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Environmental Factors Affecting Establishment and Expansion of the Invasive Alien Species of Tree of Heaven (*Ailanthus altissima*) in Seoripool Park, Seoul

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Abstract: Tree of heaven (*Ailanthus altissima* Swingle) as an invasive alien plant, appeared usually in the disturbed locations such as road-side, incised slope, and trampling path-side. They appeared abundantly in the trampling path-side but they did not appear or were rare in the interior of forest. Density and importance value of tree of heaven were proportionate to the relative light intensity measured according to distance from the trampling path toward forest interior and closely related to the breadth of trampling path as well. They were associated with annual, other exotic species or ruderal plants well. Distributional pattern of mature trees of them in the study area and its surrounding environments implied that they were introduced intentionally. Size class distribution of them showed that they are in expansion and artificial interferences such as, installing physical training space and developing hiking course functioned as trigger factors in their invasion and expansion. The results support the facts known generally in relation to invasion and expansion of the invasive alien plants. In this viewpoint, we suggest a management plan that applies ecological restoration principles to address ecosystems infected with tree of heaven by restoring the integral feature of the degraded nature and conserving the remained nature more thoroughly.

Key words: *Ailanthus altissima,* artificial interference, ecological restoration, invasion, invasive alien plant

The geographical ranges of many species are restricted by major environmental and climatic barriers to dispersal. As a result of geographical isolation, patterns of evolution have proceeded in different ways in each major area of the world.

Human have radically altered this pattern by transporting species throughout the world. In pre-industrial times, people carried cultivated plants and domestic animals from place to place as they set up new farming areas and colonies. In modern times a vast array of species has been introduced, deliberately and accidentally, into areas where they are not native (Grove and Burdon, 1986; Drake et al., 1989; Hedgpeth, 1993).

Oftentimes, such exotic plants expand their range beyond the place of initial establishment due to their advantageous life history strategies (Meffe et al., 1997). Disturbed lands in particular provide favorable microsites for invasive alien species (hereafter IAS) equipped with opportunistic or ruderal life history strategies (Johnstone, 1986; Hobbs and Huenneke, 1992; Meffe et al., 1997).

Invasive plants can cause a variety of problems in native plant communities: excluding native species; altering habitat, hydrology, and nutrient cycling; and significantly impacting plant animal diversity (Vitousek, 1986; Huston et al., 1994; Hall and Mills, 2000). Development and implementation of safe, effective eradication or control agents requires considerable time and resources, and such programs are frequently unsuccessful (Dahlsten, 1986). Furthermore, without careful selection and implementation, many chemical, mechanical, and biological control methods can themselves be detrimental to nontarget species and ecosystem health, which may accelerate the process of invasion (McNeeley et al., 2001).

IAS has the potential to invade other ecosystems and affect native biota in a direct or indirect way. They have invaded and affected native biota in virtually every ecosystem type on Earth. These species have contributed to many hundreds of extinctions, especially under islands condition, whether it is on actual islands or ecological

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islands. The environmental cost is the irretrievable loss of native species and ecosystems (McNeely et al., 2001).

IAS can transform the structure and species composition of ecosystems by repressing or excluding native species, either directly by out-competing them for resources or indirectly by changing the way nutrients are cycled through the system (McNeely et al., 2001). Increasing global domination by a relatively few invasive species threatens to create a relatively homogenous world rather than one characterized by great biological diversity and local distinctiveness (Mooney and Hobbs, 2000).

The rate of newly detected invasions is increasing over time across many ecosystems and geographic regions (Mills et al., 1993; Rejmanek and Randall, 1994; Fuller et al., 1999; Ruiz et al., 2000). The observed rate increase is often exponential. Search effort has likely increased in recent years, possibly contributing to the observed increase in invasions within some taxonomic groups. However, the overall pattern is very robust, occurring for conspicuous and well-known taxa and in well-studied systems, indicating that invasion rates have indeed increased dramatically in the last half of the twentieth century.

The strong effects of invasions, combined with an apparent increase in the rate of invasions, have caused widespread public and scientific concern, propelling policy and management actions. Many countries now have policies to limit the risk of future invasions and to reduce the impact and spread of established nonnative species (Shine et al., 2000; NISC, 2001).

Prevention of new invasions is a clear priority in emerging policies. Management actions directed at established invasions can also have merit, providing options following colonization, but such efforts are often idiosyncratic to the particular species and are potentially expensive, long-term propositions (Mack et al., 2000; Wittenberg and Cock, 2001). Successful eradication of established invasions is an unlikely outcome in many instances, even with vast improvements in capacity for "early detection" of new invasions. Furthermore, a separate effort -whether an eradication program or efforts to control spread and abundance- may be required for each invasion event, even if the same species. In contrast, strategies to prevent new invasions are directed at key transfer mechanisms, or vectors. Such vector management may be used to interrupt transfer of a particular target species, but it can also be designed to prevent simultaneously the wholesale transfer of diverse assemblages (including both target and nontarget species), providing a powerful and efficient management approach.

Most of studies on the IAS carried out in Korea focused on listing up or describing the distribution range. But expansion of IAS became already worldwide problem and the spreading effects of them are getting extended (McNeeley et al., 2001). This point highlights the urgent need for new approaches to deal with IAS, especially as a strategy to inhibit their new invasion and expansion.

Origin of tree of heaven is China. They occur nationwide in China with the exception of Gansu, Heilongjiang, Hainan, Jilin, Ningxia, Qinghai, Tibet and Xinjiang (NISIC, 2006). Nowadays, this plant is known internationally as very aggressive invasive alien species. In the United States, they are distributed across the whole country occurring in 42 states from Maine to Florida and west to California (Swearingen, 2006). They are also recognized as a thermophilous species and thereby their distribution is applied to interpret hot island effect in Germany (Sukopp and Weiler, 1986). In Korea, this plant is distributed throughout the national territory except for islands. It is known that this plant was introduced to use for medicine although it was unknown clearly when it was introduced to Korea (KFRI and KNA, 2002). Tree of heaven is a prolific seed producer, grows rapidly, and thereby can overrun native vegetation. Once established, it can quickly take over a site and form an impenetrable thicket. It also produces toxins that prevent the establishment of other plant species (Swearingen, 2006).

The objectives of this paper are clarifying the following items: (1) Where are distributed the white snakeroot, an IAS? (2) Which condition does the invasive alien plant favor? (3) How do we inhibit expansion of the invasive alien plant?

MATERIALS AND METHODS

Study area

This study was carried out in an urban park called "Seoripool Park" and surrounding urban areas located on Banpo-dong, Seocho-gu, Seoul, Korea (Fig. 1). Seoripool Park is an ecological island enclosed by the residential area (Banpo apartment complex), the educational (Catholic university) and public facilities (National library), the public facility (Court of law), and the transportation facility (Gangnam express bus terminal) in east, west, south and north, respectively. Soil of this site is originated from the granitic gneiss (Lee et al., 2002a). Vegetation of this site is covered with plantation and secondary forest (Fig. 1; Seoul City, 2000). Plantation is composed of black locust (*Robinia pseudoacacia*), aspen (*Populus tomentoglandulosa*), zelkova (*Zelkova serrata*) and Korean pine (*Pinus koraiensis*) plantations. Secondary forest is composed of *Quercus acutissima* and *Q. mongolica* communities. Soil and vegetation of this site, especially bordered on the trampling path is under severe artificial impacts due to frequent visit of surrounding residents and interferences related to indiscreet introduction of the athletic and recreational facilities and of non-native plants for horticulture and landscape architecture by the local government.

Study sites were designated to all the sites that tree of heaven appeared in the Seoripool Park.

Methods

Field survey for this study was carried out from July to September 2003 and partial resurvey was done from May to June 2004.

A vegetation map (scale of 1 : 5,000) for the study sites was constructed with GIS (Geographic Information System) program supported by ArcView (ESRI, 1996), based on urban ecological map (Seoul City, 2000) and field surveys. Density of tree of heaven was investigated in three belt transects with one meter width, which are installed from the edge of trampling path toward the interior of forest. Vegetation survey was carried out by recording cover degree of Braun-Blanquet (1964). Quadrat size for vegetation survey was 10 m × 10 m. Ordinal cover was converted to the median value of percent cover range in order to get relationships between appearance status of tree of heaven, and relative light intensity, breadth of trampling path, and species diversity in the study area (Lee et al., 2002b).

Annual ring cores were taken with increment borer at 20 cm above ground. Tree ages were obtained by counting the number of annual rings under the dissecting microscope.

Frequency distribution of diameter class of major woody plants appeared in each study site was investigated and thereby shown in diagrams. DBH (diameter of breast height) was measured by measuring tape and diameter at ground surface

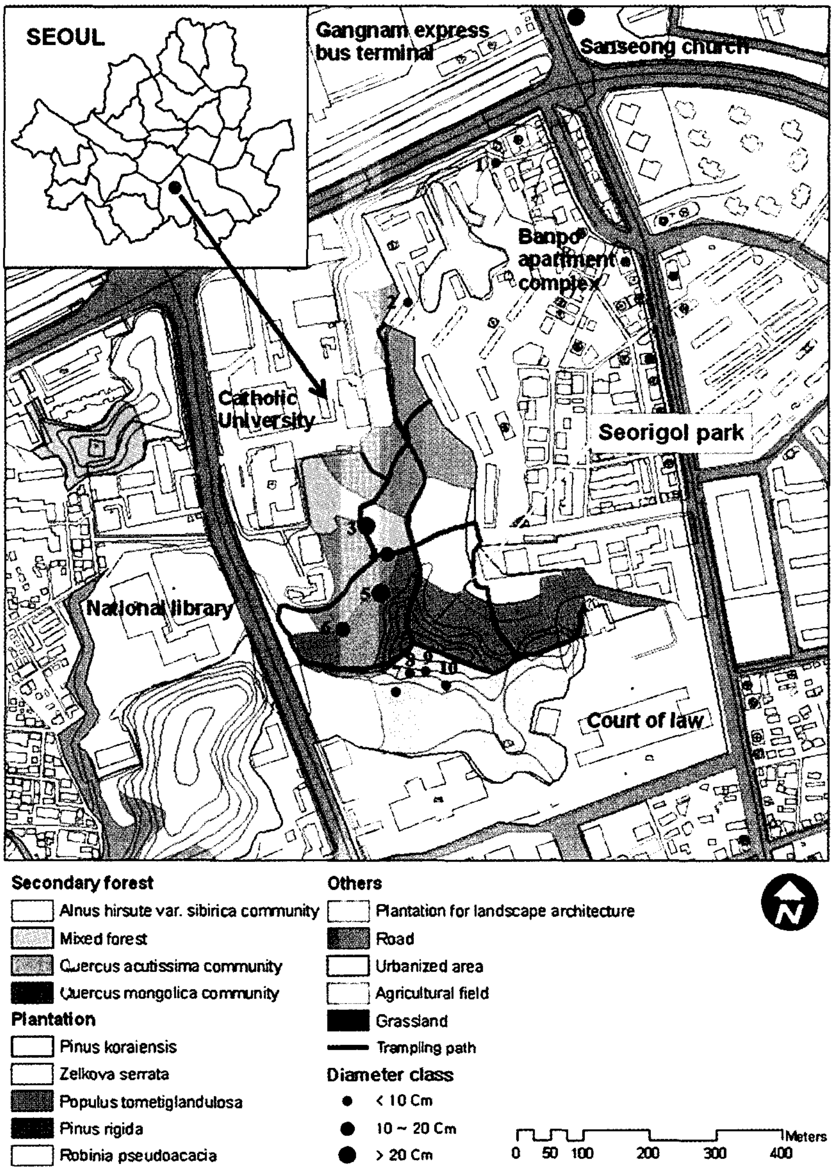

Fig. 1. A map showing vegetation distribution in the study area, Seripool Park located in Banpo-dong, Seocho-gu, Seoul. Numerals on map indicate site number. Dot size indicates size class of tree of heaven in each site.

(D_{10}) was measured for individuals below 1.3 m in height.

Environmental characteristics of habitat of tree of heaven were investigated by measuring breadth of trampling path, relative light intensity, and vegetation structure of each study site. Breadth of trampling path was obtained by measuring the distance between stems of trees, which stands on both sides of the trampling path with the measuring tape. Site 1 is located on the road-side and thereby the breadth indicates road's one. In the site 2, where is located on the incised slope, the width means the slope's one. Relative light intensity was measured with the photometer (LX-1332) in three zones within five, five to ten, and more than ten meters from the trampling path. Light intensity was obtained by averaging values measured ten times above the height level of herb layer of vegetation stratification. Light intensity in forest interior was expressed in the relative value to that in the center of trampling path as light intensity in field is very variable. On the other hand, light intensity on the trampling path was expressed in the relative value to that on the surrounding bare ground.

RESULTS

Habitat of tree of heaven

Habitats of tree of heaven in the study area, Seoripool Park were shown in Fig. 1. As was shown in Fig. 1, tree of heaven appeared in the road-side (site 1), incised slope (site 2), and around the trampling path (sites 3 to 6) and the athletic facilities (sites 7 to 10). The importance value of tree of heaven was higher in the site 7 to 10, which are located around the summit. The athletic facilities and the recreational space were installed and trees were cut to maintain the facilities in those sites. Tree of heaven is expanded rapidly centering on those sites.

Density of tree of heaven

The closer to the trampling path, the higher density was as the density was shown in 8.5 ± 3.8, 6.4 ± 3.4 and 0 in zones within five, five to 10, and more than 10 meters from the trampling path, respectively (Fig. 2).

Relative light intensity

Changes of the relative light intensity with the distance from the trampling path were shown in Fig. 3. The relative light intensity showed more than 20% within 5 m from the trampling path. The intensity was reduced in the level of 13% in the distance from 5 to 10 m and below 10% in the distance more than 10 m.

Relationship between breadth of trampling path and relative light intensity

The relative light intensity tended to increase with the increase of the breadth of the trampling path. Therefore, both parameters showed significant correlative relationship (Fig. 4).

Habitat characteristics of tree of heaven based on vegetation data

In order to clarify habitat characteristics of tree of heaven, vegetation data of each site were obtained. Vegetation data of 10 sites, in which tree of heaven occurred in the study area were summarized in Table 1. Omitted the introduced species, dominant species of site 1 to 10 were shown in *Commelina communis* and *Setaria viridis*, *Ageratina altissima*, *Oplismenus undulatifolius*, *O. undulatifolius*, *O.*

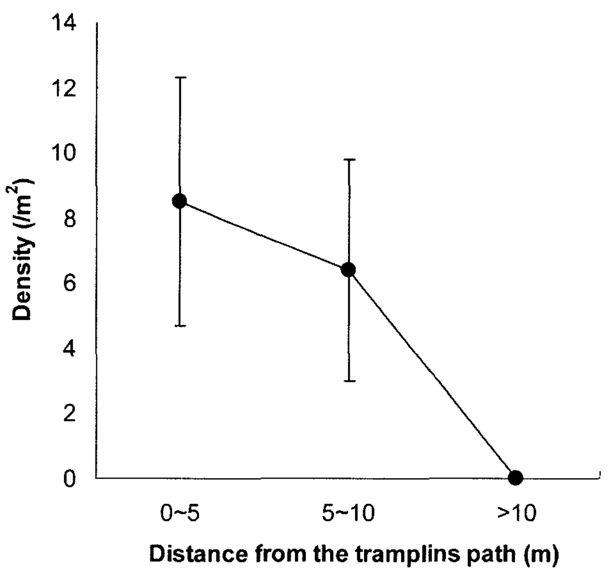

Fig. 2. Changes of density of tree of heaven with the distance from the trampling path.

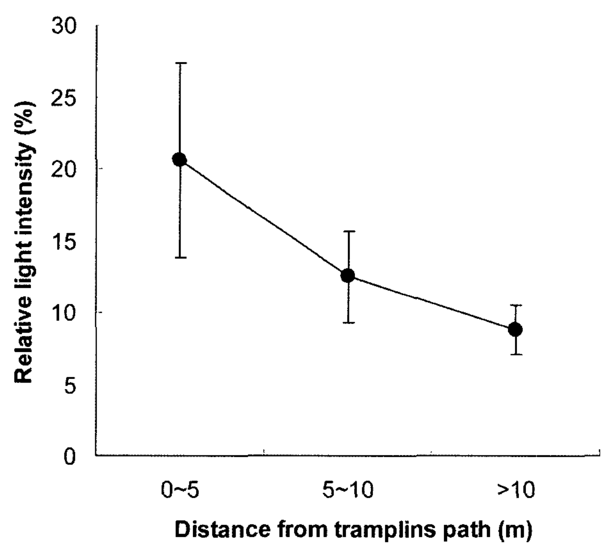

Fig. 3. Changes of the relative light intensity with the distance from the trampling path.

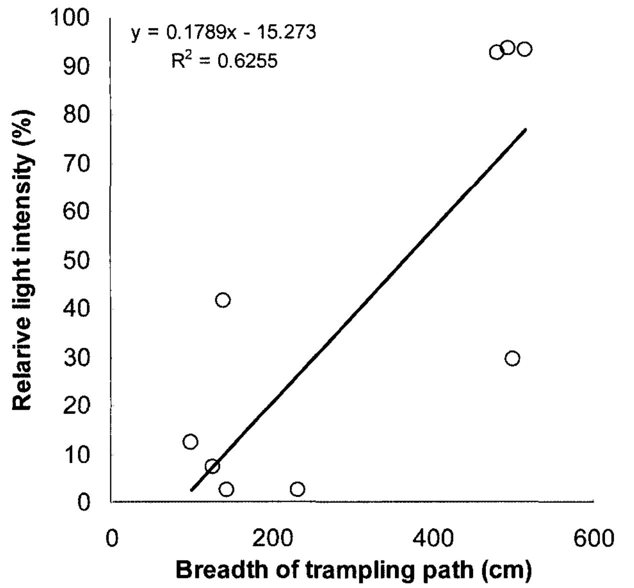

Fig. 4. Relationships between breadth of trampling path and relative light intensity in the study area.

undulatifolius, *A. altissima*, *Lespedeza cyrtobotrya*, *L. cyrtobotrya* and *Miscanthus sinensis*, *Zoysia japonica* and *Quercus mongolica*. Among them, *C. communis*, *S. viridis* and Oplismenus undulatifolius are annual and, *A. altissima* is an exotic plant. And, *L. cyrtobotrya*, *M. sinensis*, and *Z. japonica* are a sort of ruderal, which appear frequently in the site disturbed by fire or various human interferences (Grime, 1979; Lee et al., 2002a). These results demonstrated that tree of heaven usually invaded to the disturbed site.

Plant species diversity in habitat of tree of heaven

The number of plant species appeared in habitat of tree of heaven was shown in nine to twenty eight species (Fig. 5). Species richness was higher in the order of sites 5, 4, 3-6, 1, 9, 7-10, 2, and 8. On the other hand, the species rank-dominance curves was less steep in the order of sites 3, 1, 5, 4, 7-10, 9, 6, 2, and 8 and thereby showed the order similar to that by richness.

Table 1. Species composition of the study area

Species	1	2	3	4	5	6	7	8	9	10
Ailanthus altissima	8.3	5.9	33.5	3.2	14.1	13.0	40.8	44.9	44.4	3.0
Plaranus occidentalis	**20.7**	2.0	·	·	·	·	·	·	·	·
Robinia pseudo-acacia	**20.7**	·	·	·	·	·	·	·	·	·
Parthenocissus tricuspidata	0.6	·	0.6	·	·	·	·	·	·	·
Commelina communis	**20.7**	·	·	·	·	·	·	·	·	·
Chenopodium album var. centrorubrum	0.6	·	·	·	·	·	·	·	·	·
Metaplexis japonica	0.6	·	·	·	·	·	·	·	·	·
Setaria viridis	**20.7**	·	·	·	·	·	1.1	1.2	·	·
Quercus acutissima	0.6	·	·	12.0	0.8	·	1.1	·	3.6	3.0
Digitaria sanguinalis	0.6	·	·	·	·	·	·	·	·	·
Mosla punctulata	1.7	·	·	·	·	·	·	·	·	·
Artemisia princeps var. orientalis	0.6	2.0	·	·	·	·	·	3.4	·	·
Oxalis corniculata	0.6	·	·	·	·	·	·	·	·	·
Erigeron annuus	0.6	2.0	·	·	·	·	·	·	·	·
Solanum nigrum	0.6	·	·	·	·	·	·	·	·	·
Achyranthes japonica	0.6	2.0	·	·	·	·	·	·	·	·
Calystegia hederacea	0.6	·	·	·	·	·	·	·	·	·
Erechitites hieracifolia	0.6	·	·	·	·	·	1.1	·	·	·
Persicaria blumei	0.6	·	0.6	0.8	0.8	1.4	·	·	·	·
Sorbus alnifolia	·	5.9	·	0.8	2.4	·	·	·	·	·
Ageratina altissima	·	**74.3**	·	12.0	2.4	**21.7**	·	·	·	·
Pilea peploides	·	2.0	·	·	·	·	·	·	·	·
Bidens bipinnata	·	2.0	·	·	·	·	·	·	·	·
Carex humilis	·	2.0	·	·	·	·	·	·	·	·
Populus tomentiglandulosa	·	·	**25.9**	12.0	11.8	4.3	·	·	·	3.0
Cornus controversa	·	·	1.9	·	2.4	·	·	·	·	·
Quercus aliena	·	·	3.8	0.8	·	4.3	·	·	·	·
Quercus serrata	·	·	1.9	·	·	4.3	·	·	·	·

Table 1. continued

Species	1	2	3	4	5	6	7	8	9	10
Lindera obtusiloba	·	·	0.6	·	·	1.4	·	·	·	·
Oplismenus undulatifolius	·	·	**24.0**	**29.9**	**29.4**	1.4	·	·	·	·
Diospyros lotus	·	·	0.6	·	0.8	·	·	·	·	·
Magnolia obovata	·	·	0.6	·	·	·	·	·	·	·
Castanea crenata	·	·	0.6	·	0.8	2.9	·	·	·	1.0
Prunus leveilleana	·	·	0.6	·	·	·	·	·	·	·
Artemisia keiskeana	·	·	0.6	·	·	·	·	·	3.6	1.0
Pueraria thunbergiana	·	·	0.6	0.8	·	1.4	·	·	·	·
Celastrus orbiculatus	·	·	0.6	·	0.8	·	·	·	·	·
Elaeagnus umbellata	·	·	0.6	·	·	·	·	·	·	·
Spodiopogon sibiricus	·	·	0.6	0.8	0.8	·	1.1	·	3.6	1.0
Quercus dentata	·	·	0.6	0.8	2.4	1.4	1.1	·	1.2	1.0
Leersia japonica	·	·	0.6	·	·	·	·	·	·	·
Alnus hirsuta	·	·	·	2.4	2.4	**21.7**	·	·	·	·
Rubus crataegifolius	·	·	·	2.4	·	·	·	·	·	·
Viola verecunda	·	·	·	2.4	2.4	·	·	·	·	·
Ampelopsis brevipedunculata var. heterophylla	·	·	·	0.8	·	·	·	·	·	·
Persicaria thunbergii	·	·	·	12.0	11.8	1.4	·	·	·	·
Athyrium niponicum	·	·	·	0.8	2.4	4.3	·	·	·	·
Clematis mandshurica	·	·	·	0.8	·	·	·	·	·	·
Dioscorea batatus	·	·	·	0.8	·	·	·	·	·	·
Smilax nipponica	·	·	·	0.8	0.8	1.4	·	·	·	·
Symplocos chinensis var. pilosa	·	·	·	0.8	0.8	1.4	·	·	·	·
Alnus hirsuta var. sibirica	·	·	·	·	2.4	·	·	·	·	·
Quercus mongolica	·	·	·	·	2.4	4.3	3.3	·	3.6	**63.5**
Astilbe chinensis var. davidii	·	·	·	·	0.8	·	·	·	·	·
Rhus trichocarpa	·	·	·	·	0.8	·	·	·	·	·
Melica onoei	·	·	·	·	0.8	1.4	·	·	·	·
Acer palmatum	·	·	·	·	0.8	·	·	·	·	1.0
Spiraea prunifolia for. simpliciflora	·	·	·	·	0.8	·	·	·	·	·
Rosa multiflora	·	·	·	·	0.8	·	1.1	·	·	·
Ligustrum obtusifolium	·	·	·	·	0.8	·	·	·	·	·
Fraxinus rhynchophylla	·	·	·	·	·	4.3	·	·	·	·
Rhododendron yedoense var. poukhanense	·	·	·	·	·	1.4	·	·	·	·
Lespedeza cyrtobotrya	·	·	·	·	·	·	**40.8**	**18.0**	·	1.0
Arundinella hirta	·	·	·	·	·	·	1.1	3.4	1.2	·
Indigofera kirilowii	·	·	·	·	·	·	1.1	·	1.2	1.0
Miscanthus sinensis	·	·	·	·	·	·	1.1	**18.0**	1.2	1.0
Zoysia japonica	·	·	·	·	·	·	1.1	3.4	**17.8**	·
Carex lanceolata	·	·	·	·	·	·	1.1	·	1.2	1.0
Cymbopogon tortilis var. goeringii	·	·	·	·	·	·	1.1	3.4	1.2	·
Pinus rigida	·	·	·	·	·	·	·	3.4	3.6	·
Pinus densiflora	·	·	·	·	·	·	·	·	3.6	·
Scilla scilloides	·	·	·	·	·	·	·	·	1.2	·
Metaplexis japonica	·	·	·	·	·	·	·	·	1.2	·
Rhododendron mucronulatum	·	·	·	·	·	·	·	·	3.6	15.2
Pinus koraiensis	·	·	·	·	·	·	·	·	3.6	3.0

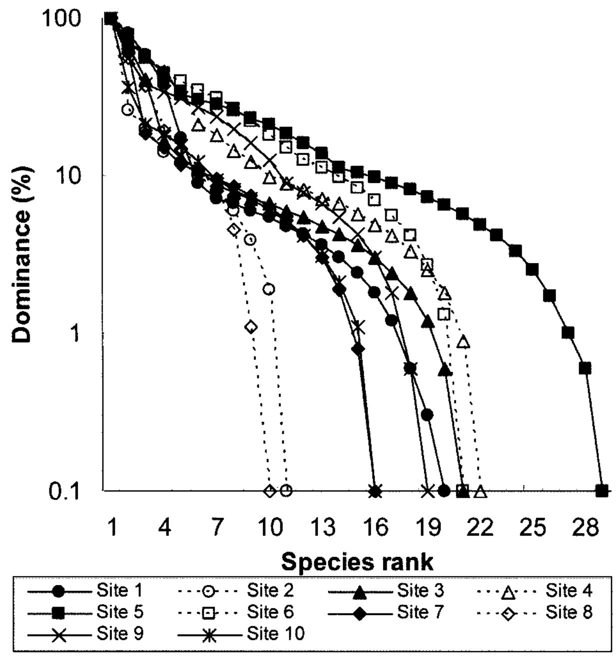

Fig. 5. Species rank-abundance curves of each study site.

Relationship between environmental factors and distribution of tree of heaven

Elton's hypothesis (Elton, 1958) asserted that species-rich systems with well-established species interactions are not susceptible to invasion of IAS. But the objection on the hypothesis was also raised much (Levine and D'Antonio, 1999; Lonsdale, 1999; Lee et al., 2003). Results of correlative analyses demonstrated that the importance value of tree of heaven showed significant relation with disturbance factors but did not such relationship with diversity related factors (Fig. 6). In this respect, results of this study resembled the latter's opinion.

Size class distribution of tree of heaven

Size class distribution of tree of heaven showed the reverse J shaped type in all sites (Fig. 7). This result means that seedling recruitment is continued and the population is invasive type (Crawley, 1997). In addition, we knew that tree of heaven established earlier are already in the mature stage, which can produce progenies by reproduction and expand their territory. Those mature trees were found in the sites 3, 5, and 6. Those sites are attributed to *Populus tomentoglandulosa* plantation near to the Catholic university based on vegetation map of the study area (Fig. 1). Considered their ages (about 35 years old) similar to that of *P. tomentoglandulosa*, they would be introduced together when *P. tomentoglandulosa* was afforested. Or they might be invaded naturally from the surrounding areas considered their excellent dispersal capacity due to seed with wing. In fact, old tree of heaven (40 years old) is planted as the street tree around the New Core Department store and the Sanseong church, which are near to this study area, and thus they could be seed sources of the surrounding areas. On the other hand, tree of heaven population of the sites 7 to 10, which are located around the summit of this mountain, is composed of young individuals. They would be dispersed from point sites within the study area, such as sites 3, 5, and 6, which hold mature trees.

On the other hand, individuals in sites 1 and 4 produced seeds and did also seedlings as were shown in Fig. 7, the results mean they arrived at maturation. Their ages obtained from the annual ring were five to years. This result reflects that this plant reach maturation.

DISCUSSION

Ecologists working on invasive species seek to address basic questions, such as: Which taxa invade? How fast do they invade? What types of ecosystems are susceptible to invasive taxa and their impacts? What is the ecological impact of their invasion? How can we contain, control, or eradicate harmful invaders? Our discussion was focused on those five questions.

Which taxa invade?

McNeeley (2001) suggested the following five predictions in relation to invasive species: Firstly, the probability of a species becoming invasive increases with the initial population size, so species introduced intentionally and cultivated plants or maintained under animal husbandry over a long period of time have greater likelihood of establishment. Secondly, species having larger native geographic ranges are more likely to be invasive than those with smaller native ranges. Thirdly, a species that is invasive in one country or location is should be considered as high risk of becoming invasive in an ecologically or climatically similar country or location. Fourthly, species with specialized pollinators are unlikely to be invasive unless their pollinators are also introduced. Finally, successful invasions generally require that the new habitat conditions are comparable to those at the point of origin, especially in terms of climate conditions.

Additional classes of exotics are species that have increased their ranges within continental areas because they are suited to the ways in which humans have altered the environment (Soule, 1990). Another special class of exotics is those that have close relatives in the native biota. When exotics hybridize with native species and varieties, unique genotypes may be eliminated from local populations, and taxonomic boundaries may become obscured (Cox, 2004).

The major predictions made by an emerging theory of plant invasiveness based on biological characters were summarized and compared with tree of heaven in Table 1.

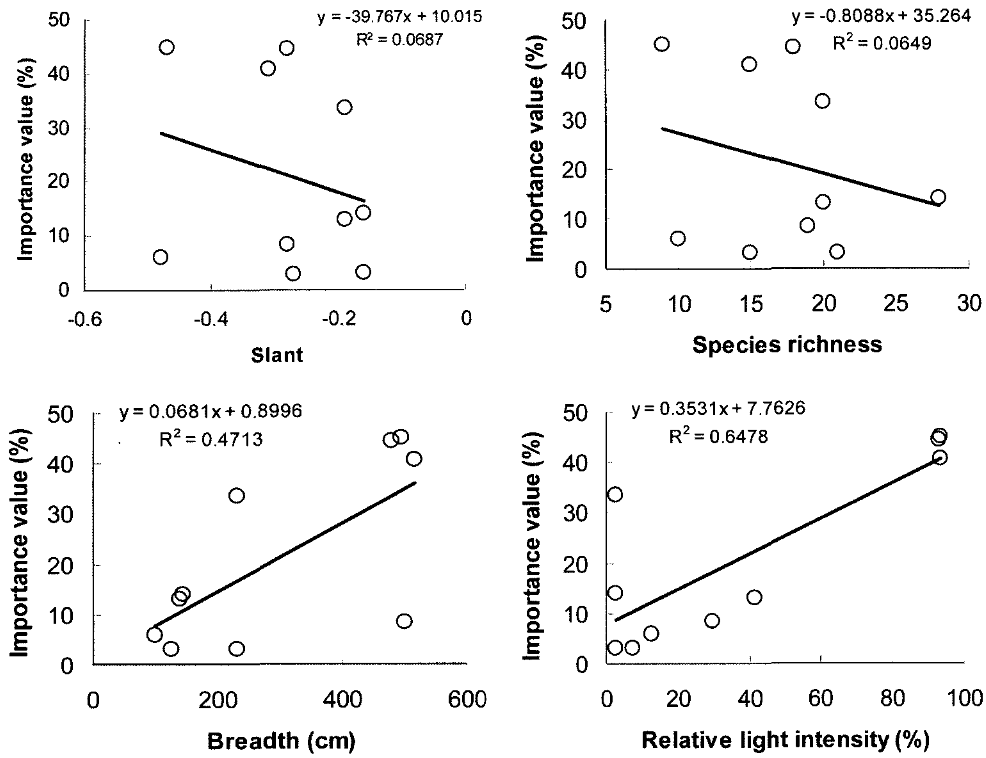

Fig. 6. Relationships between slant of species rank abundance curves (upper left), species richness (upper right), breadth of trampling path (lower left), and relative light intensity (lower right) and the importance value of tree of heaven.

The results demonstrated that tree of heaven satisfies various biological characters that invasive species have to equip with.

How fast do they invade?

The rate of spread is a function of both reproduction and dispersal, with species that reproduce quickly and spread easily moving much more rapidly (Richardson and Rejmanek, 2004). For plants, determining the rate of spread requires knowledge of the rare dispersal events that can send plants over an abnormally long distance. While the rate of dispersal is critical, other factors such as age of reproductive maturity, disturbance frequency, habitat disturbance, and fecundity also are important. Seeds can be transported over long distances by agents such as water, wind, vehicles, or livestock, often at remarkably high speeds (McNeeley et al., 2001). High reproductive capacity of tree of heaven as an early successional species and dispersal potency of their seeds with wing tell us the reason that they are distributed worldwide. Moreover, the reproductive characteristics of tree of heaven that reproduces both sexually and asexually, and early maturation can also contribute to rapid invasion and expansion of the species (Swearingen, 2006).

What types of ecosystems are susceptible to invasive taxa and their impacts?

One reason that exotic species so easily able to invade and dominate new habitats and displace native species is the absence of their natural predators, pests, and parasites in the new habitat. Human activity may create unusual environmental conditions, such as nutrient pulses, an increased incidence of fire, or enhanced light availability, to which exotic species can adapt more readily than native species. The highest concentrations of exotics are often found in habitats that have been most altered by human activity (Hobbs and Huenneke, 1992; Mooney and Hobbs, 2000). Fragmentation of forest, suburban development, and easy access to garbage have allowed the numbers and ranges of, so called roving species to increase. As these aggressive species increase, they do so at the expense of native species that are less competitive and less able to resist predation.

While all ecosystems including those in well-protected national parks, can be invaded potentially, some appear more vulnerable than others. Evolutionarily and geographically isolated ecosystems, notably oceanic islands, are particularly vulnerable. Urban-industrial areas, habitats suffering from periodic disturbance, harbors, lagoons, estuaries and the

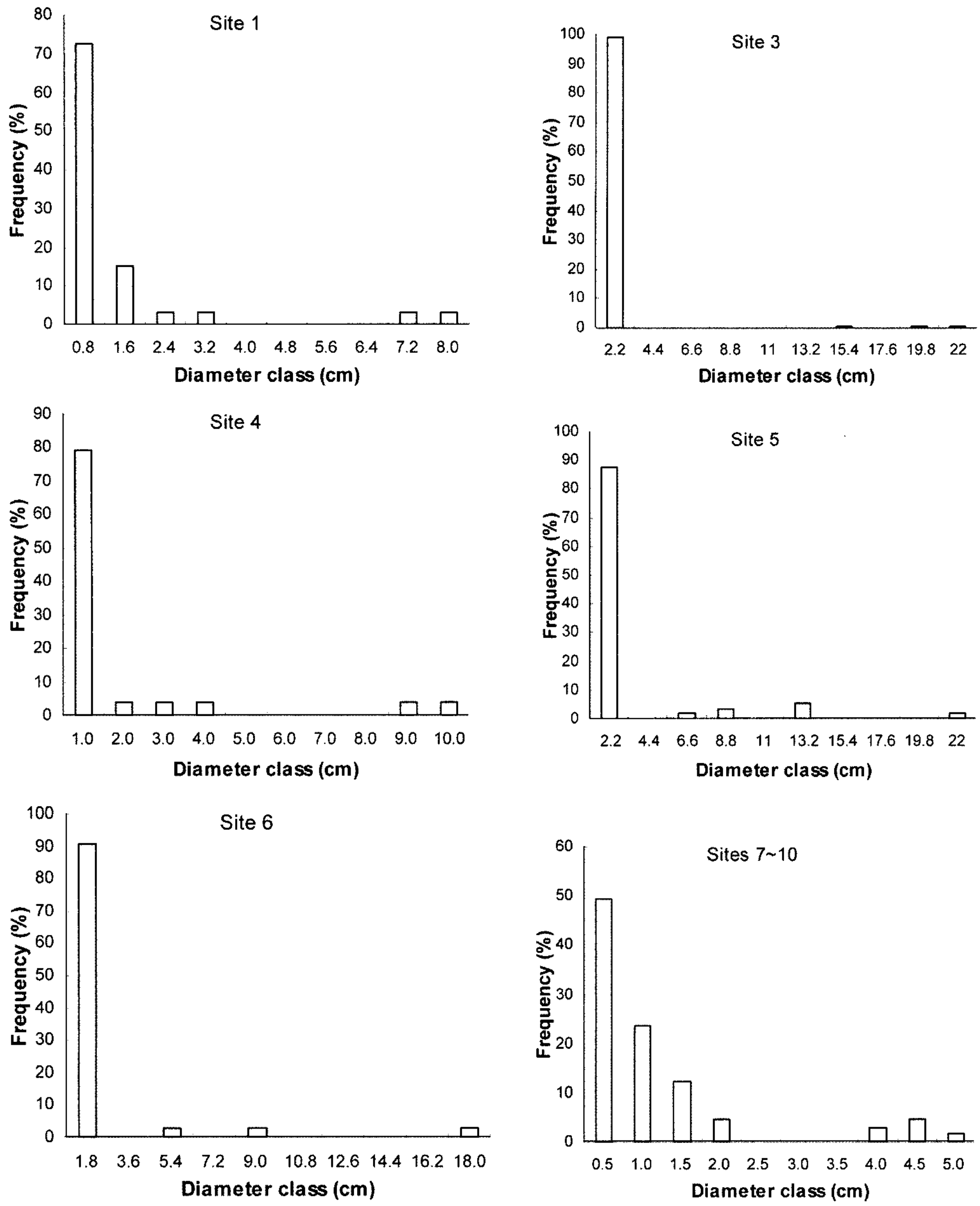

Fig. 7. Diameter class distribution diagrams of tree of heaven appeared in each site. The individuals appeared were too few to construct the diagram in the second site. Individuals of tree of heaven appeared in the sites 7 to 10 have similar size and thereby were expressed in a diagram by synthesizing data from those four sites.

fringes of water bodies, where the effects of natural and anthropogenic disturbances are often linked, are also particularly vulnerable to invasions (Kowarik, 1999).

Many ecologists supporting Elton's hypothesis (Elton, 1958) consider that systems with low diversity to be more susceptible to invasion than species-rich systems with well-established species interactions (MacArthur and Wilson, 1967; Tilman, 1982; 1997; McNaughton, 1983; Pimm, 1991; Baldacchino and Pizzuto, 1996). However, species-rich landscapes can be susceptible to a greater range of invaders because of the greater diversity of habitats typical of such landscapes (Levine and D'Antonio, 1999; Lonsdale, 1999).

Although virtually all the ecological communities are susceptible to invasion to some degree, human activities that disturb ecosystems increase the susceptibility of most ecosystems. Therefore, the continuing expansion of human activities is likely to increase the susceptibility of ecological communities to invasion (McNeeley et al., 2001).

Distribution pattern of invasive alien plant in Korea, which appeared in higher percentages in the order of industrial area (31%), riverside (30%), residential area (25%), and mountainous area (14%), shows such trends (NIER, 1995; 1996). In this study, negative correlation

Table 2. Conditions that facilitate invasion and their relevancy to the tree of heaven

Factors	Relevancy	Literatures
Constant fitness	○	Rejmánek 1999
Genetic change and phenotype plasticity	–	Purps and Kadereit 1999, Levin 2000, Willis et al. 2000, Thébaud and Simberloff 2001
Small genome size	–	Rejmánek 1996b, 1999, Grotkopp et al. 1998
Constant seed production	○	Pannel and Barrett 1998
Small seed mass	○	Richardson and Rejmánek 2004
Dispersal organ	○	Greene and Johnson 1989
Short juvenile period	○	Richardson and Rejmánek 2004
Seed dispersal by invertebrate	–	Strasberg 1995, Rejmánek 1996a, Richardson et al. 2000a
High RGR	○	Baker 1974, Grime and Hunt 1975, Bazzaz 1986, Maillet and Lopez-Grarcia 2000
Wide geographic range	○	Forcella and Wood 1984, Rejmánek 1995, 1996b, 1999, Goodin et al. 1998
Vegetative reproduction	○	Auld et al. 1983, Horak et al. 1987, Pysek 1997, Ceccherelli and Cinelli 1999, Aptekar and Rejmánek 2000
Lacks same genus or family	–	Fenner and Lee 2001, Rejmánek 1999, Lockwood et al. 2001
Mutualisms	–	Richardson et al. 2000a
Efficient competitors for limiting resources	○	Roché et al. 1994, Tilman 1999
Passive dispersal by human	○	Pannetta and Scanlan 1995

between species diversity indices and importance value of tree of heaven supports Elton's hypothesis, while the opposite was true for distribution pattern of tree of heaven concentrated around the trampling path (Fig. 7).

What is the ecological impact of their invasion?

Every alien species alters the composition of native biological communities in some way. Whether it becomes invasive (and thus harmful) depends on the particular characteristics of the alien species, the vulnerability of the host ecosystem and chance (Lonsdale, 1999; Davis et al., 2000). The changes of ecosystems may be initiated by natural disturbance (storm, earthquake, volcanic eruption, fire climate) or management regime, but are enhanced or accelerated by the invasion of alien species. Land transformation and invasions are interlinked and thus lead to further opportunities for invasion (Mooney and Hobbs, 2000).

The species composition of an ecosystem at any given location and time depends on current environmental conditions, levels and types of disturbance, balance of loss and recruitment, and composition of the regional pool of species. Increasing levels of human transformation of ecosystems may accelerate environmental change and the dramatic increase in the deliberate and inadvertent transport of biota across the globe inevitably will increase the regional species pool, while perhaps also decreasing native species and ultimately decreasing the global species pool. This combination of factors sets the stage for a radical alteration of an ecosystem (Hobbs and Hunneke, 1992; McNeeley et al., 2001).

In this study area, several disturbance factors such as road and building construction, exploitation of hiking course, installation of recreational facilities, and so on functioned in invasion window to tree of heaven (Fig. 1) and sites where they grow vigorously showed low species diversity due to their dense cover (Fig. 6). This trend reflects ecological impact of tree of heaven.

Invasive alien species can cause the extinction and extirpation of native species through competition, again largely in insular environments such as oceanic islands and fresh waters. Plants as well as animals are contributing to these losses in some cases.

The massive transformation of native vegetation by human activity and the introduction of exotic plants have placed many endemic plants at risk on many oceanic islands. In the Hawaiian Islands, for example, 469 to 690 species of introduced plants have become established in the wild (Muller-Dombois and Loope, 1990). The resultant vegetational changes, together with other anthropogenic pressures, have driven about 177 native plants to extinction.

Individual island invaders can sometimes present major threats to native plants. In Tahiti, for example, 40 to 50 of 212 island's endemic plant species are considered to be threatened by the spread of the South American shrub, *Miconia calvescens* (Meyer and Florence, 1996). This plant, introduced in 1937 as an ornamental, has spread into the mountain forests, where it forms nearly pure stands over about two-thirds of the land area of the island. At least one endemic plant is believed extinct and 15 others critically endangered as a result. Negative correlations between diversity indices and importance of tree of heaven in this study predict such likelihood (Fig. 7).

In addition, hybridization with alien species also could be a threat to a number of plants ranging from grasses and broad-leaved herbs to woody shrubs and trees (Levin et al., 1996; Daehler and Carino, 2001). Simulation models of the hybridization process indicate that it can lead to extinction of native species by aliens in five or fewer generations (Wolf et al., 2001). A current example is *Lantana depressa*, a member of the verbena family, which is distributed throughout peninsula Florida. This diploid species has come into close contact with *L. camara*, a widely planted, exotic tetraploid species. Hybrids between the two produce triploid progeny that spread vigorously through the natural habitat of *L. camara* (Sanders, 1987). It appears likely that in time these hybrids will completely displace diploid populations of *L. camara*.

How can we contain, control, or eradicate harmful invaders?

Baker (1986) noted that disturbed ecosystems are more vulnerable to infestation of IAS than undisturbed ecosystems. Our data confirm this point, as tree of heaven showed higher importance value in broader trampling path than in narrower one and density was also higher in the disturbed sites close to trampling path than in undisturbed sites like forest interior (Fig. 6). Therefore, it is imperative to protect disturbed ecosystems from human interference such as excessive use and management. Invasive alien plants can be controlled by introducing natural enemies, interfering life history cycles (e.g., disrupting pollination, seed production or germination), and mechanical and chemical removals (Baird, 1989; Berger, 1993). Moreover, it is imperative to foster closed undisturbed forest conditions to discourage disturbance-adapted invasive alien plants (Berger, 1993). In fact, a comprehensive restoration of whole ecosystems may be needed (Aronson et al., 1993; National Research Council, 1991). Artificial disturbance of forests is currently declining in rural areas of Korea, but interference from forest management remains in urban areas and may thereby cause further invasion of invasive alien plant. Therefore, we suggest a management plan that applies ecological restoration principles to address ecosystems infected with tree of heaven (Bradshaw, 1984).

However, some IAS, especially, those with similar genetic characteristics to their native counterparts (Harper, 1965), may penetrate into undisturbed ecosystems (Berger, 1993). Conventional control strategies that are specifically aimed at disturbance-adapted species may not be capable of controlling invasive alien plant in this case, and a new strategy is needed to combat this problem. Moreover, long-term monitoring and active management, after initial restoration efforts is crucial for maintenance of healthy ecosystems (Baired, 1989).

CONCLUSION

In our study area, mature tree of heaven appeared in forest fringe of trampling path-side in lowland near to Catholic University and around the Sanseong church (Figs. 1 and 7). In addition, they were planted as the street tree in front of the New Core Department store, which is remote about 500 m northward from Site 1 (personal observation). This distributional pattern of tree of heaven implies that those mature trees would be introduced intentionally. They showed similar age to trees, which compose plantations of this study area such as aspen and black locust stands. The result alludes that they might be introduced in the afforesting process of this area about 30 years ago.

Young heaven trees were observed in the vicinity of physical training ground or trampling path and their population structure showed a pattern of invasive population (Figs. 1 and 7).

Species introduced intentionally have greater likelihood of establishment (McNeeley, 2001). Introduced species oftentimes expand their range beyond the place of initial establishment due to their advantageous life history strategies (Meffe et al., 1997) as was shown in our results. Moreover, biological invasions are changing the structure and function of ecosystems and thereby cause the cumulative impact (Parker et al., 1999; Ruiz et al., 1999).

Forest edge including the disturbed site is vulnerable to invasion of invasive alien plants due to physical disturbance and nutrients input as the place where exchanges of organism, matter, and energy occur between two habitats (Wiens et al., 1993; Forman, 1995; Pickett and Cadenasso, 1995; Lee et al. 2003). Therefore, invasive alien plants are abundant in forest edge compared with undisturbed forest interior (Hobbs, 1991; Abesperg-Traun et al., 1998; Morgan, 1998). Experimental manipulation, which removed forest canopy and undergrowth, in reality facilitated invasion of invasive alien plants (Duggin and Gentle, 1998; Cadenasso and Pickett, 2001). Such phenomena suggest that invasion and expansion of invasive alien plants would be closely related to artificial disturbances. As was shown in the results of this study, tree of heaven was introduced intentionally and expanded in the artificially disturbed sites such as a ground for physical training (Figs.1 and 7). Tree of heaven appeared abundantly in the trampling path side and the density decreased greatly toward the forest interior (Fig. 2). They flourished in the location where the other plants either disappeared or their growth is cowered greatly, while they did not occur in the site, in which the native plants grow vigorously (Fig. 6). They were associated with annual, other exotic species or ruderal plants well. Size class distribution of them showed that they are in expansion and artificial interferences such as, installing physical training space and developing hiking course functioned as trigger factors in their invasion and expansion. In general, it was known that invasive alien plants invade frequently in the part where function of the nature is weakened, whereas they do not extend their range in location, which the nature equips with the integral feature and thereby the function is strengthened (Kim et al., 2000; Lee et al., 2002a). Results of this study resembled the facts known generally in relation to invasion and expansion of the invasive alien plants. As a futuristic plan to prevent invasion and more expansion of the IAS, we suggest a comprehensive restoration plan, which recovers integrity of forest edge by applying protective planting to the disturbed sites, such as trampling path side and open space for physical training and conserves the remained nature more thoroughly (Panetta and Hopkins, 1991; Hobbs, 1991).

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