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Structure and Dynamics of Korean Red Pine Stands Established as Riparian Vegetation at the Tsang Stream in Mt. Seorak National Park, Eastern Korea

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ABSTRACT: The structure and dynamics of Korean red pine stands established in the riparian zone were studied in the Tsang stream in Mt. Seorak National Park, in east-central Korea. Pine stands were classified into four successional stages, the initial, establishing, competitive, and stabilizing stages, based on the age distribution of a dominant tree, *Pinus densiflora*, the vegetation stratification, and the microtopography of the riverine environment. The stages usually corresponded to disturbance frequencies, depending on the horizontal and vertical distances from the watercourse. Stands of the initial and establishing stages lacked tree or subtree layers, or both. As stands progressed through the developmental stages, soil particle size became finer and moisture retention capacity was improved. The stand ordination reflected the developmental stage, and the species ordination differentiated species specializing in relatively dry and wet habitats. The results of the analysis of vegetation dynamics provided ecological information which will be useful for understanding the developmental processes of vegetation established in riparian zones. Species diversity indices usually increased across developmental stages, following the typical pattern for successional processes. We discuss the importance and necessity of riparian vegetation in Korea, where most riparian forests have disappeared due to excessive human land use.

Key words: Developmental stage, Korean red pine, Mt. Seorak, Riparian forest, Vegetation structure and dynamics

INTRODUCTION

Riparian ecosystems are spatially and temporally dynamic and are shaped by fluvial geomorphic processes. There are, therefore, physical and biological links between terrestrial and aquatic environments (Gregory et al. 1991). Riparian ecosystems usually support higher species richness and densities of wildlife than other nearby ecosystems (Johnson and Simpson 1971, Carothers et al. 1974). Riparian vegetation retains suspended sediments, thus decreasing the quantity of solids in suspension in watercourses and improving the quality of the water (Howard-Williams et al. 1986, Cooke and Cooper 1988, Pinay and Decamps 1988, Haycock and Burt 1990, 1991, Fustec et al. 1991). Vegetation also slows the flow of torrential rains and collects eroded material, reducing the effects of flooding downstream. Furthermore, highly developed root systems reinforce the banks of streams (Salinas and Guirado 2002).

These advantages, together with the considerable enhancement of the landscape that this vegetation affords, justify considering riparian vegetation as a habitat type of primary importance (Salinas and Guirado 2002). The maintenance and restoration of this vegetation thus deserves to be made a priority in land management projects.

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

Plant ecologists usually recognize two main kinds of vegetation dynamics (Miles 1979, Van Andel et al. 1993, McCook 1994). Following some kinds of disturbance, succession is the gradual process of ecosystem development that proceeds towards relatively stable conditions. Mosaic or cyclical processes are smaller scale dynamics or mini-successions by which the character of stable vegetation is maintained (Watt 1947, Runkle 1985, van der Maarel and Sykes 1993). Plant ecologists have focused predominantly upon the internal mechanisms (autogenic processes) which bring about ecosystem development. External or allogenic processes are recognized as important for initiating succession (for example, the creation of a fresh surface following the retreat of a glacier) or for initiating successio-

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nal change from one state to another. However, ever since Clements (1916) first introduced the concept of succession, ecologists have been mainly interested in the ways in which plants themselves modify their environments and thus determine the successional sequence.

With the dominance of studies of autogenic processes in the field of plant ecology, there is a danger that researchers may fail to appreciate the importance of external processes in determining ecosystem development. It is essential to recognize the dynamics of the physical environment as an integral part of the systems that we study.

Decamps (1996) has pointed out that on the floodplains of large rivers, one can observe a sharp contrast between forest dynamics in the active floodplain, i.e., that part of the floodplain which is regularly flooded during moderate flood events, and those on former floodplains, i.e., river terraces. Forests within the active floodplain, i.e., sequential successional and mosaic forests, are regenerated through allogenic processes such as competition and gap formation.

The river is a dynamic place in which the topography is changed over the years and seasons by the action of running water. Regeneration of biological communities progresses within the very short term in riparian habitats. The maximum successional period is several decades or <100 years and most riparian zones fluctuate at one- or several-year intervals. Riparian zones are ecosystems dominated by herbaceous plant communities, and annual plants, and are places in which the dynamics of several temporal systems are intermingled (Lee et al. 2003).

Riverine environments are defined as environments containing running water. Riverine ecosystems are created by the action of running water and maintained by the morphology and vegetation of the river. The river is constantly changing the landscape through the processes of erosion, sediment transport, and depositition. Therefore, the river is a dynamic ecological space, in which disturbance is a primary driving force (Naiman and Bilby 1998).

This study aims to clarify the processes of establishment and development of Korean red pine forests in riparian zones including gravel bars, a typical upstream landscape element.

STUDY AREA

The study area, the Tsang stream, is located on the eastern side of Mt. Seorak, in the east-central Korean peninsula (38° 09' 57.5" ~38° 10' 13.6"N, 128° 28' 22.8"~128° 31' 01.9" E) (Fig. 1). The

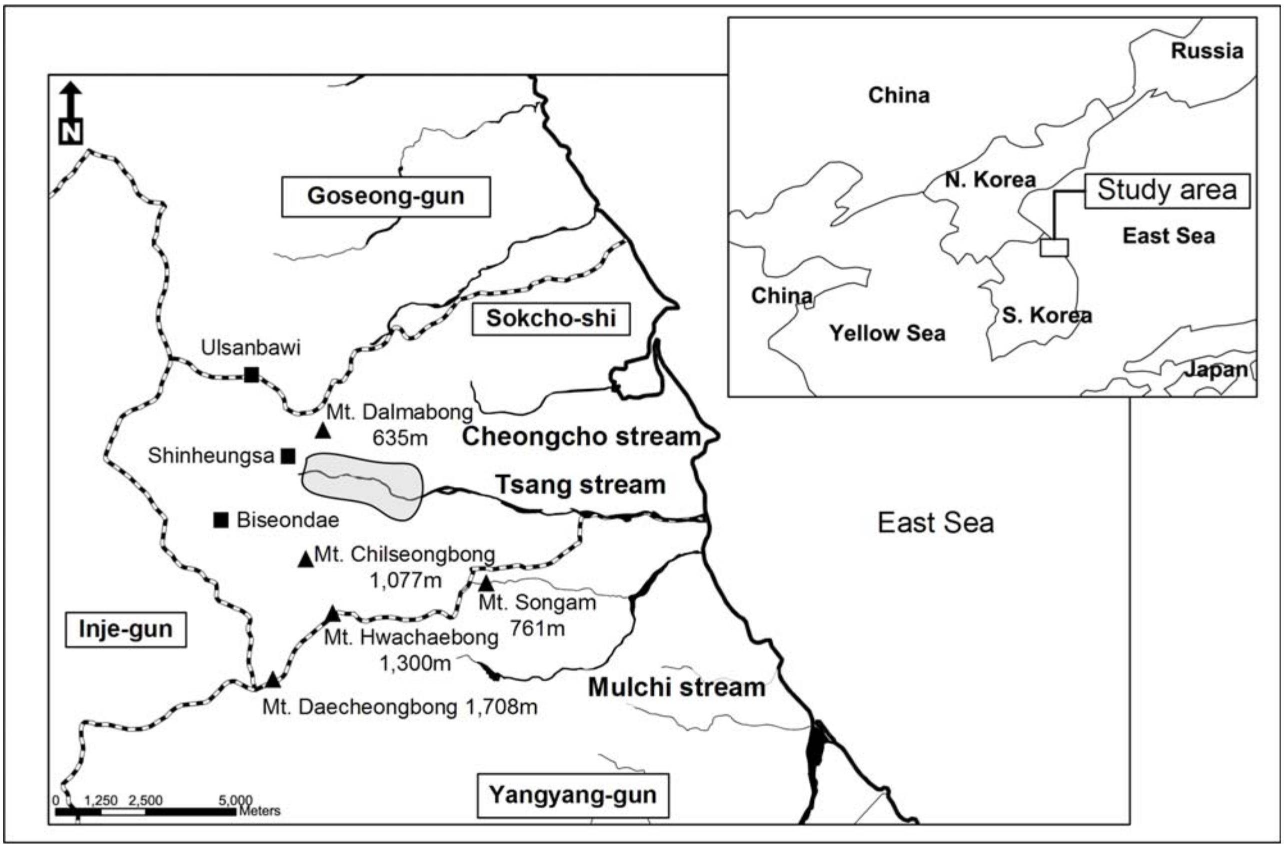

Fig. 1. A map showing the study area, the Tsang stream in Mt. Seorak National Park, eastern Korea. The study area is indicated in gray.

Bulguksa granite, formed in the Cretaceous Period, is the major bedrock of Mt. Seorak and most of the soil is composed of saprolite from weathered granite (Chun et al. 2006). Substrates in the riparian zone vary from cobble and pebble to sand, silt and clay from upstream to downstream. The mean annual temperature and precipitation in the area from 1961 to 1999 were 12℃ and 134 cm, respectively (KMA 2001). The study area is near the southern limit for migration of northern species during the Tertiary Period, and was within the area of migration of southern species in the Quaternary Period (Yim and Baik 1985). Despite over- exploitation during the Japanese occupation and destruction during Korean War, the forests in this area have relatively been well-preserved. Recently, the national park was designated as a UNESCO Man and Biosphere (MAB) Reserve. The vegetation of Mt. Seorak is best described as temperate deciduous forest dominated by oaks (*Quercus* spp.) in the lower elevations, and mixed with coniferous trees in the higher elevations. *Pinus densiflora* forests constitute approximately 11% of the twenty-one different vegetation types on Mt. Seorak (Yim and Baik 1985). Yim and Baik (1985) found naturally occurring *P. densiflora* in rock outcroppings, ridge tops, and slopes as well as in disturbed deciduous forests and in pebbles on the shores of streams in the Mt. Seorak area. The Tsang stream originates from the Shinheungsa and runs through Mt. Seorak national park and Sokcho city and ultimately flows into the East Sea. This study was carried out in the upstream part of the stream.

METHODS

Developmental stages of Korean red pine stands were classified based on the age distribution of a dominant tree, *P. densiflora*, vegetation stratification, and microtopography of the riverine environment (Table 1). The height of vegetation was measured for five trees selected randomly by altimeter. The diameter of mature trees was measured as the diameter at breast height (DBH) and those of seedlings and saplings were as the diameter at 30 cm from the ground surface, D_{30}. The diameter was measured using a measuring tape. Diameter class distribution diagrams were depicted by the frequency distribution of each class divided at regular intervals.

Vegetation sampling was conducted from May to September 2005～2006. A total of 70 sample plots were established in habitats with Korean red pine stands of four developmental stages, including waterfront (the initial stage), the interior (the establishing stage) and central parts (the competitive stage) of gravel bars, floodplains (the competitive stage), and stream banks (the stabilizing stage). Plot sizes varied from 5 m × 5 m (for seedlings and saplings of <5 m height) to 10 m × 10 m (for overstory trees of >8 m height) depending on stand heights. All the plants in each plot were identified to species, following Lee (1996). The frequency and dominance (Braun-Blanquet 1964) of all herbaceous, woody seedling, shrub (0.8～2 m), understory (2～8 m), and overstory (>8 m) plants were determined in each plot. The dominance values for 49 species (>20% frequency) were converted to Maarel's (1979) scale (1～10), and subjected to Detrended Correspondence Analysis (DCA; Hill and Gauch 1980, McCune and Mefford 1999) for ordination. 35 woody and 14 herbaceous plants were selected for species ordination. As a measure of species diversity, Shannon Wiener's Diversity Index (H') was calculated (Magurran 2004). Vegetation structure was compared using one-way analysis of variance (ANOVA), followed by Newman-Kuel's pairwise mean comparison at the 95% confidence level (Samuels and Witmer 2003).

Soil samples were collected in 29 randomly selected plots in the four developmental stages (6 each in the initial and the establishing stages, 10 in the competitive stage, and 7 in the stabilizing stage). In each plot, four samples were collected from the A_1-horizon (top 20～25 cm), pooled, and air-dried. Soil particle size distribution (gravel >2 mm in diameter, sand 0.05～2 mm, and silt & clay <0.05 mm) was determined by successive sieving through 2 mm and 0.05 mm mesh screens. Moisture retention capacity was determined by subtracting dry weight (48 hours at 105℃) from saturated (with H_2O) weight. These soil parameters were compared among the developmental stages using one-way analysis of variance, followed by Newman-Kuel's procedure with 95% confidence level (Samuels and Witmer 2003).

Table 1. Criteria for classification of developmental stage of *Pinus densiflora* stands on the riparian zone of the Tsang stream

Stage	Stratification	Vegetation structure	Habitat characteristics
Initiation	Two layers	Herb layer level	Frequent and intensive disturbance as waterfront of gravel bar
Establishment	Three layers	Usually shrub layer level	Frequent but relatively weak disturbance as the interior of gravel bar
Competition	Four layers	Tree layer level but poor development of understory	Relatively less frequent disturbance as central part of gravel bar
Stabilization	Four layers	Tree layer level with integrated structure	Relatively stable as a stream bank

RESULTS

Vegetation Structure of *Pinus densiflora* Stands by Developmental Stages

Stands of the initial stage lack tree and subtree layers, and stands of the establishing stage also lack the tree layer. Coverage of the shrub layer increased with the developmental stage, and coverage of the herb layer also increased with the developmental stage except in the initial stage, where herbaceous plants were dominant. Coverage of the subtree layer was reduced as the tree layer was established. The height of the tree layer increased but its coverage hardly changed with the developmental stage (Table 2).

Soil Environmental Characteristics for Each Developmental Stage of *Pinus densiflora* Stands

The percentage of gravel in the substrate decreased with advancing developmental stage, whereas the sand content increased. The silt and clay contents also increased with the developmental stage, except in the establishing stage. The moisture retention capacity increased as the stands matured (Table 3).

Species Composition

On Axis I of the Detrended Correspondence Analysis plot, the stands of the initial stage was the farthest right, and the stands were placed, from right to left, in order of their developmental stage (Fig. 2). In the species ordination plot for woody plants, plants that favor wet conditions, such as *Salix gracilistyla* (SAGR), *Populus maximowiczii* (POMA), *Securinega suffruticosa* (SESU), *Aristolochia mandshuriensis* (ARMA), *Fraxinus rhynchophyla* (FRRH), *Betula schmidtii* (BESC), etc., were located on the right, while terrestrial plants, such as *Quercus variabilis* (QUVA), *Syringa reticulata* var. *mandshurica* (SYRE), *Callicarpa japonica* (CAJA), and *Morus bombycis* (MOBO) tended to be placed on the left side on Axis I (Fig. 3). In the species ordination plot for herbaceous plants, plants that favor wet conditions, such as *Artemisia princeps* var. *orientalis* (ARPR) and *Phragmites japonica* (PHJA), were located on the right, while terrestrial plants, such as *Oplismenus undulatifolius* (OPUN), *Calamagrostis arundinacea* (CAAR), *Carex siderosticta* (CASI), *Solidago virga-aurea* var. *asiatica* (SOVI),*Carex humilis* (CAHU), *Clematis heracleifolia* (CLHE) tended to be placed on the left on Axis I (Fig. 4).

Table 2. Vegetation structure for each developmental stage of *Pinus densiflora* stands on the riparian zone of the Tsang stream. T_1: tree layer, T_2: subtree layer, S: shrub layer, H: herb layer. Each value is expressed as mean ± SE

Factor	Initial stage	Establishing stage	Competitive stage	Stabilizing stage	p^*
T_1-Height (m)	–	–	11.8± 1.9	14.8± 1.1	0.0001
T_1-Coverage (%)	–	–	91.9± 6.6	89.6± 4.8	0.2701
T_2-Height (m)	–	4.6 ±0.4	5.3±1.2	5.4± 0.8	0.0509
T_2-Coverage (%)	–	41.1±27.3	21.2±16.9	27.3±20.4	0.0161
S-Height (m)	1.2± 0.2	1.9± 0.5	1.8± 0.3	1.8± 0.3	0.0048
S-Coverage (%)	14.0±10.8	37.1± 28.1	43.2±22.0	47.3±21.7	0.0449
H-Height (m)	0.6± 0.2	0.5± 0.2	0.6± 0.1	0.6± 0.2	0.1939
H-Coverage (%)	40.0±19.9	8.2± 4.2	23.2±16.9	40.8±23.5	0.0001

* Probability of error for rejecting H_o in ANOVA.

Table 3. Physical properties of soil for each developmental stage of *Pinus densiflora* stands on the riparian zone of the Tsang stream. Each value is expressed as mean ± SE. MRC: moisture retention capacity

Parameter	Initial stage	Establishing stage	Competitive stage	Stabilizing stage	p^*
Gravel (%)	40.95±16.41	35.04±19.69	25.47±18.68	17.59±12.49	0.0928
Sand (%)	58.70±16.32	64.81±19.70	74.01±18.45	81.34±12.53	0.1008
Silt & Clay (%)	0.36± 0.16	0.15± 0.03	0.53± 0.42	1.07± 0.90	0.0114
MRC	19.24± 1.10	17.92± 1.82	27.51± 4.14	30.61± 7.59	0.0002

* Probability of error for rejecting H_o in ANOVA.

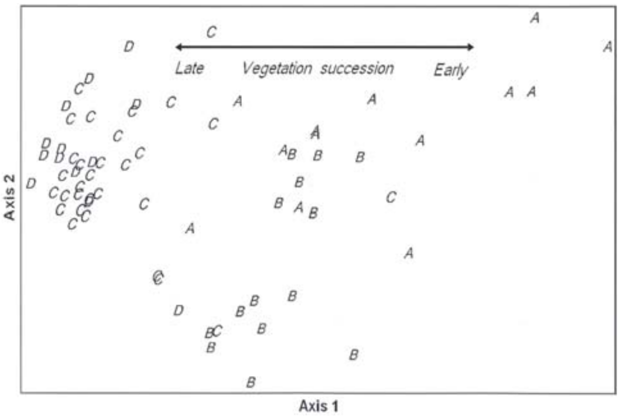

Fig. 2. DCA (Detrended Correspondence Analysis) ordination from the 70 plots including 49 plant species in the riparian zone of the Tsang stream in Mt. Seorak National Park, eastern Korea. A: initial stage, B: establishing stage, C: competitive stage, D: stabilizing stage.

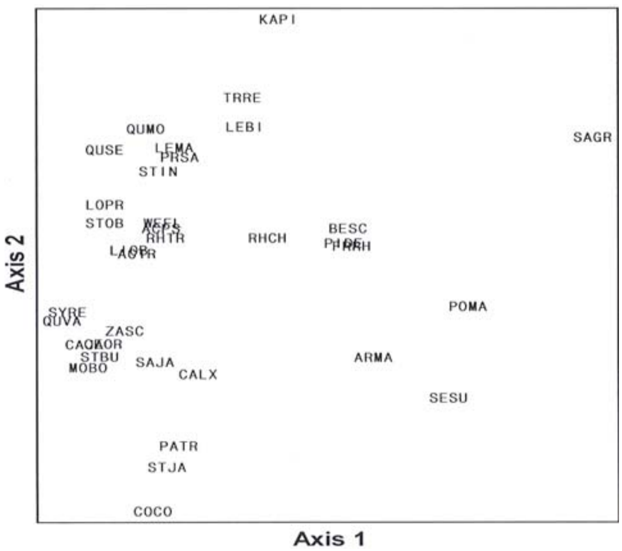

Fig. 3. Species ordination of 35 woody plants from 70 plots in the riparian zone of the Tsang stream in Mt. Seorak National Park, eastern Korea.

ACPS: *Acer pseudo-sieboldianum*, ACTR: *Acer truncatum*, ARMA: *Aristolochia manchuriensis*, BESC: *Betula schmidtii*, CAJA: *Callicarpa japonica*, CALX: *Carpinus laxiflora*, COCO: *Cornus controversa*, FRRH: *Fraxinus rhynchophylla*, KAPI: *Kalopanax pictus*, LEBI: *Lespedeza bicolor*, LEMA: *Lespedeza maximowiczii*, LIOB: *Lindera obtusiloba*, LOPR: *Lonicera praeflorens*, MOBO: *Morus bombycis*, PATR: *Parthenocissus tricuspidata*, PIDE: *Pinus densiflora*, POMA: *Populus maximowiczii*, PRSA: *Prunus sargentii*, QUMO: *Quercus mongolica*, QUSE: *Quercus serrata*, QUVA: *Quercus variabilis*, RHCH: *Rhus chinensis*, RHTR: *Rhus trichocarpa*, SAGR: *Salix gracilistyla*, SAJA: *Sapium japonicum*, SESU: *Securinega suffruticosa*, STBU: *Staphylea bumalda*, STIN: *Stephanandra incisa*, STJA: *Styrax japonica*, STOB: *Styrax obassia*, SYRE: *Syringa reticulata* var. *mandshurica*, TRRE: *Tripterygium regelii*, WEFL: *Weigela floribunda*, ZASC: *Zanthoxylum schinifolium.*

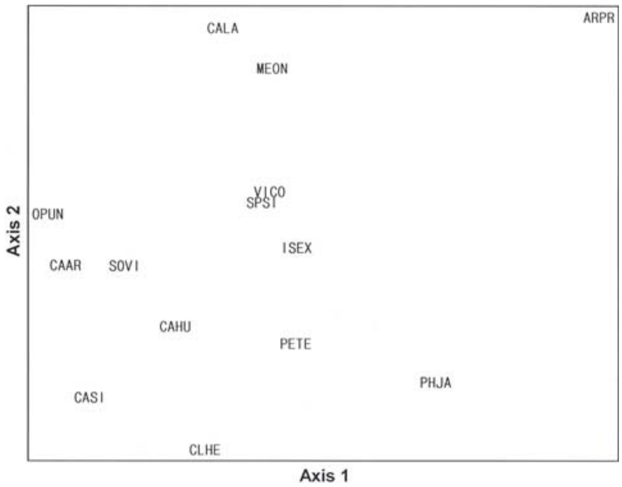

Fig. 4. Species ordination of 14 herbaceous plants from 70 plots in the riparian zone of the Tsang stream in Mt. Seorak National Park, eastern Korea.

ARPR: *Artemisia princeps* var. *orientalis*, CAAR: *Calamagrostis arundinacea*, CAHU: *Carex humilis*, CALA: *Carex lanceolata*, CASI: *Carex siderosticta*, CLHE: *Clematis heracleifolia*, ISEX: *Isodon excisus*, MEON: *Melica onoei*, OPUN: *Oplismenus undulatifolius*, PETE: *Peucedanum terebinthaceum*, PHJA: *Phragmites japonica*, SOVI: *Solidago virga-aurea* var. *asiatica*, SPSI: *Spodiopogon sibiricus*, VICO: *Viola collina.*

Stand Dynamics

In the initial stage, the sizes of Korean red pines showed a reverse J-shaped distribution, being dominated by seedlings with diameter <1.0 cm. As the diameter class increased, the percentage occupation by *Populus maximowiczii* and *S. gracilistyla* became higher (Fig. 5A). In the establishing stage, the size classes of pines were normally distributed. Most pines were juveniles, which are <5 cm in DBH and few other species appeared (Fig. 5B). In the competitive stage, the size classes of pines again showed a normal distribution, while other species showed reverse J-shaped distributions (Fig. 5C). Dead pines, which consisted of individuals <14 cm DBH, increased in this competitive stage. *P. maximowiczii* appeared in all diameter classes but their frequency was not high. In the stabilizing stage, pine size classes again showed a normal distribution, whereas those of other species were the reverse J-shape. *P. maximowiczii* appeared in almost all diameter classes but their frequency was not high (Fig. 5D).

Species Diversity

The number of species, diversity index, and maximum diversity index tended to increase with advancing developmental stage excepting in the establishing stage. The evenness index showed a similar trend, as well, but the dominance index showed no clear relationship with developmental stage (Table 4).

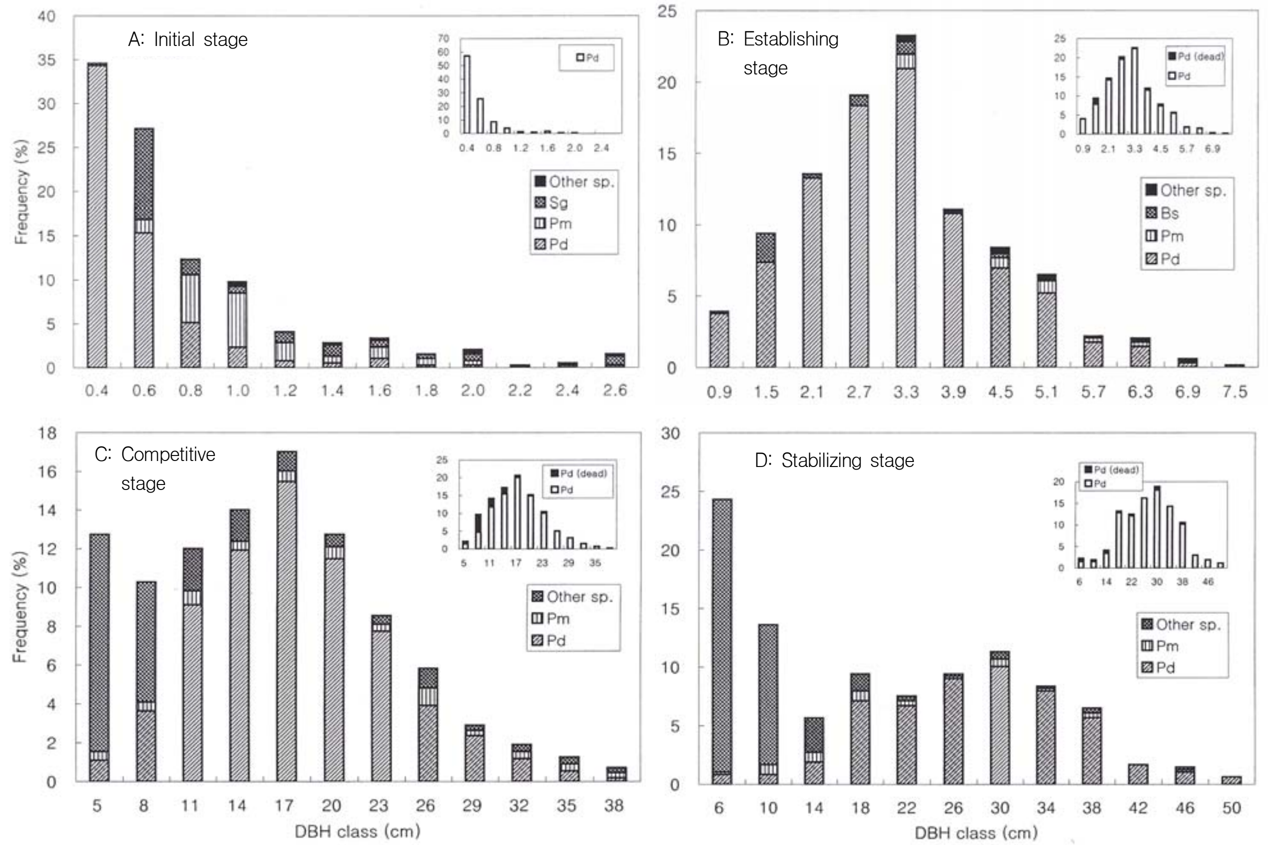

Fig. 5. Frequency distributions of diameter classes of major woody plants in the riparian zone of the Tsang stream in Mt. Seorak National Park, eastern Korea.

Table 4. Species diversity for each developmental stage of *Pinus densiflora* stands on the riparian zone of the Tsang stream

Index	Initial stage	Establishing stage	Competitive stage	Stabilizing stage
No. of species	14.5±4.5	10.9±3.5	37.8±12.0	41.9±13.2
Diversity (H')	1.635	1.386	1.949	1.977
Evenness (J')	0.912	0.891	0.893	0.930
Dominance (D')	0.088	0.109	0.107	0.070
H'_{max}	1.792	1.556	2.182	2.127

DISCUSSION

Riparian Zones as Habitats for Pine Stands

Well-drained sands or gravels weathered from granites and eroded by storm water during the summer monsoon months are a favorable soil type for Korean red pines. With its wide range of tolerance, *P. densiflora* normally occurs on thin and infertile soils of rock outcroppings, weathered rocks, ridge tops, and sandy or pebble shores of streams. It can also grow well in disturbed soils on mountain slopes and bases after forest thinning or brush removal near human settlements (Lee 1976, Toyohara 1984, Skeen et al 1993, Lee and Hong 2001, Lee 2002, Lee et al 2004, Chun et al 2006).

Our study area, located in the upstream area of the Tsang stream, extended from the Hangye stream and Sogongweon to Biseondae on Mt. Seorak. The substrate is comprised of cobble and pebble. This coarse substrate particle size makes the study site very dry in spite of the periodic water supply. Korean red pine forests, which are desiccation-tolerant, have become established in the upstream riparian zone. However, the riverine environment is frequently exposed to natural and artificial disturbances (Malanson 1993, Briggs 1996, Naiman 1998) and receives plentiful solar radiation as a result. These environmental characteristics of the upstream areas of the Tsang stream make it an appropriate habitat for Korean red pine stands.

Dynamics of Korean Red Pine Stands in Riparian Zones

The habitat for the initial stage is the waterfront of gravel bars, which are usually comprised of cobbles transported by floods (Table 1). These sites are adjacent to watercourses and therefore are frequently flooded. As a result, the pine population consists of seedlings and saplings and the frequency distribution of diameter classes shows a reverse J-shape, demonstrating that these populations are in the invasion stage (Barbour et al 1998). Periodic flooding increases the water supply, promoting germination of pines and frequent disturbance increases the light intensity, which can facilitate growth of pine seedlings (Lee et al. 2004). However, these sites are unstable, which means that established plants can be washed away during the flooding season. This variable habitat is characterized by the prevalence of pines in the seedling or sapling stages (Fig. 5).

In these waterfront habitats, *S. gracilistyla*, *Populus maximowiczii, Securinega suffruticosa*, and *Artemisia princeps* var. *orientalis* and *Phragmites japonica* are the major species of woody and herbaceous plants, respectively. Those plants are wind-dispersed, and are usually found at streamside (Naiman and Bilby 1998). *Populus* and *Salix* are typical riparian pioneer species worldwide (Malanson 1993), and *Phragmites japonica*, which has the highest importance value and deep roots, contributes to the stabilization of the habitat (Song and Song 1996, Lee and Kim 2005).

S. gracilistyla and *P. maximowiczii* in this habitat generally had larger diameters than pines (Fig. 5), which implies that these plants were established in this site earlier than pines. Their facultative reproductive strategies, including both vegetative and sexual reproduction, as well as their strong root systems, plentiful seed production, distant seed dispersal, and other characteristics may contribute to their earlier establishment (Briggs 1996, Naiman and Bilby 1998).

Pine stands in the establishing stage are located in the interior of gravel bars (Table 1). This habitat is exposed on flooding disturbance like the initial stage but flooding in the interior occurs less frequently. As a result of these habitat characteristics, although some juvenile pines in the establishing stage reach the subtree layer, most individuals are in the shrub and herb layers (Table 1).

Aside from pines, *Populus maximowiczii, Phragmites japonica, Spodiopogon sibiricus*, and *Fraxinus rhynchophylla* were dominant species in this habitat. The diameter class was normal and the frequencies of the species other than pine were very low (Fig. 5). This result suggests that pines and other plant species occurring in this site are disturbance-dependent and shade-intolerant (Williams and Johnson 1990). The absence of species competitive with pine may be due to the relatively unstable habitat conditions.

The habitat of the competitive stage is located in the central interior parts of gravel bars and floodplains. Therefore, these habitats experience a lower frequency of flooding disturbance. Communities in this stage were stratified into four layers, including tree, subtree, shrub, and herb layers (Table 1). *P. maximowiczii*, *L. maximowiczii*, *P. japonica, F. rhynchophylla*, and *S. incisa* dominate this habitat together with pine. The species composition of this stage was similar to that of the fourth stage (Fig. 2). The diameter class distributions of both pine and *P. maximowiczii* were normal, whereas those of the other species were the reverse J-shape (Fig. 5). This result would suggest that the present pine community will be replaced by the other species in future (Oliver and Larson 1990, Lee 1995a, b, Barbour et al. 1998), but the other species usually consist of subtree and shrub species such as *Lindera obsusiloba*, *Sapium japonicum, Callicarpa japonica, Lespedeza maximowiczii*. Therefore, succession from a pine-dominated to a shrub-dominated landscape should not be expected. In this stage, the number of dead trees was much higher than in the earlier successional stages. Tree death may be due to self-thinning (Day 1972, Lee and Kim 1989), but flooding damage could also be a crucial causal factor (Lee 1996).

Habitats in the stabilizing stage are situated on stream banks, and thereby maintain relatively stable environments (Table 1). This habitat is influenced by large-scale floods, which appear at several-decade intervals but are not generally affected by periodic flooding during the rainy season. This habitat type contains a large number of plant species due to the close biological links between aquatic and terrestrial environments. Plant species from mountainous habitats appeared more frequently than aquatic plants. *S. incisa, C. humilis, S. sibiricus, L. obtusiloba, F. rhynchophylla,* and *S. japonicum* were dominant species, along with pine. The diameter class distribution for pines was normal, while that of other species had the J-shape, as in the third successional stage (Fig. 5). Therefore, other vegetation may replace the pine stand in later successional stages (Oliver and Larson 1990, Lee 1995a, b, Barbour et al. 1998). Other species in habitats of this stage include species such as *S. japonica, S. obassia, Q. serrata*, and *Q. mongolica* in the tree and subtree layers. Therefore, further succession is expected in habitats of this stage (Ming 1987, Kim and Yim 1991, Orwig and Abrams 1994, Andrzejczyk and Brzeziecki 1995). However, when the dynamic characteristics of riverine environment are considered, it is difficult to generalize from short-term preliminary research like this study. Further long-term ecological research will be required for proper interpretation of the patterns of succession in Korean red pine stands in riparian habitats.

The Importance of Riparian Forests

Riparian forests are one of the biosphere's most complex ecological systems but also one of the most important for maintaining the vitality of the landscape and its river (Naiman and Decamps 1990, 1997). Riparian forests are highly variable in space and time, reflecting the inherent physical heterogeneity of the drainage basin, the processes shaping its morphology, and the character of the biotic community, as shown in the study. Riparian forests are the products of interactions among biophysical factors whether they are occurring in the past and present, while the forests have strong feedback are influenceds as well on the geological structure and the processes by which they are shaped (Tsujimoto 1999).

The riparian forest extends laterally from the active channel to the active floodplain and terraces (Table 1, Gregory et al, 1991). Riparian forests are very diverse floristically and structurally, which is expressed in relatively high levels of species richness, plant biomass, and structural complexity (Tables 2 and 4). Spatially, riparian forests are heterogeneous mosaics of vegetation patches possessing a wide variety of species (in various stages of succession) arranged in linear patterns corresponding to valley bottoms (Table 1 and Fig. 2). A mosaic of plant communities and the attendant structural and species diversity develops in riparian forests in response to varied disturbances (White and Pickett 1985, Agee 1993).

Many programs and technical documents related to mitigating non-point sources of pollution of streams have adopted a two-tiered approach or policy, which includes: 1) upland measures to control soil erosion and nutrient transport; 2) riparian measures, especially riparian buffers, to intercept or process sediment and pollutants before they enter a stream or river (US EPA 1995, Lowrance et al. 1995, 1997a, b). However, it has been known for some time that riparian buffers can play a much larger role than simply “intercepting or preventing” pollutants from entering streams and rivers (Sweeney 1993). Specifically, buffers can help maintain or enhance the overall health of a stream ecosystem, thereby improving its ability to provide important “ecosystem services” (Daily and Ellison 2002) to humans such as in-stream processing of nutrients, pesticides, etc. Thus, the conservation, restoration, and management of riparian zones should play a critical role in maintaining and improving water quality in streams and rivers throughout the world.

In Asian countries where people depend on rice as a staple food, most floodplains of rivers have been transformed to rice fields, and high banks were constructed along waterways to prevent flooding. Consequently, the widths of most rivers were reduced sharply. More recently, many rice fields have been transformed to urban areas. As a result of these continuing transformation processes, riverside communities have degenerated or been destroyed by tree cutting, the introduction of exotic species, the diversion and channeling of water for agriculture, and the use of river beds and shores for cultivation or roads. Therefore, riparian landscapes, including river ecosystems and their surrounding environments, have lost many of their original features. Non-point pollution sources are also increasing due to excessive land use as a result of population growth and urbanization. Therefore, it has become imperative that effective steps be taken to restore the lost riparian forests (Lee et al. 2005, Lee et al. 2006).

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