〈 **Review** 〉

Application of Landscape Ecology to Ecological Restoration

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ABSTRACT : To date, restoration ecology has focused on local areas, particularly small-scale ecosystems. As such, restoration ecology has been applied to areas with clear boundaries, such as roads, abandoned mines, wetlands, and forest ecosystems. However, those involved in these restoration efforts, due to their tendency to implement comprehensive plans to change the landscape structure, and their mismanagement of the restoration process, have more often than not wound up weakening the ecological functions of surrounding ecosystems, and in further degrading the ecosystem which they were trying to restore. To resolve these problems and restore a comparatively large-scale region, methods to assess the impact of such restoration efforts on surrounding ecosystems must be developed. These include expanding the scale of restoration efforts; in other words, moving from the local to the landscape scale. As a conclusion, practice of ecological restoration is increasingly moving towards landscape scale in order to deal with these problems.

Key words : Ecological restoration, Ecosystem management, Global changes, Landscape ecology, Long-term ecological research, Restoration ecology

INTRODUCTION

The Necessity and Objectives of Ecological Restoration

It has been urgent issues to preserve natural environment, which human activities are not influenced. However, in the reality it is not easy to find such natural environment. It is very difficult to restore the degraded natural environment to the original state. Nevertheless, as the ecosystem conservation and maintenance of biological resources are closely related to the future human life quality, it is impossible to estimate the value of restoration and remediation of the degraded nature, only depending on the economic efficiency (Harker *et al*. 1999).

Wildlife and ecosystem have a resiliency to restore the damages at some degree (Jordan *et al*. 1987, Bradshaw 2000, Choung *et al*. 2004). In the case of the secondary forest or farming land after the clearance of forests cutting, if human activities are not interfered anymore, ecological succession to gradually restore the biota is carried out. Although there are no original forests which never been interfered from human in the Central and Southern Europe, Germany and Poland have great forests that can be regarded as original forests in many areas of their countries. These forests are the results of restoration of the forest ecosystem, which was reduced by clearing forests in the past. As such, the largely restored forest, if they have ecological functions, will go back to the forest state which is close to the potential vegetation by the ecological processes.

Meanwhile, it has become important to protect and restore wildlife at species level (Harris 1984). For example, buffalo which was the symbolic animal of the great prairies in North America had high possibility of extinction due to the merciless hunting at the beginning of the 20th century. However, due to the aggressive protection of the population, the number of buffalos has been increased to tens of thousands. However, the protection efforts at species level or positive restoration efforts have regarded as the incomplete restoration if this was not connected to the conservation of habitat matrix of the species. By protecting the prairie, which was the habitat of buffalos, the restoration of buffalos and habitat matrix has been successfully achieved (Turner *et al*. 2001). As a species influences the overall ecosystem, the importance of the protection of species has been increased.

What measures should be taken to preserve the nature that was not interfered by human activities yet and to restore the degraded

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ecosystem? Of course, it would be an important method to thoroughly manage the relevant area by designating as the natural protection area and national parks. However, it might be challenged to the opposition of the residents who have desire of the development which is related to the economic profits of the area. In this case, it is necessary to persuade the resident to cooperate for the ecological management, emphasizing the importance of biodiversity and suggesting the qualitative life of the environmentally advanced countries. In the case of the development, the efforts should be brought to minimize the damage of ecosystem based on the ecological knowledge (Whisenant 1999, Urbanska *et al*. 2000, Choung *et al*. 2004). For the area that is necessary to restore, the principles and methods to introduce the ecological restoration should be selected to rehabilitate as soon as possible.

Necessity of The Long-Term Ecological Research Data and The Interdisciplinary Cooperation

The term of 'sustainable development' has been recently used a lot. This term was used at the IUCN in 1980, which implies the economic development in the viewpoint of natural environment protection or the ecosystem conservation oriented social development. As such, as it was introduced to be compatible with the ecosystem conservation and economic development, it has not been clearly defined about which directions are right (Urbanska *et al*. 2000). For the future global environment, there have been suggested the opinions based on the optimism and pessimism. However, considering the future ecosystem and environment, it is very important to establish the new concept of nature conservation. For example, it is necessary for scholars, researchers, politicians, and development planners to share the ecological concepts, which are based on that we should not pass over the degraded nature and desolated urban environment to our descendants, and to establish the national policy for the nature conservation (Throop 2000).

The 21st century is stated as the second era of ecology, or the era of global environment and ecosystem. Under the assumption that local problems of environmental pollutions such as the water pollution and air pollution emerged from the economic development during the 20th century have been somewhat solved, countries have focused on creating the new paradigm in the environmental policies. The advanced countries are oriented to establish the 'integrated management system for the nature-human-society networks', which the nature and human can coexist. Human activities which have affected the nature have been globally carried out (Hong *et al*. 2004a).

The restoration period of the degraded area might be taken from several decades to hundreds of years. However, as the earth has provided various resources and energies which are necessary for the survival of human beings, it is necessary to provide sustainable management of global environment. In order to assure the biological resources and energies, countries have carried out invisible wars. At this point, the concept and principles to provide solutions of the paradigm of new environmental policy should be originated from ecology. 'Ecology' was started as the basic research field to study the correlations between the wildlife and their habitat's environment. It has been global trends to study the ecology, extending the synthetic field, which studies of the structure, functions, dynamics of human, environment and society (National Institute of Environmental Research 2003, Ministry of Environment 2004). 'Ecosystem' is the production resources and lump of energies. All the biotic and abiotic factors are connected each other like by the food web and energy flow. Through the various paths to the final consumer, which is the human, the ecological system provides lives to many creatures. The global-scale environmental changes impact the structure and functions of local ecosystem through various paths and the results of the impacts are feedback to human. Therefore, it is necessary to develop preliminary tools to predict and analyze the cause and effects of the problems that might occur during the complicated ecological processes (Fig. 1). The current studies of ecology have been carried out in research institutes, universities, and environmental organizations. However, there have been difficulties to share the study results, materials and information. The advanced countries such as the North America, England, Japan, and Germany have monitored their major ecosystems for several decades. These countries have strived to establish the integrated ecological management system based on the interdisciplinary studies, in order to study of the effective usage of biological resources and energies as well as the management of ecological system in the socioeconomic viewpoints.

Various ecological monitoring and integrated management by researchers have been already carried out in the advanced countries. The accumulation of the basic ecology data at national level will provide the environment-ecosystem-geographical information to restore the ecosystem in the future. In addition, it is necessary to monitor the changes of the ecosystem after the restoration (Ministry of Environment 2004).

The various ecological systems in Korea such as the forest ecosystem, coastal ecosystem, freshwater ecosystem, urban ecosystem, and rural ecosystem are linked to more than one heterogeneous ecosystem, not existing as solely (Hong *et al*. 2004a). The natural environmental and socio-cultural conditions as well as the human activities in the past and present have been spatially emerged crossing all over the ecosystems. The successful environmental policies in the 21st century will be depended on the research fields which have the characteristics of 'integrated ecology'. The integrated ecology contains to analyze and interpret the changes of ecological

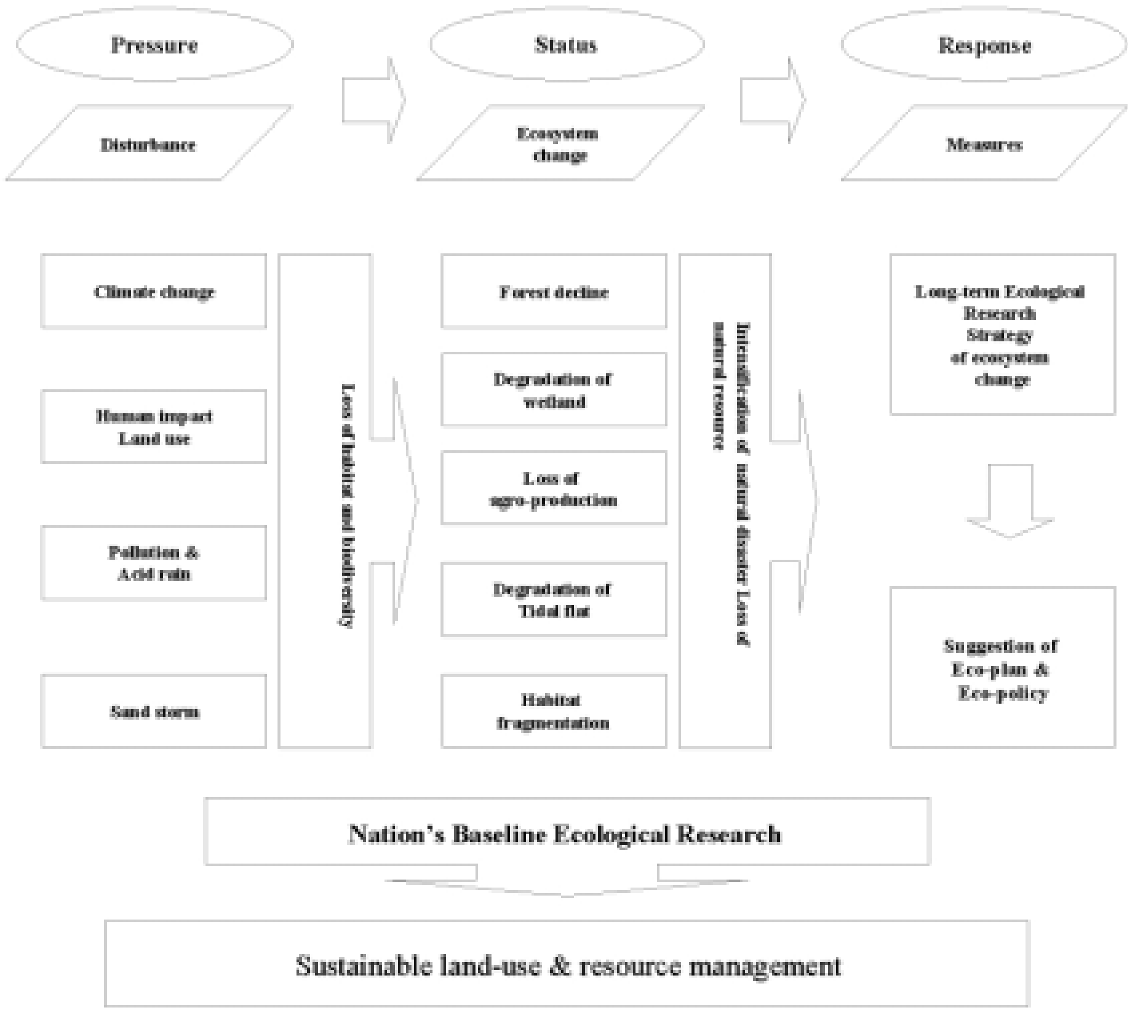

Fig. 1. Conceptual diagram illustrating the impact of global environmental changes to the ecological system (Ministry of Environment 2004).

systems based on the synthetic ecological points, not the particular ecological point or system, in addition to the provision of the sustainable and quantitative ecological monitoring data.

In this meaning, the 'Long-Term Ecological Research Project' within the 'Nation's Baseline Ecological Research Project' by the Ecological Society of Korea is a long-term based monitoring project of the same spot for dozens of years in the future (i.e., Ministry of Environment 2004). As the global environmental changes, which impact to change of ecosystem, have been spatially extended, it is necessary to develop the spatial research methods to understand these processes. At this point, the 'global ecology' and 'landscape ecology and planning' are regarded as the main field to provide technological methods, which contribute to spatially extend the long term monitoring and scale of the research. The direction of environmental policies by country has been rapidly progressed. As we mentioned in the above, the environmental policies of the advanced countries to assure and maintain the biological resources are based on the comprehensively integrated management, covering the species/population level to the ecosystem, landscape, and global scales. Furthermore, 'the restoration ecology and technology', which assess, evaluates, and restores the degraded ecosystem using the temporal and spatial monitoring and analysis methods, has been paid attentions as the advanced practical field to realize the principles of ecology. The overall environmental engineering such as the civil engineering, urban engineering, transportation engineering, water quality engineering, atmosphere engineering, and architecture engineering have been cooperated with the ecology related field to study of the ecological systems including the forests, freshwater, coasts, cities, and rural areas. This cooperative study contributed to develop the ecological restoration as a new field of 'interdisciplinary integrated ecology studies' (Hong *et al*. 2004a).

Concept of Ecological Restoration: Spatial Consideration

Generally considering, restoration measurements are dependent on the species, population, habitat, ecosystem, water quality, and soil. However, the ecosystem level restoration, which is based on the interaction between the physiotope and biotope environments, should consider the time for the degraded ecosystem to recover its original ecological processes as well as the simple restoration to the original state (Whisenant 1999, Bradshaw 2000, Webb 2000). All of these restoration measurements are possibly carried out, by transforming the structural and functional characteristics of ecosystem (Harker *et al*. 1999)

According to Hobbs and Norton (1996), 'restoration' is a broad of activities to recover the degraded system. Therefore, ecological restoration can be carried out: i) Restore the disturbed area as a minor area like mines. In this case, the restoration should be carried out, by manipulating the physical and chemical characteristics and rehabilitating the vegetation. ii) Improve the characteristics of land quality to have more productivity. The decline of the function of land is a global trend, and has caused to reduce the productivity of agriculture, pastures, and forests. In this case, the restoration should be aimed to recover the land use system, which has sustainable productivity. iii) Improve the values of nature conservation on the protected landscape areas. The majority of the preserved areas are affected from the disturbance (livestock, alien species, pollution, and fragmentation), which were directly caused from human activities. In this case, the restoration should be focused on eliminating the causes of the disturbance. iv) Recover the ecological processes in the landscape- and regional-scale. It is necessary to limit human activities in the landscape scale, which impacts the ecological processes, not only to make efforts to restore the protected area. As the protected area is connected to the ecological process of landscape scale and mass flow (hydrologic runoff, biological migration, genetic flow), it is difficult to preserve only the conservation area. Therefore, if necessary, integrated measures with the preservation and usage are required (e.g., core-buffer-matrix model).

The development of environment-friendly engineering technologies and introduction of ecological principles are differently applied depending on the characteristics, goal, and objectives of restoration for the relevant area. The characteristics of restoration ecology include the existing environmental management, restoration of the degraded ecosystem, and aggressive activities to newly introduce the ecosystem if necessary (Aanen *et al*. 1991). In this point, the ecological restoration, which has recently discussed in Europe, suggest the useful methods to achieve the temporal and spatial stability and soundness of habitats such as the interaction of biological communities, as well as the creation, restoration, development, and preservation of ecosystem (Fig. 2). Three concepts are introduced in the ecological restoration:

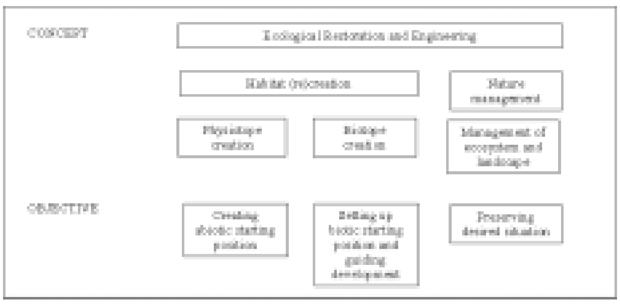

Fig. 2. The concepts and objectives of ecological restoration. The concepts of restoration include the direction of the related research and projects within ecology and engineering.

1) Physiotope creation is a method to create the development of ecological community and natural processes, by changing the abiotic elements.

2) Biotope creation is a measurement to assure the space for the introduction of new species, by providing the appropriate disturbance during the developmental process of ecological community.

3) Created habitats need to enforce the appropriate management, according to the habitat developmental process.

The ecological management should be differently applied, depending on the core habitat, buffer, networking, ecotone, landscape quality. As such, it can regard as the application of landscape ecological research, considering the spatial structure and function of habitat and ecosystem (Hansen and di Castri 1992, Forman and Collinge 1996, Hobbs 1999, Whisenant 1999, Hobbs 2002, Forman *et al*. 2003).

METHODOLOGY

Applying Landscape Ecology to Restoration Ecology

Landscapes are composed of land mosaics which have spatio-temporally emerged as a result of the interactions of human and natural environments. These land mosaics are subject to the patchiness and fragmentation processes which are in turn caused by the physical environment, natural disturbances, and human activities (Forman 1995, Turner *et al*. 2001). As a result, the landscape configuration as well as the ecological characteristics of these land mosaics can be altered. Meanwhile, the landscape structure is caused by the characteristics of an independent patch and its spatial interaction with other patches, while the landscape function is decided by physical and chemical flows, and the biological transportation that occurs between patches. Landscape changes stem from changes in independent patches or from changes in their configuration or interaction with each other. These three basic principles of landscape ecology are closely connected to each other (Hong *et al*. 2000, Lee 2001, Lee *et al*. 2004).

Given the impact that human activities have on the natural environment, which has included the degradation of natural ecosystems and changes in biodiversity, studies related to human activities causing natural disturbances have been carried out on such topics as temporal and spatial changes in landscapes, landscape heterogeneity, and landscape restoration.

A spatial patterns, heterogeneity, and diversity of landscape are a reflection of the natural phenomena, disturbances and human activities which take place within that particular region. In addition, within spatially heterogeneous landscapes wildlife and plants live alongside each other in their own habitats. Therefore, the structural diversity of landscapes is closely related to the diversity of species and habitats as territory.

However, when the spatial configuration of landscape structure is ignored, the possibility of uncertain disturbances caused by such factors as forest fires and irrational human activities increases tremendously. This oversight has already resulted in the advent of many environment problems such as the isolation and loss of habitats, as well as the destruction of ecosystems.

Landscapes are influenced by cultural factors such as human socioeconomic activities, as well as by time. Consequently, unique landscape patterns and changes have a profound effect on the existing landscape. To understand the spatial patterns and ecological processes (changes) which occur within a landscape, especially within those which have been affected by human activities, sociocultural factors, such as land use and demographic changes in the region, should be analyzed along with the landscape structure (Hong *et al*. 2000). A change of landscape heterogeneity is a complicated and diverse phenomenon which involves such factors as size and shape of landscape elements, configuration of landscape patches, and spatial interaction of them. The changes of landscape heterogeneity was investigated by two levels: i) changes of landscape heterogeneity among the ecosystems found in a particular region, ii) changes of heterogeneity of the landscape elements found within a single landscape. Several landscape indices have already been developed to assess changes of landscape heterogeneity. The assessment of landscape heterogeneity should be accompanied by a measurement of the structural changes that have taken place, as well as by the collection of data on the number, size, and configuration of the patches which make up the landscape under study (Whisenant 1999, Hong and Kim 2002, Hobbs 2002).

Principles of Landscape Ecology

As this field began in Europe and then spread to the North America and other countries, many different definitions of what constitutes a landscape have emerged (Lee 2001, Lee *et al*. 2004). However, within the field of landscape ecology, the term 'landscape' has been understood to refer to multi-ecosystems, which in turn refers to a single ecosystem possessing ecological function which interacts with surrounding ecosystems. For example, forested landscape, which is one of the main landscape elements, consists of different scaled forest patches, examples of which include coniferous forests, broadleaved forests, conifer-broadleaved mixed forests, pine forests, oak forests, and alder forests. The areas of these forested landscapes can reach the scale of a few Km^2. Landscape ecology is focused on a spatial understanding of ecological processes such as the mass flow and biological behavior within a patch, as well as between patches. A landscape element is a kind of heterogeneous space which is demarked by boundaries. Different physical and ecological phenomena take place within each unit ecosystem that makes up a landscape. Certain forest patch, thus, might be affected by distinct ecosystems (e.g., lakes, streams, plantations and meadows) or by the surrounding land-use (e.g., cities, farming and nature preserve areas). These patches might be bordering on heterogeneous forests which are affected by other community types such as forest fires, timber harvesting, climax forests, or specific sere of succession within their particular ecosystems (Harris 1984, Choung *et al*. 2004).

Landscape ecology has identified three main ecological characteristics when it comes to landscapes: structure (patterns), functions (ecological processes), and dynamics (changes) of landscape (Forman and Godron 1986, Hong *et al*. 2004a). While the landscape function is determined by the physical, chemical and biological transport which occurs between forest patches, the landscape structure determines the characteristics of each forest patch and its spatial relationship with other forest patches. Meanwhile, landscape change is determined by the configuration of forest patches, and changes in their interactions with each other. The core principle of landscape ecology is that: the landscape structure influences landscape function, and this landscape function in turn influences landscape structure, which means that landscape change influences both landscape structure and function (Forman and Godron 1986, Turner 1989, Turner *et al*. 1995, Lee 2001, Hong *et al*. 2004b, Lee *et al*. 2004).

1. Landscape structure

The main component of a landscape system is land mosaics. Land mosaics, with their various patterns of forest patches, clearly reveal the diversity and complexity that is involved in the ecosystem composition. As a result of the development of remote sensing and geographical information systems (GIS) much has been learned about landscape patterns. The scale of the research area should be decided before the actual assessment of landscape patterns can be carried out, with research process to be used selected in accordance with the decided-upon scale. Because of their failure to set an appropriate scale for the research before actually implementing the restoration effort, many projects have been plagued by problems such as misunderstandings, unexpected results and the wrong application of research results, which in turn have led to the creation of an imbalance between the practiced ecosystem and surrounding ecosystems, as well as to ecosystem degradation itself. Landscape boundaries are usually larger than those set by humans for administrative convenience. As water flow has been the main geographical determinant of natural boundaries, the most commonly accepted natural landscape boundary has been watersheds (Kang 2004). Level of patch is also an important determinant of the landscape pattern. Each patch possesses a series of unique characteristics (size, composition, age), which can affect the internal structure of the patch and ecological processes at the landscape level. To develop a proper understanding of ecosystem patterns and the complexity of ecological processes, there is a need to recognize that the patterns and processes which occur at one landscape level can be affected by the patterns and processes which occur at other landscape levels (e.g., scaling up and scaling down).

Landscape patterns are the result of the interaction between various factors. On a broader scale, vegetation composition and its pattern is closely related to regional climate such as temperature and precipitation, as well as to changes in soil and geographical patterns. Climate, soil, and geography are to a certain degree determinants of vegetation patterns in broad scale. However, within the broad pattern, one can also find different smaller patterns. These small-scale patterns may be determined by smaller-scale soil characteristics or particular climate variables, or may be dependent on other factors. Species turnover, which refers to changes in the distribution of a population within a particular landscape or patch, also affects the complexity of vegetation patterns. On the other hand, patchiness may be the result of species dispersal, which occurs as a result of regional disturbance or of micro-environmental variations.

The distribution of forest patches and vegetation succession are determined by disturbances (Harris 1984, Choung *et al.* 2004). The intensity of disturbance determines the size and pattern of forest patches. Vegetation succession in the degraded area can be preceded either by environmental variations caused by disturbances, the climatic characteristics after the disturbance, or by interaction with other disturbance factors. Disturbances capable of having an impact at the landscape scale include physical disturbances such as forest fire, drought, frost, high temperatures, storms, or wildlife induced soil erosion, as well as biological disturbances such as a rapid increase in harmful organisms or insects. Artificial disturbances are another important element of the ecosystem (Hong *et al.* 2000). These artificial disturbances have affected the creation and preservation of ecosystems and landscapes. Human activities such as land use, timber harvesting, soil removal, and the introduction of alien species have not only brought about changes in these ecosystems or original states, but their continuous degradation (Smith *et al.* 2000).

2. Landscape heterogeneity

Landscape heterogeneity is determined by the spatio-temporal interaction between landscape elements as well as by the characteristics such as their size, pattern, and composition of these elements. While right methods of measuring and assessing the characteristics of landscape heterogeneity have not yet been developed, it can be observed at two different levels: between landscapes (regional scale) and within a particular landscape itself (landscape scale).

Many landscape indices, which are based on the estimation of the number of landscape elements, the area they occupy, and the length of their boundaries, have been used to quantify landscape patterns and landscape heterogeneity (Forman 1995, Lee 2001, Turner *et al.* 2001). Another method which has been employed is that of analyzing patterns of plant species' richness and evenness variations. Many landscape indices have been developed and applied in the ecology field which can be used when clear differences in landscape patterns are found. However, the accuracy of these indices when applied to landscapes where the pattern differences are not as clearly pronounced remains to be verified. In the case of Korea which has rugged topography, there is a need to assure that the landscape indices developed by other countries are constantly upgraded at the implementation level. Nevertheless, such indices can be used to compare the characteristics of a particular landscape across time. Another factor which can affect results is changes in the measurement scale. As changing the grain (spatial resolution) and extent (overall study area) influences the number of patches, the measurement of landscape heterogeneity is also affected. Analyses of landscape heterogeneity should be able to ascertain the number of patches, their size and relative configuration, and to demonstrate the characteristics of the landscape structure and its composition. The assessment of the heterogeneity between landscapes, regional heterogeneity, is very hard to carry out. Functional heterogeneity can be identified using the background of special ecological processes (i.e. animal transport or water flow). While the landscape index for heterogeneity is widely used, given the fact that some problems exist with regards to the interpretation of the results obtained with this method, caution should be employed when using it either at the academic or practical level.

3. Ecotone and edges

Ecotone can be found on various scales spanning from biological populations to single patches. The mass flow which occurs in landscapes is regarded as important because of the fact that it occurs along the boundaries between different patches (Hansen and di Castri 1992). For example, while matter from streams flows to coastal tidal flat after having gone through the river estuary, the seawater flows back to the river through the coastal tidal flat. Moreover, both mass flow and biological transport occur during this kind of ecological process. Such an ecotone can be considered to be a distinct characteristic of coastal landscapes. The size and shape of a patch affects the edges of patch. Physical, chemical, and biological transport and flow move from one patch to the adjacent patch. This process is controlled by the 'edge effect' originating from the size and shape of the patch.

Landscape Transformation and Restoration Planning

1. Land use and habitat fragmentation

The fragmentation process, during which large habitats and land are segmented into small fragments as a result of irresponsible land use, has increasingly been recognized as an important environmental problem. Many species, including some large mammals and birds, are unable to maintain their populations in small habitat patches, and as such become extinct in that area as a result of the fragmentation process, which in turn, results in lowering species diversity. Moreover, land transformation destroys the connectivity of stream networks and degrades the water quality of aquifers and the natural disturbance regimes, while also negatively affecting other ecological processes that are necessary for species to evolve and maintain. Fragmentation is only one of the natural and human processes through which land is transformed from one pattern to another (Forman and Godron 1986, Hong *et al*. 2000, Lee *et al*. in press).

From an ecological viewpoint, landscape change and the spatial transformation processhave important implications. Five processes have been associated with the land fragmentation and transformation processes affecting habitats (Fig. 3):

1) Perforation: the process of making new land use type of existing habitats and land. This process marks the onset of the land transformation process (i.e., forest cutting, development of residential areas in forested landscapes)

2) Dissection: partition of a specific region into sections of the same width (i.e. the building of roads and railroads in forests and land)

3) Fragmentation: involves the reduction of the habitat, ecosystem, and land use patterns into smaller scale units. Here, it should be noted that the size of these fragmented units is discontinuous. As such, when an area is divided into sections of the same size, this is considered to be an example of dissection; however, sections which are not uniform in size represent an example of fragmentation. Thus, dissection involves a specific type of fragmentation. While roads, train rail, electricity power lines, and windbreak forests represent examples of dissection, timber clearance, farmland, residential areas, and meadows all fall under the fragmentation category. Dissection and fragmentation may have similar or completely different ecological effects, depending on whether the corridor created during the dissection or fragmentation processes emerges as a barrier to species transport.

4) Shrinkage: refers to a decrease in the size of a patch. An example of this would be that of the remnant forest around a residential area decreasing as a result of the development of new farmland or the expansion of the residential area.

5) Attrition: the process through which the small-sized patches and corridors disappear.

These five spatial processes, which affect a various range of ecological features from biodiversity to soil runoff and water quality, demonstrate unique spatial attributes. The perforation, dissection, and fragmentation processes, which emerge at the beginning of the land transformation process, affect the entire region or all patches within that particular region. Meanwhile, the shrinkage and attrition processes affect individual patches and corridors. The size and density of landscape patches increases as a result of the dissection and fragmentation processes, but are eventually decreased as a result of attrition (Fig. 3). As small-sized patches have a tendency to disappear, the mean patch size decreases during the first four processes found above, but increases as a result of attrition. Moreover, all five processes decrease the total area of an inner habitat. Meanwhile, the connectivity of the matrix, which determines corridor continuity and habitat networks, is decreased as a result of the dissection and fragmentation processes. The total perimeter created between the original and transformed land types increases during the fragmentation process, only to decrease during the shrinkage and attrition processes. As such, as each spatial process affects the spatial attributes of a landscape, ecological characteristics must also be affected.

These five spatial processes are usually overlapped during the land transformation process. If patch appear in a forested landscape as a result of the appearance of artificial patches such as residential areas or roads, the perforation and dissection processes will be active. Fragmentation and shrinkage usually appear near the middle stage of the landscape transformation process.

Forest patches a and b are biological habitat spaces. Both play an important role as inhabitation spaces for the various species found in the area. In the case of the landscape on the left, although the two patches are quite a distance from each other and there is

Spatial process	Patch number	Average patch size	Total interior habitat	Connetivity across area	Total boundary length	Habitat	
						Loss	Isolation
Perforation	0	-	-	0	+	+	+
Dissection	+	-	-	-	+	+	+
Fragmentation	+	-	-	-	+	+	+
Shrinkage	0	-	-	0	-	+	+
Attrition	-	+	-	0	-	+	+

Fig. 3. Major spatial processes occurring during the land transformation process and their effect on spatial attributes. + = increase; - = decrease; 0= no change. The effects are estimated in the block-colored land patterns and habitats. The white-colored land patterns surround the landscape (Adopted from Forman 1995, Hong and Kim 2002).

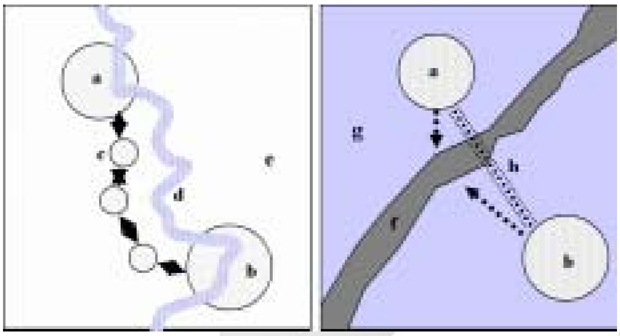

Fig. 4. Patch-corridor-matrix and network models.

a lack of direct connectivity, the fragmentation of species transport can be prevented by forest patch c, which plays the role of the stepping stone. In addition, when stream d is present, animals can use it as both their habitat space and corridor. In this case, c and d play the roles of corridors. If these corridors are artificially created, they then become eco-corridors. Meanwhile, patches a and b found in the landscape on the right cannot be naturally connected because they have been fragmented by roads and residential area f. However, by building eco-corridor h, they can be artificially connected. Here, the matrix plays an important role in activating the eco-network. While the matrix found in the landscape on the left, matrix e, shares similar trends with the surrounding area, the matrix in the landscape found on the right, matrix g, is totally different from its surrounding area. In the landscape on the right, although eco-corridor h is created, its efficiency will be decreased as a result of the effects of the surrounding area.

2. Landscape ecological attributes for restoration planning

The principles of landscape ecology can be used to identify both the detailed and broader ecological attributes of the spatial elements targeted for ecological restoration (Forman and Collinge 1996, Whisenant 1999, Hobbs 2002, Forman *et al*. 2003). The following ecological attributes can be used in the landscape restoration planning (Fig. 4). These can be duplicated whenever necessary:

1) Patch and boundary: small patches, patch with minimum dynamic areas, boundary surface, edges of natural resources area, and lobe and cove of patch boundary which exhibit the dispersal funnel and drift-fence effects

2) Corridor: number and size of gap, number of stepping-stone patches, conduit, road corridors serving as both barriers and sources, position of the valleys in which the Venturi's effect appears, 1st order stream which hydrologically control the mass flow, second-fourth order streams which control erosion, nutrients, and fish, meanders which control environmental problems caused by land use, floodplain patterns, width of stream system, corridor connectivity

3) Network, matrix, and mosaic: connectivity and circuitry of network and matrix, perforation in the matrix, spatial configuration of patch, divergence and dispersion of habitat patch, ecological network of natural resource area

4) Mass flow and biological transport: source and sink of heat, gas, and matter, local species extinction in metapopulation, increase colonization within the metapopulation

CONCLUSIONS

Ecological Restoration of Landscape System

Most of the information and methodologies related to ecological restoration are obtained from studies on local site and the implementation of an ecological restoration should indeed start from such a site. A local site has been affected by the broader context surrounding local site, restoration planning of the local site should not be focused exclusively on the restoration site. As ecological processes in landscape and regional scale can influence on the ecosystem to be restored, such factors should be considered during the planning stage. Therefore, restoration should not only be carried out within the specified restoration site, but also on the scale of the broader landscape surrounding the site to be restored (Whisenant 1999, Turner *et al*. 2001, Hong *et al*. 2000, Hong *et al*. 2004b).

Thus, how should restoration be implemented on the landscape scale? What objectives should be selected? Which landscape characteristics should be transformed in order to reach these objectives? What technologies should the ecologists apply to do so? Hobbs (2002) has presented some of the stages associated with the development of landscape-scale restoration programs:

1) Assessment of problems which require attention
   a. Changes in the biological community (i.e. loss or decrease of species, invasion of alien species)
   b. Changes in the ecological functions of the landscape (i.e. species movement, flow of water and nutrients)
   c. Changes in the value of landscape beauty
2) Determination of the cause of the problems
   a. Elimination and dissection of original vegetation
   b. Changes in vegetation / landscape patterns and structures
   c. Abandonment of traditional management
3) Selection of realistic restoration objectives
   a. Maintenance of the existing biota and avoiding any further damage
   b. Decrease in the deterioration rate of land and water quality
   c. Maintenance or improvement of potential biological productivity
   d. Achieve the various objectives using a comprehensive method
4) Development of effective planning and management tools
   a. Formation of plans which take into consideration all other landscape patterns and conditions
   b. Introduction of measures designed to achieve a proper spatial understanding and bring about solutions
   c. Reaching of an understanding between land owners and restoration managers
   d. Use of an aggressive approach which makes possible the modification of the process whenever necessary

However, the above list contains indicators that have yet to be scientifically proven or that lack validity. For example, the need for measurement indicators capable of demonstrating the 'state' or 'soundness' of a landscape is not clearly identified. This is one of the main reasons why problems have emerged during the actual application in the field. It has been suggested that in order to resolve this problem the concept of ecosystem soundness, which explains the state of the ecosystem, should be introduced. The core elements used to show the soundness of an ecosystem include an analysis of the ecosystem's organizational structure, which is based on its biological productivity, the biological interaction and diversity found, as well as the ecosystem's resilience, which can be judged by its ability to maintain its systemic structure and functions even when under environmental stress.

From the landscape ecological principles, landscape process is closely related to landscape patterns. Therefore, before transforming a landscape pattern using a specified method, the decisive factors (biological migration, metapopulation dynamics, and system flow) between the landscape pattern and process should be identified in order to ascertain the specific ecological processes which might appear. Once these factors are uncovered, proper estimates of the kinds of ecological constructions (e.g., stepping stone, ecological corridors, eco-bridge) which should be installed in the new landscape can be formed. In addition, as the landscape becomes more fragmented, a threshold or turning point will be reached, beyond which point the distribution of biota will decrease further and the majority of the species will disappear. As such, there is a need during this process to develop an ecological reaction model in order to be able to identify the core landscape and its dynamic functions. Such a model can be simple or complicated, quantitative or conceptual. Moreover, this model can focus on the basic characteristics or specific elements of that particular landscape.

Whisenant (1999) developed two kinds of thresholds, one of which is caused by biotic interactions, and the other by abiotic limiting factors (Fig. 5a). If a system is degraded as a result of biological change (i.e. changes in the species composition by over-grazing), the restoration method adopted should be one which concentrates on bringing about biological transformation, such as removing the causes (i.e. livestock) or readjusting the biological composition (i.e. restoring the vegetation). Meanwhile, when a system is degraded by abiotic factors (i.e. soil erosion, pollution), the restoration effort should be focused on improving the physical and chemical environment once the cause of the degradation has been removed.

The same model can be applied on the landscape scale. The specific ecosystem developed by Whisenant (1999) is preconditioned on the existence of a landscape scale (Fig. 5b). Here, one must consider the potential for a threshold to appear as a result of the decrease in biological connectivity caused by the fragmentation and transformation of the habitat. Moreover, the threshold at which a broad transformation in the physical process of a landscape can occur, as a result of such factors as hydrology, must also be considered. Once a landscape has been fragmented, the recovery of its connectivity should become the overarching objective of the restoration project. In the case of a fragmented forest, the restoration project should be concentrated on restoring the habitat by planting new trees, or on securing eco-corridors for specified wildlife. In cases where a stream is dissected, the restoration effort should be focused on restoring the flow of the stream. This is also the case with regards to restoration efforts designed to alter the physical environment, which are also capable of overcoming the biological threshold. For example, the restoration of large-scale vegetation to prevent the emergence of a hydrological imbalance can also contribute to the heightening of the biological connectivity at the same time.

Guidelines for Landscape Restoration

Proper guidelines of landscape restoration that are based on the

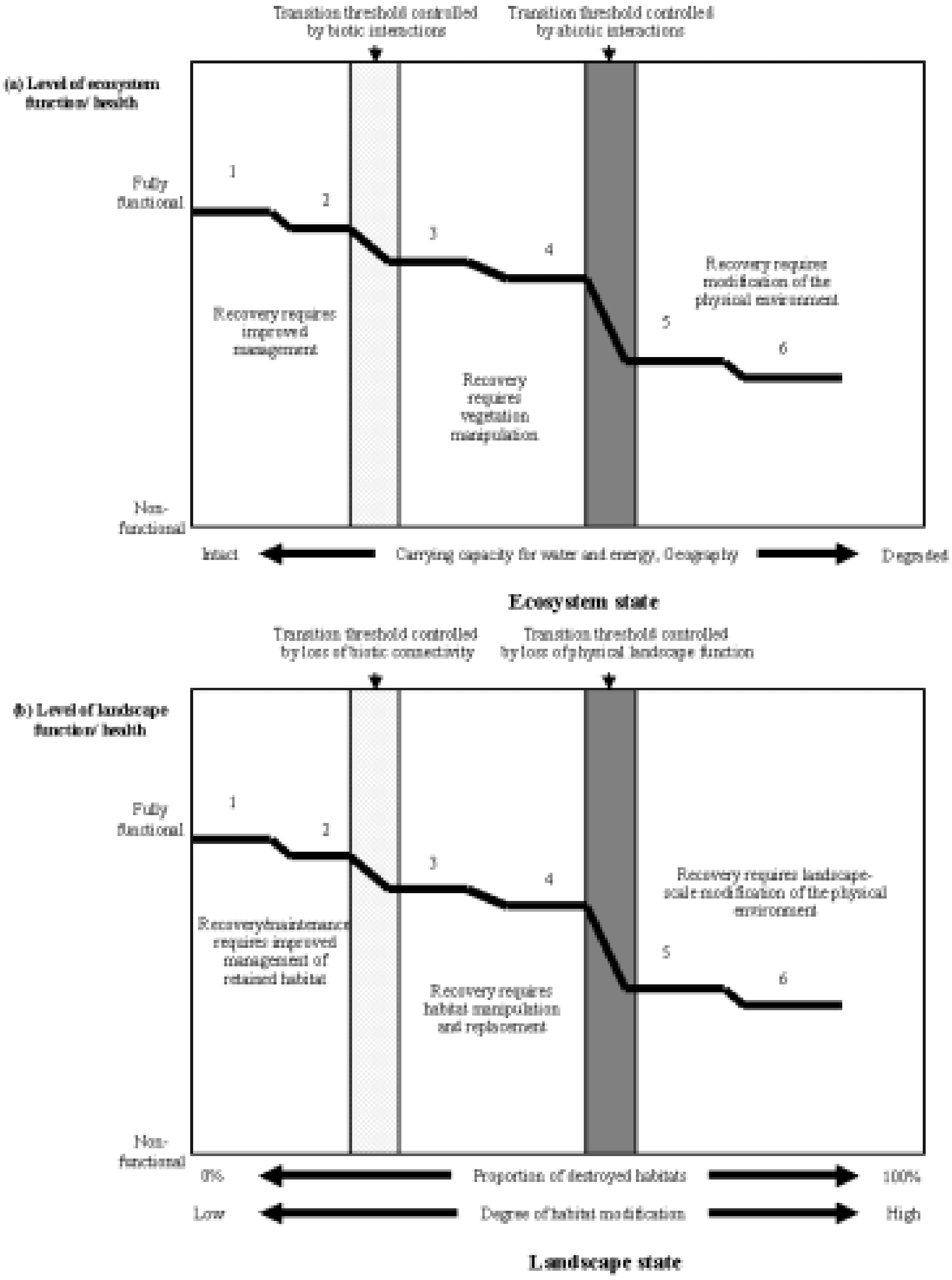

Fig. 5. Restoration planning for an ecosystem whose state is determined by biotic interactions and by limiting factors caused by abiotic conditions (a). Restoration planning for a landscape whose state is determined by a loss of biological connectivity and physical landscape functions (b). (Whisenant 1999, modified from Hobbs 2002)

objectives and desired direction of the restoration project and its management should be selected (Forman *et al*. 2003). These guidelines should be: applicable to the majority of the landscape patterns; based on various landscape structures; and should be based on the species found in that particular landscape. Lastly, the spatial options developed for a specific landscape should be related to the structure of the actual landscape, the target species, and the management objectives for that specific area.

Given the fact that the impact on various ecosystems must be considered, restoration on the landscape scale faces a much more complicated task than restoration planning in local level when it comes to the identification of causes and the development of solutions (Whisenant 1999, Webb 2000). Landscape restoration planners must first address the causes of the degradation of the landscape and ecosystem before they can determine which landscape ecology principles will be necessary during the actual restoration. During this initial stage questions such as: what decisions should be made with regards to the restoration of the landscape? What are the proper landscape management and restoration tools to be used? Can these tools be applied to island biogeography? How should the large and small-sized patches be arranged? How should the adjacent patches be managed? must all be addressed (Whisenant 1999). Once this has been completed, detailed restoration measures addressing such issues as the adjacency of the landscape to large-sized patches, vegetation restoration, and the preservation of the habitat patch, should be drawn up. Although such questions do not allow us to formulate an exact assessment of the degradation which has occurred at the landscape scale, the identification of local characteristics through the above-mentioned questions can lead to a better understanding of the soundness of the landscape (Table 1). One of the characteristics used to assess the soundness of the landscape is the structural aspects which have caused the degradation of the landscape. More caution should be exercised when judging the functional aspects of landscapes. Once the assessment of local characteristics has been carried out, guidelines must be developed with regards to the restoration effort at the landscape scale.

This paper was introduced landscape ecological guidelines which can be used for restoration engineering projects such as the building of ecological corridors, eco-roads and nature-type stream systems, and which have already been applied in Korea. In the North America which has emerged as the leader in ecological restoration engineering, landscape restoration has combined conservation and restoration of wildlife habitats (Table 2). All of this clearly proves that the need for restoration ecology has moved beyond the level of simple human systems to that of a global network linking nature-man-society (Aanen *et al*. 1991, Throop 2000, Hong *et al*. 2004b). Lastly, Whisenant (1999) suggests the following guidelines (Hobbs 2002) for the restoration of degraded natural landscapes:

- The rehabilitation effort itself may turn out to be one of the causes of the degradation of the natural landscape.
- The research process should be regarded as being just as important as the actual implementation process.
- Appropriate levels of restoration planning should be established
- Landscape planning should be established to heighten the ability to preserve limited resources.
- Plans should be drawn up to protect ecosystem diversity within the landscape.
- Landscape restoration plans should be designed to maintain ecosystem processes.
- Design restoration plans which connect the landscapes.
- Design plans which facilitate the use of patches as habitat source of species within the landscape.

Table 1. Degraded landscape indicators. Local problems can be applied at the landscape scale (Whisenant 1999)

Indicator of degradation at the local scale	Potential degradation indicator with regards to ecological interactions at the landscape scale
• Decrease in vegetation and litter layer	• Dissection of ditches
• Decline in soil structure (chemophysical structure)	• Excessive amounts of soil
• Decrease in the soil organic matter	• Changes in water levels which could potentially affect the hydrological process
• Decrease in moisture content	• Increase in salinization by over-use of subsurface water
• Increase in wind erosion	• Decrease in seed diversity
• Lack of nutrients	• Excessive transport of nutrients to surrounding landscapes
• Decrease in nutrient levels	• Damage to wildlife
• Decrease in biodiversity and its function	• Inappropriate pollination
• Decline in seed bank diversity	• Decrease in landscape diversity
• Decline in the diversity of the soil organism and in their activity levels	• Dissection of landscape
• Increase in soil salinization	

Table 2. Duerksen's principles governing the protection and restoration of habitats at the landscape scale (Adopted from Turner *et al.* 2001)

Biological principles	
Principle 1	• Conserve the large-sized forest patches adjacent to natural vegetation
Principle 2	• Protect the habitats for migration and distribution of key species
Principle 3	• Protect rare landscape elements (traditional residential areas, rural villages, old tree),
Principle 4	• Assure the connectivity of wildlife (ecological corridors and bridge for wildlife)
Principle 5	• Protect the ecological processes in preserved areas (forest fires, floods)
Principle 6	• Manage the landscape for the habitat protection of rare species
Principle 7	• Balance between the wildlife habitats and public areas.
Principles for biological conservation in local areas	
Principle 1	• Maintain the buffer zone between the core wildlife habitat and residential area.
Principle 2	• Install ecological corridors in the human activity area.
Principle 3	• Avoid encounters with predators.
Principle 4	• Control the pet population such as dogs and cats.
Principle 5	• Create an pseudo-ecosystem in the developed area which possesses the characteristics of a natural ecosystem(green space in roof, wall and road)
Additional principles	
Principle 1	• Respect empirical studies based on scientific opinions.
Principle 2	• Accept the various solutions to complicated environmental problems.
Principle 3	• Establish conservation planning having clear objectives for wildlife protection.
Principle 4	• Persuade peoples that nature conservation should be made a priority.
Principle 5	• Recognize that all models may not perfect in all cases.
Principle 6	• Assess the results of each restoration activity before introducing the next stage of planning.
Principle 7	• Improve the quality of wildlife habitat by developing detailed development plans.

- Establish plans to increase animal induced seed dispersal.
- Design plans to increase wind induced seed dispersal.
- Design landscape plans which increase the interaction between wildlife.

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LITERATURE CITED

Aanen, P., W. Alberts, G.J. Bekker, H.D. van Bohemen, P.J.M. Melman, J. van der Sluijs, G. Veenbaas, H.J. Verkaar and C.F. van de Watering (eds.). 1991. Nature Engineering and Civil Engineering Works. Pudoc, Wageningen, Netherlands. 139 p.

Bradshaw, A.D. 2000. What do we mean by restoration? *In* K.M., Urbanska, N.R. Webb and P.J. Edwards (eds.), Restoration Ecology and Sustainable Development. pp. 8-14. Cambridge University Press, Cambridge.

Choung, Y.-S., B.-C. Lee, J.-H. Cho, K.-S. Lee, I.-S. Jang, S.-H. Kim, S.-K. Hong, H.-C. Jung and H.-L. Choung. 2004. Forest responses to the large-scale east coast fires in Korea. Ecol. Res. 19: 43-54.

Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine and T.C. Winter. 2003. Road Ecology: Science and Solutions. Island Press. Washington. 481 p.

Forman, R.T.T. 1995. Land Mosaics. The Ecology of Landscapes and Regions. Cambridge University Press. Cambridge, 632 p.

Forman, R.T.T. and S.K. Collinge. 1996. The spatial solution to conserving biodiversity in landscapes and regions. *In* R.M. DeGraaf and R.I. Miller (eds.), Conservation of faunal diversity in forested landscapes. Chapman & Hall. pp. 537-568.

Forman, R.T.T. and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, New York. 619 p.

Hansen, A.J. and F. di Castri. 1992. Landscape Boundaries: Consequences for Biotic Diversity and Ecological Flows. Springer-Verlag. New York. 452 p.

Harker, D.F., G. Libby, K. Harker, S. Evans and M. Evans. 1999. Landscape Restoration Handbook. Lewis Publishers. 850 p.

Harris, L.D. 1984. The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity. The University of Chicago Press, Chicago.

Hobbs, R.J. 2002. The ecological context: a landscape perspective. *In* M.R. Perrow and A.J. Davy (eds.), Handbook of Ecological Restoration (Vol. 1). Cambridge University Press, Cambridge. pp. 24-45.

Hobbs, R.J. 1999. Restoration ecology and landscape ecology. *In* J.A. Wiens and M.R. Moss (eds.), Issues in Landscape Ecology. The International Association for Landscape Ecology. pp. 70-77.

Hong, S.-K., H. Kang, E.-S. Kim, J. G. Kim, C.-H. Kim, E.-J. Lee, J.-C. Lee, J.-S. Lee, B.-S. Ihm, Y. Choung and H.-L. Cheong. 2004a. Restoration Ecology and Engineering (Revised). Life Science Publishing Co., Seoul.

Hong, S.-K., S. Kim, K.-H. Cho, J.-E. Kim, S. Kang and D. Lee. 2004b. Ecotope mapping for landscape ecological assessment of habitat and ecosystem. Ecol. Res. 19: 131-139.

Hong, S.-K. and D.-Y. Kim. 2002. Land Mosaics: The Ecology of Landscapes and Regions, Sungkyunkwan University Press. 681 p. (Korean Edition of Forman 1995)

Hong, S.-K., Y.-D. Rim, N. Nakagoshi and N.-K. Chang. 2000. Recent spatio-temporal changes of landscape structure, heterogeneity and diversity of rural landscape: Implements for landscape conservation and restoration. Korean J. Ecol. 23: 359-368.

Jordan, W.R., M.E. Gilpin and J.D. Aber. 1987. Restoration Ecology: A Synthetic Approach to Ecological Research. Cambridge University Press. 342 p.

Kang, H. 2004. Watershed landscape system. *In* Hong, S.-K., H. Kang, E.-S. Kim, J. G. Kim, C.-H. Kim, E.-J. Lee, J.-C. Lee, J.-S. Lee, B.-S. Ihm, Y. Choung and H.-L. Cheong (eds.), Restoration Ecology and Engineering (Revised). Life Science Publishing Co., Seoul.

Lee, D. 2001. Landscape Ecology. Seoul National University Press. 349 p.

Lee, D.-K., M.-S. Kim, B.-H. Ku, K.-H. Kim, D.-S. Kim, J.-H. Na, S.-W. Yun, M.-W. Lee, S.-W. Jeon, H.-L. Choung, K.-D. Cho, J.-G. Je and S.-K. Hong. 2004. Landscape Ecology. Bojindang Publishing Co. 518 p.

Lee, E., K. Kim, K. Kim and D. Lee. Forest fragmentation in the lower region of the Han River basin, South Korea from 1983 to 1996. *In* S.-K. Hong *et al.* (eds.), Ecological Issues in a Changing World: Status, Response and Strategy. Kluwer Academic Publishers, Dordrecht, The Netherlands (in press).

National Institute of Environmental Research. 2003. Ecosystem Survey and Sandstorm Control in Northwest China with Special Reference to Inner Mongolia. Kookmin University. 236p.

Ministry of Environment. 2004. Report of National Long-term Ecological Research Project. The Ecological Society of Korea.

Smith, M.A., W.A. Loneragan, C.D. Grant and J.M. Koch. 2000. Effect of fire on the topsoil seed banks of rehabilitated bauxite mine sites in the Jarrah forest of Western Australia. Ecol. Manag. Restor. 1: 50-60.

Throop, W. 2000. Environmental Restoration: Ethics, Theory and Practice. Humanity Books. New York. 240p.

Turner, M.G., R.H. Gardner and R.V. O'Neill. 2001. Landscape Ecology in Theory and Practice. Springer-Verlag, New York. 401 p.

Turner, M.G., G.J. Arthaud, R.T. Engstrom, S.J. Hejl, J. Liu, S. Loeb and K. McKelvey. 1995. Usefulness of spatially explicit animal models in land management. Ecol. Appl. 5: 12-16.

Turner, M.G 1989. Landsape ecology: the effect of pattern on process. Ann. Rev. Ecol. Syst. 20: 171-197.

Urbanska, K.M., N.R. Webb and P.J. Edwards. 2000. Restoration Ecology and Sustainable Development. Cambridge University Press, Cambridge. 396p.

Webb, N.R. 1997. The development of criteria for ecological restoration. *In* K.M. Urbanska, N.R. Webb and P.J. Edwards (eds.) Restoration Ecology and Sustainable Development. pp. 133-158. Cambridge University Press, Cambridge.

Whisenant, S.G. 1999. Repairing Damaged Wildlands: A Process-oriented, Landscape-scale Approach, Cambridge University Press. 312 p.

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