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Distribution Pattern of White Snakeroot as an Invasive Alien Plant and Restoration Strategy to Inhibit Its Expansion in Seoripool Park, Seoul

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White snakeroot (*Ageratina altissima* (L.) R. King & H. Robinson) as an invasive alien plant appeared more abundantly at lower elevations where frequent artificial interferences prevailed than at higher elevations where such impacts were less. They appeared abundantly in introduced forests such as black locust plantation but they did not appear or were rare in natural forests such as oak forest. But an exceptional phenomenon where white snakeroot did not appear was found in a Korean pine stand with dense cover afforested recently. Appearance status of white snakeroot in each section of trampling path depended on breadth of the path and relative light intensity. Growth of white snakeroot measured as the number of ramet per genet, height, and biomass was better near the trampling path and was reduced toward the forest interior. The growth was proportionate to the relative light intensity measured according to distance from the trampling path. Such results support the fact generally known in relation invasion and expansion of the invasive alien plants. From this viewpoint, we suggest a management plan that applies ecological restoration principles to address ecosystems infected with white snakeroot by restoring the integral feature of the degraded nature and more thoroughly conserving the remaining nature.

In modern days, many species have been introduced, deliberately and accidentally, into areas where they are not native (Grove and Burdon, 1986; 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).

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 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).

Exotic plants are often considered beneficial nurse crops for reclamation of degraded lands. Lugo (1997) reported the growth of native plants under the canopy of exotic trees, and Vitousek and Walker (1989) found that an exotic tree (*Myrica faya*) increased productivity and species richness by enhancing nutrient availability. However in most cases, exotic plants, with their advantageous life history strategies in disturbed environments, reduce or displace native species and alter ecosystem function, raising concerns for conservation of native systems (Mooney and Drake, 1986; Vitousek, 1986; Schofield, 1989; Simberloff et al., 1997).

White snakeroot was reported for the first time by Lee and Yim (1978) in Korea. Since then, their distribution

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range (Yim and Jeon, 1980; Yim et al., 1987; Yang, 1989; NIER, 1995; Kil et al., 1998, Seoul City, 1999) and expansion (Lee, 1987), relationship between environmental factors and their distribution (Suh et al., 1997; Hyun 1998), genetic structure of the population (Chun et al., 2001), ecological characteristics and assessment of environmental risk (Kil, 2003) have been studied in Korea. Most of studies on the IAS carried out in Korea focused on listing up or describing the distribution range. But expansion of IAS already became a worldwide problem and the spreading effects of them are becoming 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

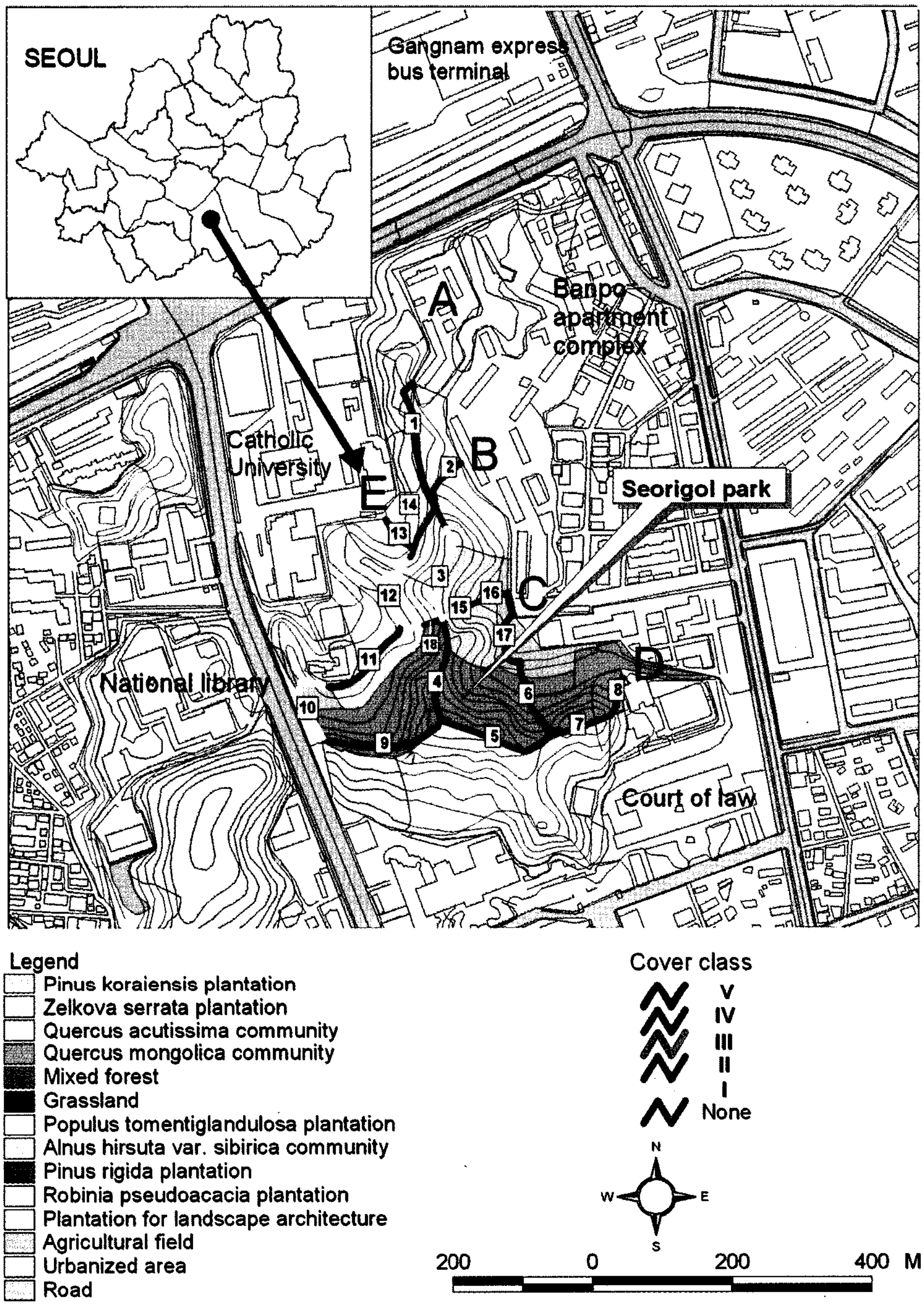

Fig. 1. A map showing vegetation distribution and cover of white snakeroot (*Ageratina altissima*) in the study area, Seorigol park located in Banpo-dong, Seocho-gu, Seoul. A, B, C, D, and E indicate the entrances of the park and numbers in quadrangle show the section number of trampling path.

new invasion and expansion.

The objectives of this paper are to clarify the following items: (1) Where are the white snakeroot distributed? (2) What condition does this invasive alien plant favor? (3) How do we inhibit expansion of this invasive alien plant?

Study Area

This study was carried out in an urban park called "Seoripool Park" and surrounding urban areas located in Banpo-dong, Seocho-gu, Seoul, Korea (Fig. 1). Seoripool Park is an ecological island enclosed by the residential area (the Banpo apartment complex), the educational (Catholic university) and public facilities (National library) and 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*). 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.

Methods

Field survey was carried out from July to September 2002 and partial resurvey was done from May to June 2003.

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. Distribution map of white snakeroot was constructed by expressing cover class of Braun-Blanquet (1964) evaluated through field survey on the geographic map of 1:5,000 scales. Sections of trampling path were divided by expressing homogeneous range of cover class of white snakeroot. Ordinal cover was converted to the median value of percent cover range in order to get relationships between appearance status of white snakeroot, and relative light intensity and the breadth in each section of trampling path (Lee et al., 2002b).

Breadth of trampling path was measured with a measuring tape. Relative light intensity was measured with a photometer (LX-1332) in three zones within 5, 5 to 15, and 15 to 25 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.

Growth of sample plant was analyzed by the number of ramets per genet, height and biomass in the same distance ranges as when the light intensity was measured. Biomass was regarded as dry weight dried for 48 hours in dry oven of 80°C. Biomass was measured by dividing into above and below ground parts. Measurements on growth have ten replicates.

Results

Cover classes of white snakeroot in 18 sections divided by homogeneous range of cover class showed none to IV. Coverage of white snakeroot was higher in sections located on lowland and tended to decrease towards the mid-slope except for sections 15, 16, and 17. On the other hand, they did not appear around summit (Fig. 1). Among sections, which have no snakeroot, lack in 15, 16, and 17 sections would be due to shading by dense

Appendix I. Breadth of trampling path, relative light intensity (RLI) and cover class of white snakeroot in 18 sections of trampling path divided by appearance status of white snakeroot. Cover class is based on Braun-Blanquet (1964)

Section	Breadth (cm)	RLI (%)	Cover class	Remarks
1	560.0±126.3	30.1±4.1	IV	
2	264.0±8.9	7.4±3.7	III	
3	306.0±88.3	14.5±3.2	I	
4	260.0±17.3	2.4±0.3	None	
5	127.5±7.6	13.3±3.4	None	Around summit
6	125.9±8.5	2.6±3.5	None	
7	125.5±4.8	3.3±0.4	None	
8	125.8±8.0	2.0±0.3	None	
9	144.0±8.9	3.5±1.2	None	
10	140.0±7.5	41.5±5.5	I	Plantation for landscape architecture
11	145.8±4.9	2.5±0.7	II	
12	232.0±11.0	2.5±0.6	I	
13	238.0±17.9	10.0±2.3	III	
14	288.0±11.0	12.7±3.0	IV	
15	245.0±9.5	57.6±3.9	I	Young zelkova plantation
16	163.0±4.5	51.9±3.1	None	Young Korean pine plantation
17	165.0±5.5	52.5±3.5	None	Young Korean pine plantation
18	60.0±10.0	2.6±0.8	None	

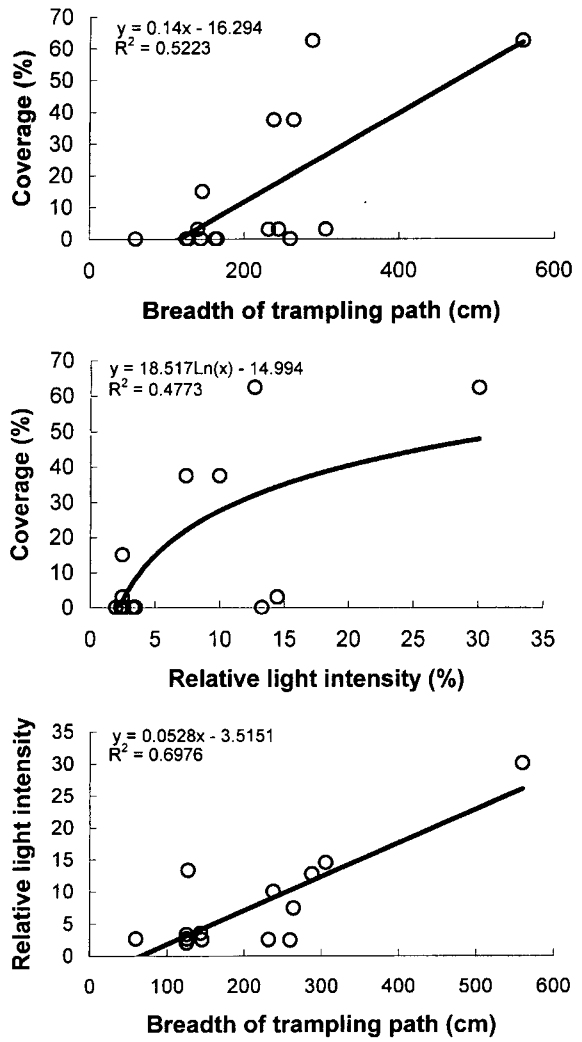

Fig. 2. Relationships between breadth of trampling path and coverage of white snakeroot (upper), relative light intensity and coverage of white snakeroot (middle), and breadth of trampling path and relative light intensity (lower).

young plantation afforested recently and dense canopy of native forest might also inhibit their invasion in sections 4, 6, 7, 8, and 9. But lack of white snakeroot in the section 5 with high relative light intensity implies that other environmental factors besides light may influence invasion and expansion of white snakeroot (Appendix I). Excluding sections 15, 16, and 17, which was located amidst young pine plantation afforested recently and section 10, which was covered with dense vine stand introduced for landscape architecture, cover of white snakeroot in trampling path side showed significant correlation with both breadth of and relative light intensity on the trampling path. Both factors were also significantly related to each other (Fig. 2).

People frequently visit the lowerpart of the mountain park but the frequency decreased towards the summit.

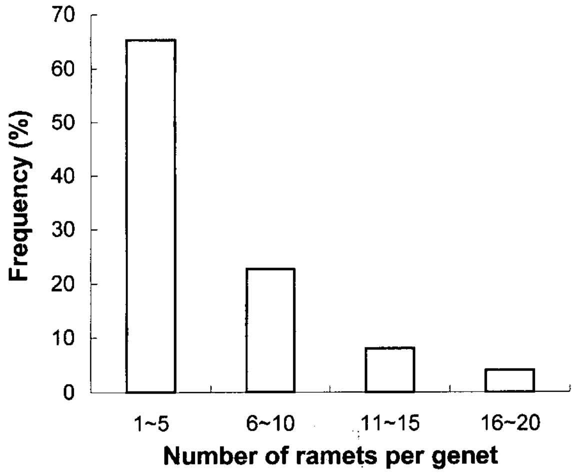

Fig. 3. Frequency distribution of the number of ramets per genet.

Breadth of trampling path is wider in lowland than in upland, reflecting such trends (Fig. 1 and Appendix I). Such a difference in artificial interference would affect the abundance of white snakeroot depending on site. On the other hand, forest at the lower elevation is comprised of introduced plantation, such as black locust and aspen plantations, whereas that around the summit is of native oaks, and such a difference of naturalness could also influence the distribution of white snakeroot.

65% of genets occurred one to five ramets and 23% did six to ten ramets (Fig. 3). But genet with 20 ramets also appeared.

The closer to the trampling path, the more was the number of ramets per genet: 7.3±4.8, 4.9±4.0, and 3.3±2.4 in zones within 5, 5 to 15, and 15 to 25 meters from the trampling path, respectively (Fig. 4). The most

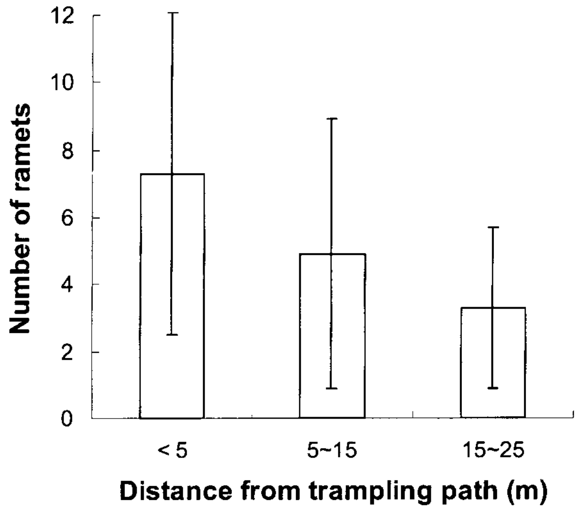

Fig. 4. A comparison of the number of ramets in three zones with different distance from trampling path. Data are mean±SD (n=10).

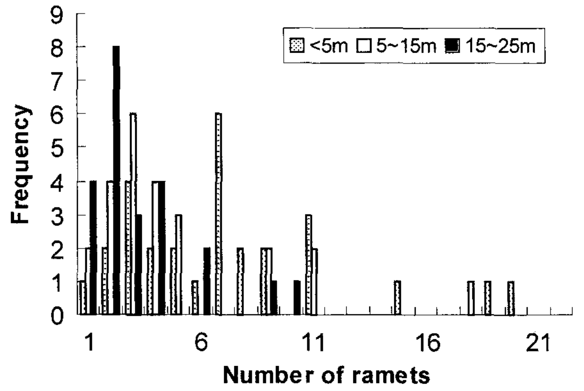

Fig. 5. A comparison of frequency of the number of ramets in three zones with different distance from the trampling path.

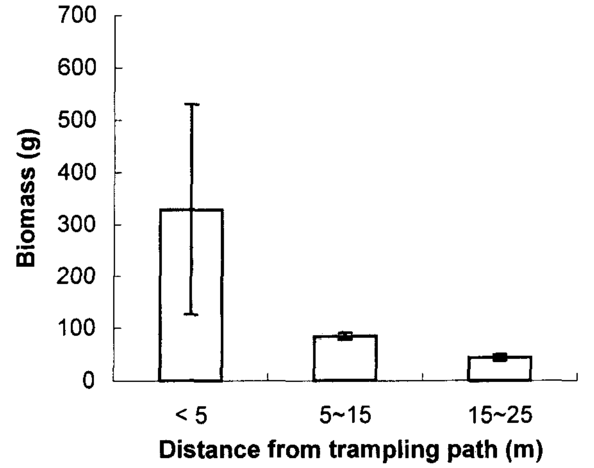

Fig. 7. A comparison of biomass in three zones with different distance from the trampling path. Data are mean±SD (n=10).

number of ramets per genet was inversely proportionate to the distance from the trampling path: 20, 18 and 10 within 5, 5 to 15, and 15 to 25 meters from the trampling path, respectively. In addition, the number of ramets with the highest frequency also increased as it approached the trampling path: seven, three, and two in each zone classified by the distance from the trampling path (Fig. 5). The height of white snakeroot increased as it came close to the trampling path: 96.9±7.9, 74.8±7.7, and 64.1±10.8 cm in each zone (Fig. 6).

Biomass of white snakeroot decreased as it receded from the trampling path, resembling the response shown in the number of ramets and height growth of the plant (Fig. 7). The trend would be due to the fact that better grown genets with many ramets and higher stature distribute in the nearby trampling path. The ratio of aboveground to underground biomass showed the same response (Fig. 8). Considering that old genets tend to distribute close to the trampling path, this result would be due to their resource allocation strategy. That is to say, newly established genets behind in competitive ability for light due to lower nutrients stored in the underground to supply to the ramets formed in the following year. Meanwhile, genets with many ramets store small amounts of nutrients underground because they distribute resources to various parts (Huston and Smith, 1987; Tilman, 1988).

Relative light intensities were 20.6±6.8%, 12.5±3.2%, and 8.8±0.7% in three zones different in distance from the trampling path (Fig. 9). The above results in growth responses and resource allocation pattern of white snakeroot were closely related to the different relative light intensities depending on the zone. Difference in relative light intensity can be regarded as difference in artificial disturbance as the relative light intensity in

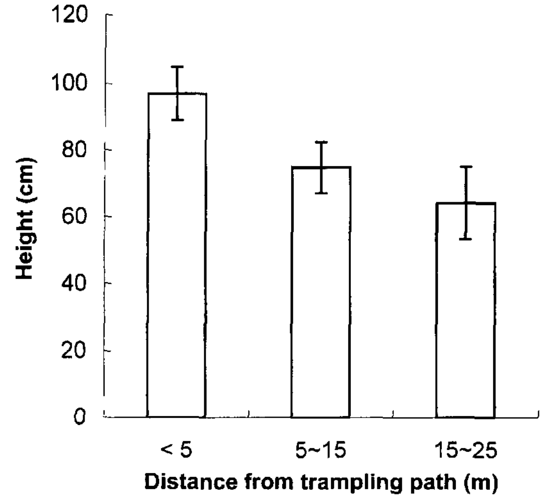

Fig. 6. A comparison of height in three zones with different distance from the trampling path. Data are mean±SD (n=10).

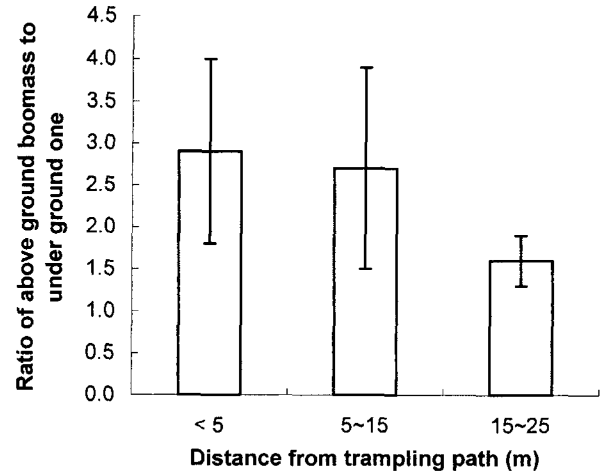

Fig. 8. A comparison of ratio of above ground biomass to under ground one in three zones with different distance from trampling path. Data are mean±SD (n=10).

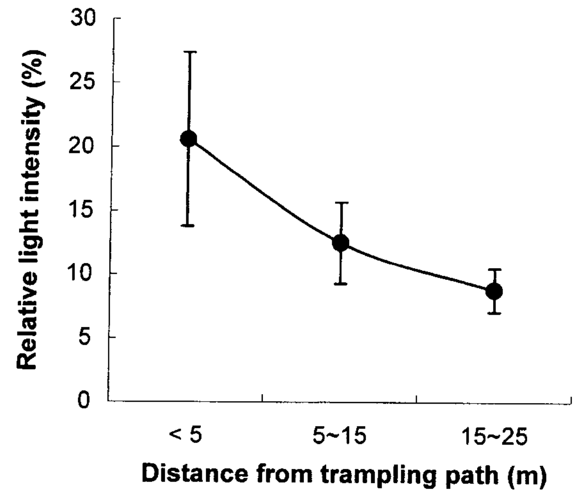

Fig. 9. Changes of relative light intensity with distance from trampling path. Data are mean±SD (n=10).

each zone with different distance from the trampling path similar to a gap depends on canopy cover, vegetation stratification, undergrowth density and cover, and so on in the location (Pickett and White, 1985). In reality, the breadth of trampling path was wider in lowland than upland (Fig. 1 and Appendix I) and the relative light intensity on the trampling path showed significant correlation with the breadth (Fig. 2).

Discussion

Environmental conditions susceptible to invasion of IAS

While all ecosystems including those in well-protected national parks can potentially be invaded, 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 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) think that systems with low diversity is 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 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 concentrated around the trampling path and vigorous growth around there for white snakeroot reflected such trends. In addition, distribution pattern of invasive alien plants in Korea, which appeared in higher percentages in the order of industrial area (31%), riverside (30%), residential area (25%), and mountainous area (14%), also shows such tendencies (NIER, 1995; 1996).

Factors determining invasibility of plant

The spread rate for invasive alien plants is determined by 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 are also 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).

In Korea, Compositae including white snakeroot occupied the highest percentage as 25.5% among invasive alien plants and followed by Gramineae (17.8%), Cruciferae (8.6%), Leguminosae (5.8%), Polygonaceae (5.8%), Amaranthaceae (3.4%), and Convolvulaceae (3.4%) (NIER, 1995; 1996). Taxa, which occupy higher percentage, usually have better dispersal agents, higher reproductive capacity, and shorter life cycle (Kim et al., 2000). In these respects, it can be estimated that they are equipped with general characteristics of invasive alien plant mentioned earlier (McNeeley et al., 2001).

Ecological impact of IAS

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, or fire climate) or the 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 will inevitably 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; Parendes and Jones, 2000; McNeeley et al., 2001).

In this study area trampling played a role of invasion window to white snakeroot and sites where they grow vigorously showed low species diversity due to their dense cover (personal observation of authors). This trend reflects ecological impact of white snakeroot.

Management recommendations for white snakeroot infected ecosystems

Baker (1986) noted that disturbed ecosystems are more vulnerable to infestation of IAS than undisturbed ecosystems. Our data confirm this point, as white snakeroot showed higher cover in broader trampling path than in narrower one and further higher stature and biomass, and more ramets in the disturbed sites close to trampling path than in undisturbed sites like forest interior (Figs. 4 to 7). 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 white snakeroot (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

The increased mobility of people and their goods bring increased likelihood of movement of species around the earth (McNeeley et al., 2001). In fact, the number of invasive alien plants increased rapidly since the opening of port when Korea began to actively exchange with foreign countries and the number is increasing more rapidly as the interchange becomes more frequent (NIER, 1995; 1996). Forest edge including trampling path 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). Therefore, invasive alien plants are abundant, whereas species diversity is lower in forest edge compared with undisturbed forest interior (Hobbs, 1991; Abesperg-Traun et al., 1998; Morgan, 1998). In reality, experimental manipulation removed forest canopy and undergrowth facilitated invasion of invasive alien plants (Duggin and Gentle, 1998; Cadenasso and Pickett, 2001). Such phenomena imply that invasion and expansion of invasive alien plants would be closely related to artificial interferences. As was shown in the results of this study, the more frequent artificial interference, the more abundant was white snakeroot as an invasive alien plant. In this respect, we could conclude that they were expanded by human activity and grew better in the condition that the environment was destroyed and thereby competitors were reduced and light intensity increased.

White snakeroot as an IAS appears more abundantly at lower elevations where frequent artificial interferences prevail than at higher elevations where such impacts are less (Fig. 1). On the other hand, they appeared abundantly in the introduced forest such as black locust plantation but they did not appear or were rare in the natural one such as oak forest (Fig. 1). But an exceptional phenomenon was also found as in the case of entrance C. The lack of white snakeroot in the entrance would be due to dense cover of Korean pine stand afforested recently.

White snakeroot grew well in the trampling path side but the growth shrunk greatly toward the forest interior (Figs. 4 to 7). They flourished in the location where the other plants either disappeared or their growth is cowered greatly, while they did not occur in sites where the native plants grow vigorously (personal observation of authors). In general, it was known that invasive alien plants invade frequently at sites where function of the nature weakened, whereas they do not extend of the nature is equip ped with the integral feature and thereby the function is strengthened (Kim et al., 2000; Lee et al., 2002a). The results of this study resembled the facts known generally in relation to invasion and expansion of the invasive alien plants. From this viewpoint, we suggest a comprehensive restoration plan which recovers integrity of forest edge by applying protective planting in the trampling path side to inhibit expansion of white snakeroot as an IAS (Hobbs, 1991; Panetta and Hopkins, 1991).

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