etc., dominated the tree forest zone (Fig. 2).

The reference information systematized by synthesizing the above-mentioned results was expressed as a stand profile including waterway, bare ground, grassland, shrub, tree forest, and upland forest zones (Fig. 2). We recommended *P.*

japonica, *Persicaria nodosa*, *C. dimorpholepis*, etc., as the candidate plant species to create a grassland zone based on vegetation data collected through a field survey. *Salix* spp. including *S. gracilistyla*, *S. integra*, etc., and *S. koreensis*, *A. tataricum* subsp. *ginnala*, *J. mandshurica*, *F. rhynchophylla*, *Alnus japonica*, etc., were suggested as the reference information to establish the shrub-land and tree forest zones, respectively.

Species composition of riparian vegetation

As the result of stand ordination based on the vegetation data obtained from the restored reaches, existing urban reaches (unrestored reach), and natural reference reaches, the restored reaches were arranged in the right part, while the existing urban reaches and natural reference reaches were arranged in the left part on Axis I. On the other hand, the existing urban reaches and natural reference reaches were divided into the lower and upper parts, respectively, on Axis ll. But some stands of the existing urban reaches were located close to some stands of the natural reference reaches, and thereby showed a similarity in species composition (Fig. 3).

Species diversity

The species richness of the restored reach was higher compared with those of the natural reference and the unrestored urban rivers (Fig. 4). The diversity index also reflects the result (Fig. 4).

Exotic species

The percentage of the exotic species in the restored reaches was lower than those in the natural reference and the unrestored urban rivers (Table 3). But the percentage of landscaping and garden plants was significantly higher compared to the two other sections (Table 3).

Habitat types

The percentage of the terrestrial plants in the restored reaches was significantly higher compared to the other two sections, while the proportion of the amphibious plants was the reverse (Table 3). On the other hand, the wetland plants did not show any significant difference among the reaches.

Discussion

Evaluation of restoration effects

The trajectory of a restoration project may be viewed in terms of ecosystem structure and function (Hobbs and Cramer 2008; Lake et al. 2007), both of which are impacted greatly by degradation. The fundamental goal of restoration is to return a particular habitat or ecosystem to a condition close to its pre-degraded state. Complete restoration would involve a return to that state, while a partial return, or other trajectories, would result in rehabilitation or replacement with a different system (Aronson et al. 1993; Bradshaw 1984, 1987; Lee et al. 2020; McDonald et al. 2016; Society for Ecological Restoration International

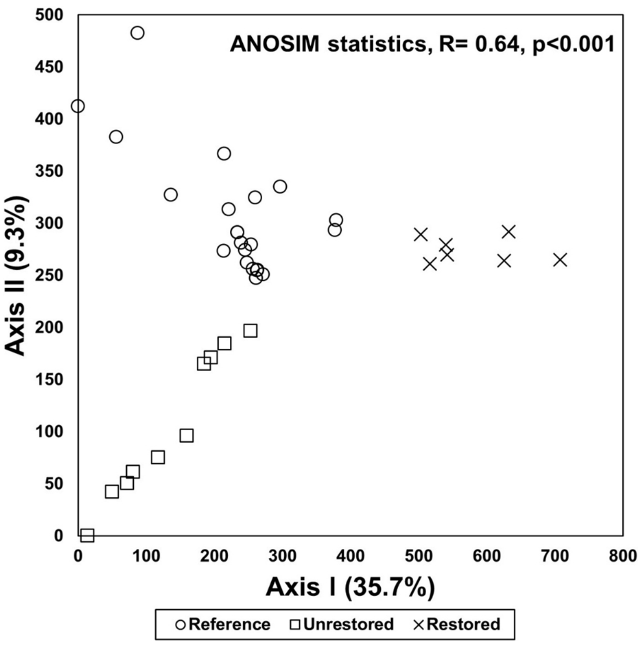

Fig. 3 Detrended Correspondence Analysis ordination of stands based on vegetation data collected from the restored, natural reference, and urban reference streams.

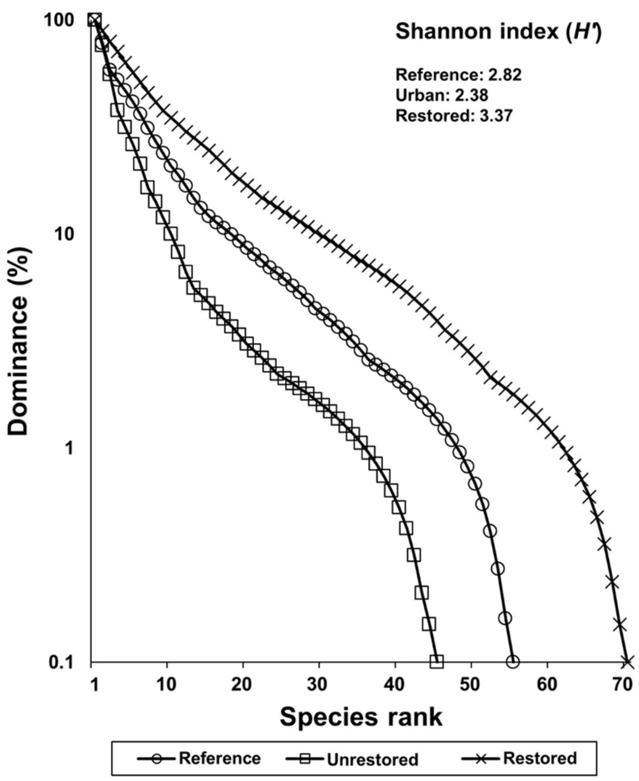

Fig. 4 A comparison of species rank–dominance curves of vegetation among the restored, unrestored, and natural reference streams. Reference: natural reference river; Urban: urban reference river; Restored: restored river.

Table 3 Comparison of the percentages of alien, garden, terrestrial, amphibious and wetland plants in the restored, unrestored and reference reaches in the Nakdong River

Floristic characteristics	Restored reach	Unrestored reach	Reference
Origin of plants			
Alien species	5.1^{a} (1.7)	25.6^{b} (2.3)	16.4^{c} (2.4)
Garden species	26.7^{a} (4.0)	1.2^{b} (0.8)	0.0^{b} (0.0)
Habitat types			
Terrestrial	79.1^{a} (4.1)	56.1^{b} (4.7)	59.7^{b} (4.6)
Amphibious	2.2^{a} (1.1)	10.8^{b} (1.5)	13.9^{b} (2.3)
Wetland	18.6 (4.2)	33.1 (3.9)	26.5 (3.4)
Total species number	70	54	75

Numerals in parenthesis are standard error.
Different letters denote the significant difference among the reaches ($p < 0.05$).

Science & Policy Working Group 2004).

To effectively restore degraded areas, or to protect existing high-quality areas, we must be able to define the attributes of "normal", undegraded (or "healthy") habitats as a model (Lee et al. 2020; Lüderitz et al. 2004; McDonald et al. 2016; Society for Ecological Restoration International Science & Policy Working Group 2004). One way of setting a baseline from which to measure 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; Lee et al. 2008b).

To evaluate a stream, the ecological attributes of the stream are compared with those from an "undisturbed" reference (Gilvear and Bryant 2016; Rood et al. 2003; White and Walker 1997; Whittier et al. 2007). In the present study, we compared the species composition and biodiversity of the restored reach stream with the natural reference and unrestored urban rivers.

The species composition of the restored reach showed a significant difference from that of the reference river (Fig. 4). Moreover, the difference was bigger than that between the unrestored urban river and the reference river (Fig. 4). The reason for this problem is that the reference information the most important in ecological restoration was not applied like most river restoration projects conducted in Korea (An et al. 2022; Lee et al. 2020).

The species diversity of the restored reach was higher than that of the unrestored urban stream and even higher than that of the natural reference river (Fig. 4). However, many gardening plants, as well as exotic plants, were included among the plant species, which were introduced in the restored section (Table 3). In addition, a comparison of the habitat types of plant species appearing, including introduced plants, revealed that the terrestrial plants occupied a high percentage compared to the unrestored and natural reference rivers (Table 3).

Based on these results, the project can be evaluated as an artificial park construction project that includes waterways rather than a river restoration project. Results were produced that did not fit the original purpose of the river restoration project. However, a very large amount of money was invested in this project. Moreover, similar projects are being carried out nationwide every year, wasting a lot of money and energy. An overall review and revision for the current river restoration project are urgently required.

Recommendations for the improvement of the current river restoration project

The riverine landscape is comprised of stream and riparian ecosystems. When water flows in stream ecosystems go over the channel bank, riparian ecosystems are formed (Gary et al. 2008; Goodwin et al. 1997). A riparian ecosystem is the ecotone between aquatic and terrestrial ecosystems. A riparian ecosystem consists of several fluvial surfaces, including Channel islands and bars, channel banks, floodplains, and lower terraces (Goodwin et al. 1997). Riparian ecosystems are divided depending on flooding regime (Goodwin et al. 1997). One zone, which is frequently inundated, is subjected to current-day fluvial geomorphic processes, and is at elevation that allows shallow-rooted plants to extract water from the water table. The other zone, which is far from the waterfront, is thus inundated less frequently. This zone was formed by past fluvial geomorphic processes, was higher in elevation, and contained vegetation which was dominated by deeply rooted plants capable of extracting water from the underlying alluvial aquifer (Goodwin et al. 1997).

However, in most Korean rivers, the spatial range of those riparian ecosystems has been narrowed greatly due to excessive land uses, including the development of rice fields and urbanization in the riparian ecosystem. Therefore, it is very difficult to find a stream with a complete structure (Lim et al. 2021). However, the so-called remote stream, which is far from the city and is less influenced by humans, such as the upstream reaches of the Nakdong

River, has a relatively intact system of streams, as was shown in Figures S1 and S2. In the upcoming of river restoration projects, information collected through the systematic study on rivers with a near-natural appearance should be organized and carried out using it as reference information.

Importance of the reference information

Ecological restoration is an ecological technology that seeks to provide habitats for various living things and secure the future environment of mankind by curing the nature that humans have damaged by imitating the system and function of the integrated nature (Aronson et al. 1993; Berger 1993; McDonald et al. 2016; National Research Council 1991; Society for Ecological Restoration International Science & Policy Working Group 2004). It goes beyond the stage of clarifying its substance by exploring an object. It is a treatment as well as an operation for the natural environment, in which the damaged nature is returned to an intact state through treatment based on knowledge and information on the nature obtained through a study, as a doctor operates on and treats a patient. Therefore, the diagnostic evaluation that assesses the damage degree and the reference information that is a guide to healing are key information in ecological restoration. In particular, reference information becomes the goal of restoration in the process of establishing a restoration plan, and after restoration practice, it becomes a tool to assess its success or failure (An et al. 2014; Lee 2016; McDonald et al. 2016; Society for Ecological Restoration International Science & Policy Working Group 2004).

The reference information is usually obtained from an ecosystem (or landscape) that retains its intact appearance among ecosystems (or landscapes) located close to the restoration site (Doll et al. 2003). Reference information should capture the natural complexity of the landscape so that ecosystems can better withstand degradation in present and future conditions (Halme et al. 2013). Furthermore, restoration efforts may be more effective if the spatial range is expanded to include the surrounding environment, occupied mainly by floodplains, weirs, and the surrounding areas (Beechie et al. 2010; Frissell and Ralph 1998; Lim et al. 2021).

Since the late 1990s, the term river restoration has been used in Korea, and various river restoration projects have been under way in the river management departments such as local governments and several central governments. Since the Cheonggyecheon Restoration Project, implemented in 2005, many local governments and central government agencies in Korea have been competing to carry out river restoration projects, but such projects do not follow systematic ecological restoration procedures and methods. Therefore, they have invested a lot of money and energy but have not achieved the results of ecological restoration (An et al. 2014).

Ecological restoration means copying nature by studying a system of the integrated nature. We have to grasp the features of integrated nature to heal the disturbed nature. The reference information collected from places with a complete natural appearance contains such features. Ecological restoration could be implemented in accordance with a restoration plan established on the basis of such reference information. However, in the restoration project practiced in Korea, the reference information, which is the goal of the restoration plan and a yardstick for evaluating the restoration effect, is rarely utilized, and the restoration is carried out by the subjective judgment of the operator. In other words, restoration projects without goals or models are being carried out. Therefore, exotic species that should be completely excluded from restoration projects are often introduced, and it is common for introduced species to be placed outside the ecological distribution or outside of suitable micro-habitats that can perform greater ecological functions. Therefore, the quality of nature is not improving even if the restoration project continues (An et al. 2014; Lee 2016; Lee et al. 2008a; Lim et al. 2021). In order to achieve the development of restoration projects by solving these problems, and furthermore to achieve the improvement of the environment, the principle of restoration must be established. It is necessary to establish a system of examination for restoration plans and evaluation on restoration effects by law (An et al. 2014). First of all, the restoration plan should be evaluated to select the restoration project operator. Furthermore, in order to complete the restoration project, the restoration effect should also be assessed. At this time, the reference information can be a tool for evaluating the level of restoration plans and a standard for evaluating the completeness of restoration projects.

Meanwhile, most river restoration projects that have been practiced in Korea to date have been concentrated on the waterfront, rather than the floodplain or other riparian zones beyond. In addition, plant species introduced for restoration include many plants that grow in a lentic system rather than a lotic one.

The results are due to an absence of reference information. Rivers in Korea flood during the monsoon season every year. Moreover, the frequency and intensity of extreme weather events are forecasted to be increased in relation to climate change in the future (Lee et al. 2011). In this respect, a true restoration of rivers based on reference information, which could prepare for meteorological disasters due to climate change, which are expected to become more frequent, are urgently required (Easterling et al. 2000; Lee et al. 2011; Lim et al. 2021; Seavy et al. 2009). Moreover, restoration effects could be larger if the spatial range is expanded to include the surrounding environment, occupied mainly by floodplains, weirs, and the surrounding areas

(Beechie et al. 2010; Frissell and Ralph 1998; Lee et al. 2020), and if plant species to be introduced are selected properly based on the reference information.

Conclusions

The restored Hwangji Stream tributary was evaluated with low naturalness in terms of both the morphology of the stream and the composition and spatial distribution of vegetation. The diverse functional groups were introduced for the vegetation restoration, but the flooding regime, which is significant in the spatial distribution of riparian vegetation, was not correctly reflected. Exotic or gardening plant species that were not ecologically suitable for the location were introduced, and thus a measure to improve these problems is required. As the ecological principle was not reflected in the restoration plan, the stream was constructed as a steep slope structure. The waterfront was not designed to accommodate changes from flooding disturbance, making the micro-topography of the stream simpler and the naturalness lower. Overall, this project can be evaluated as an artificial park construction project that includes waterways rather than a river restoration project. In this respect, the active adaptive management plan seems to be needed to improve those problems. As an improvement measure, first of all, we have to grasp the features of the integrated river to heal the disturbed river. For example, we have to prepare and systematize reference information by studying a system of the integrate river to realize ecological restoration. Second, an examination system for the qualification of restoration project operators should be intensified and the restoration plan should be evaluated to select competent restoration project operators. Finally, the restoration effect should be assessed as a part of the restoration project. When these institutional devices are supported the level of ecological restoration could be improved in Korea.

Supplementary Information

Supplementary information accompanies this paper at https://doi.org/10.5141/jee.23.085.

Table S1. Criteria for evaluating the naturalness based on morphological and ecological characteristics of the river in South Korea (Ministry of Environment 2007). **Fig. S1**. An appearance of the reference reach in the upper Nakdong River. **Fig. S2**. Maps showing the naturalness grade of the upstream reach of the Nakdong River, selected as the natural reference reach (right), compared to the other river sections in Korea (left). **Fig. S3**. An appearance of the unrestored reach with in Taebaek City in the Hwangji Stream of the upper Nakdong River. **Fig. S4**. An appearance of the restored reach near Hwangji pond in the Hwangji Stream of the upper Nakdong River.

Abbreviations
Not applicable.

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Authors' contributions
CSL designed the study. CSL, BSL, and JWS collected and analyzed the data. BSL and CSL wrote the initial draft of the manuscript. All authors read and approved the final manuscript.

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