# Estimation of Plant Seed Dispersal through Artificial Soil Movement in Incheon Urban Area

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**Abstract - In this study, soil seed and bud bank analysis were performed to assess the mass of potential vegetation in soils less than 1 year old after covered and estimate the amount of seed bank transport through construction in urban area. The ratio of exotic species number to total species number in study sites and the landfill control site was 0.29 and 0.39, respectively. All plots pooled, mean species number and total mean seedling density per $m^2$ in the top 10 cm of soil was 11±0 (average±S.E.) and 8037±221. Total plant seeds by artificial soil trasnsfer were estimated to be 53 thousand million $m^{-2}$ $yr^{-1}$ in 10 cm soil depth. It reveals that soil transfer accelerates seeds and vegetation movement and makes urban vegetation mixed and common.**

**Key words : artificial soil transfer, plant dispersal, seed bank, urban area**

## INTRODUCTION

In urban area, many human activities have degraded biological diversity and made biological materials extinct. Land-use practices are a major cause of the decline in biodiversity in recent decades (Soulé 1991). The introduction of novel mechanical disturbances such as building and highway construction, soil excavation and landfill is part of exotic disturbance regimes (ter Heerdt *et al.* 1996). But, ironically, there are many events that make biological dispersal speedy. Of these, artificial soil transfer through construction is common works all over the city. The transport is a removal, one of land-use categories. Of these, the soil movements from construction works make many subsequent events. Anthropogenic deposit soils are at present a notable component of the urban landscape (Rebele 1992). The major parts of soils land filled in urban area have various origins and characteristics. The viable seeds, buds and clonally derived cuttings such as roots and stems are ones of biological ingredients in those soils. The soils are transported during human construction activities. Therefore, biological materials in soils are also co-transported with soil transfer. At the first colonization stage, the initial plant appearance from soil seed bank and bud bank plays an important role in soil stability, hydrologic process, biogeochemical cycle and landscape aesthetics. Organisms that persist in transit or soon after release can have grave effects on human health, devastating economic impacts and can threaten native biodiversity and ecosystem function (Kolar and Lodge 2001). Plant invasion through soil seed bank transfer in urban area is another patterns of invasion. Such species transport has serious consequences for both man and nature (Lodge 1993). The seed bank has a role in maintaining floristic diversity and must be taken into account in management (Roberts 1981). The movement of soil containing seeds and fragments of vegetative material has been a major factor in causing the further spread of the plant (Child

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and Wade 1999). This is a kind of dispersal by man, anthropochory. The accidental transport of seeds within soils during construction causes convergence of urban vegetation pattern and develops spontaneous vegetation. The vegetation changes before and after soil intact transference were monitored to evaluate its methods (Worthington and Helliwell 1987). Investigations about soil transport by natural factors were much conducted (Le Bayon *et al.* 2002). The floristic changes and their dynamics by this anthropogenic activity have been not nearly assessed and scrutinized and the accidental plant introduction by soil transfer has been rarely quantified (Heatwole and Walker 1989). The main purpose of this investigation is to quantify and assess seed bank co-transported with soils during construction in urban area.

## MATERIALS AND METHODS

### 1. Study sites

Nine study sites including a landfill control site were in Incheon Metropolitan City (37° 58′N, 126° 47′E), most recently and widely constructed areas in Korea (Incheon Metropolitan City 2001). Nine study sites are located on parts of following areas: NIER Boundary Slopes, Sangsan APT, City Railway 1 Line, Dongmak Crossroad, Gyeyang-Gu Soil Storage, Namchon-Dong Namdong Industrial Complex, Incheon International Airport Expressway, Seochang Pedestrian Overpass and Yongjongdo-Outside Circulation Expressway Ramp. In these constructed areas, diverse soils derived from disturbed areas such as forest edge, construction regions and reclaimed land have been used as covering soils in open new lands. In 2001, Incheon International Airport opened and the port of Incheon is being enlarged and Songdo Intelligent City is being developed. Total area of Incheon is 965 $km^2$ and its population is 2562321. In 2000, the total number and total floor areas of building permitted by municipality are 4449 $m^2$ and 3.4 $km^2$, respectively. The number of building and households of apartment are 141 and 11715, respectively. Total road length and area are 1.6 km and 31 $km^2$. The number, length and area of pedestrian overpass are 37, 1545 m and 6105 $m^2$ (Incheon Metropolitan City 2001).

### 2. Landfill control site

The soil formation history of all study sites was less than 1 year and all sites were cut and filled. The same analysis on KyongSeo landfill site was conducted as a control to compare flora and seed mass with experiment sites. The landfill site has 7-year-old soils after closure. Landfills are sites where soil dumps of various origins for soil covering stockpiled. Therefore, they are most deeply intermingled with soils from many sites of urban area. The soils of landfill seem to have little variations than experiment sites in views of vegetation composition and seed amounts on a plot scale. So, they were selected as a control site.

### 3. Seed and bud bank

A seed bank is an aggregation of ungerminated seed potentially capable of replacing aboveground plants (Leck *et al.* 1989). Soil seed bank analysis for classifying and measuring abundance of underground vegetation was performed on ten plots per site at nine sites in 2001 to estimate the mass of seed bank in soils. The soil seed bank was sampled according to a seedling emergence method (Roberts 1981). Samples were taken in the beginning of March, prior to the fresh seed rain, since I was mainly interested in the persistent buried seed bank. Natural stratification of the seeds had taken place in the constructed area during the previous winter period. I followed the recommendation of Hayashi & Numata that at least 500~600 $cm^3$ of soil should be sampled to allow detection of most of the species in grassland seed banks (Hayashi and Numata 1971). At 10 randomly located plots (size $1 \times 1$ $m^2$) each site (area $40 \times 40$ $m^2$), 10 cores (4 cm diameter) of 10 cm depth per each plot were sampled at regular intervals. The 10 cores per plot were pooled to give one sample (Bekker *et al.* 1997; ter Heerdt *et al.* 1996). The pooled samples were spread in a thin layer (ca. 2 mm) over a 2 cm of sterile sand in individual trays. 10 control tray filled with sand monitored any airborne seed contaminants. All trays were randomly arranged in an unheated greenhouse (the range of temperature and relative humidity in the greenhouse were 18~53 and 72~98%) every week and were watered regularly from above with tap water. No Fertilizer was applied. After 3 months all remaining seedling were removed after identification (Perez *et al.* 1998). The soil was the stirred and a second crop of seedlings identified over the subsequent 3 months. The emerged seedlings were identified as soon as possible, counted and removed. Unidentifiable seedlings were transplanted to pots and grown, where necessary, until flowering. No attempt was made to assess the number of ungerminated seeds possibly remaining on the samples (Kalamees and Zobel 1998).

### 4. Vegetation analysis

All flora germinated including bud bank were recorded and counted individually. Nomenclature follows Lee and Park (Lee 1999; Park 1995, 2001). For analyses of invasion origins, native species are defined as indigenous to Korea and exotic species are species that are not indigenous to Korea, introduced intentionally or accidentally and have their origin outside Korea.

### 5. Soil physico-chemical analysis

Soils for chemical analysis were sampled in depth 0~10 cm in plots, using hand shovel. The soil samples were analyzed by methods following: pH (1 : 2 = W/V; Jackson 1967); Organic matter (Wakley-Black method; Page *et al.* 1982); Total-N (Kjeldahl method; Page *et al.* 1982); P (Bray No. 1 method; Page *et al.* 1982); K, Ca and Mg (Ammonium acetate extraction method; Page *et al.* 1982); Sand, Silt and Clay (Hydrometer method; Carter 1993).

### 6. Calculation of total seed bank transferred

The mean individuals germinated per unit area by specific zones were multiplied separately by soil transfer area estimated separately according to specific following zones to assess total seed bank transferred by soil movements. Considering three types of earth-moving activity: excavations for houses, mineral production and road building (Hooke 1994), the study sites were categorized as 3 specific zones, that is, housing green space zone (HGSZ), open miscellaneous zone (OMZ), and road slopes zone (RSZ), to calculate seed bank amounts on zone basis in Incheon. HGSZ are areas that are covered with soils for mitigating in circumference of building lots and legally designated green areas in constructed area. OMZ are neglected derelict lands owned by municipalities. RSZ are slopes made by mountain cut or artificial roadfill slopes, paralleling along roads. It was assumed that the area of RSZ corresponds to 4% of total road area (Personal communication with Korea Highway Corporation). HGSZ comprised 2 sites, NIER Boundary Slopes and Sangsan APT. OMZ contained 4 sites, City Railway 1 Line, Dongmak Crossroad, Gyeyang-Gu Soil Storage and Namchon-Dong Namdong Industrial Complex. RSZ included 3 sites of Incheon International Airport Expressway, Seochang Pedestrian Overpass and Yongjongdo-Outside Circulation Expressway Ramp. In Incheon, 2000, the area of HGSZ, OMZ and RSZ were 0.5, 38, and 1.2 $km^2$, respectively (Incheon Metropolitan City 2001). The step by step calculation procedure to obtain total seed bank transferred by soil movements is as follows: I calculated the mean individuals germinated (MIG) per unit area according to specific 3 zones, exclusive of species separation ($MIG/area_{HGSZ}$, $MIG/area_{OMZ}$, $MIG/area_{RSZ}$; $area_{HGSZ}$, $area_{OMZ}$ and $area_{RSZ}$ represent soil transfer areas corresponding to housing green space zone, open miscellaneous zone and road slopes zone, respectively). MIG per unit area according to specific 3 zones was multiplied independently by each zonal area ($area_{HGSZ}$, $area_{OMZ}$, $area_{RSZ}$) and then the products were added together to calculate total seed bank transferred by soil movements. All data were based on census results in 2000 (Incheon Metropolitan City 2001). The individuals germinated used for calculation of total seed bank transferred were counted in 10 cm soil depth because a majority of seeds were found at this depth (Harper 1977).

### 7. Data analysis

Because the sample numbers were unequal, I employed the GT2-method to execute multiple comparisons among pairs of means of seedling density, species number, exotics number and natives number (Sokal and Rohlf 1995a, b). I used a 5% experiment wise error rate. The differences of a pair of means and their MSD (Minimum significant difference) were compared.

## RESULTS

### 1. Composition of seed and bud bank

Total species number appeared was 48, small compared with 54 of the landfill control site. Analyzed on conditions that all plots were pooled, mean species number per $m^2$ in the top 10 cm of soil were $11 \pm 0$ (average $\pm$S.E.). In HGSZ, mean species number of NIER Boundary Slopes and Sangsan APT were $4 \pm 1$ (average$\pm$S.E.) and $4 \pm 1$, respectively. In OMZ, mean species number of City Railway 1 Line, Dongmak Crossroad, Gyeyang-Gu Soil Storage and Namchon-Dong Namdong Industrial Complex were $7 \pm 1$ (average$\pm$S.E.), $5 \pm 1$, $2 \pm 1$ and $3 \pm 1$, respectively. In RSZ, mean species number of Incheon International Airport Expressway, Seochang Pedestrian Overpass and Yongjongdo-Outside Circulation Expressway Ramp were $2 \pm 1$, $6 \pm 1$, and $3 \pm 1$, respectively. The mean species number per unit soil volume was not significantly different among zones and a landfill site from GT2-method (Fig. 1). Over 50% of species appeared overlapped between study sites and the landfill control site as 58% and 52%, respectively (Table 1). Annual plants appeared more than biennial and perennial plants. *Digitaria ciliaris*, an annual graminoid, existed most frequently in all plots. *Cardamine flexuosa*, an annual herb and *Oxalis cormicula*, a perennial herb were followed in decreasing order of frequency (Table 1). *Salix koreensis*, as only a tree species, appeared on 6.7% frequency of all plots. This species is a very invasive pioneer tree in urban area because its seeds spread well by wind. But, it was rare in the landfill control site. A nitrogen fixing creeping plant, *Phaseolus nipponensis*, appeared in urban soil. No more nitrogen fixation plants were recorded. However, Of 90 plots, A minority of individuals appeared ($n$ = 8) were derived from bud bank, vegetative fragments (8.9% frequency). *Artemisia princeps* var. *orientalis, Ixeris dendata*, Gramineae spp., *Capsella bursa-pastoris* and *Stellaria aquatica* grew

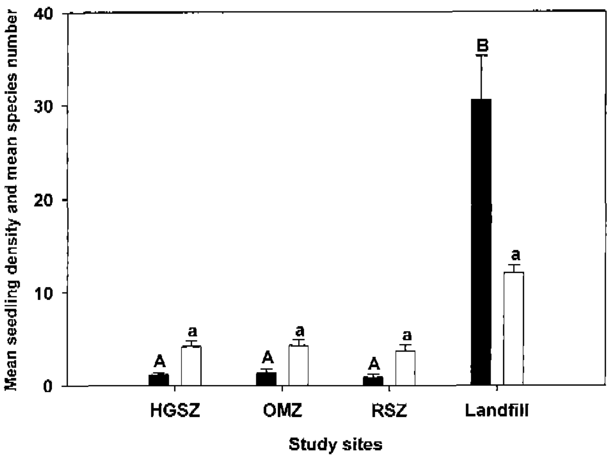


**Fig. 1.** Mean seedling density ($\times$ 1000 seeds per $m^2$; black rods) and mean species number (number per 127 $cm^3$; white rods) in the top 10 cm of less than 1-year-old urban soils according to zones and 7-year-old landfill soils in Incheon. The different letters above rods means significant difference among zones ($P < 0.05$). HGSZ, OMZ and RSZ mean housing green space zone, open miscellaneous zone and road slopes zone, respectively.

**Table 1.** Vascular species that germinated in both less than one year old urban soil and the landfill soil. Also indicated are the life history, presumed origin of each species and frequency that appeared in total 90 plots of urban soils

| Species | Life history | Presumed origin | Frequency |
|---|---|---|---|
| Graminoids | | | |
| *Setaria viridis* | Annual | Native | 6 |
| *Panicum bisulcatum* | Annual | Native | 2 |
| *Panicum dichotomiflorum* | Annual | Exotic | 21 |
| *Digitaria sanguinalis* | Annual | Native | 30 |
| *Echinochloa crus-galli* | Annual | Native | 18 |
| *Cyperus microiria* | Annual | Native | 14 |
| Herbs | | | |
| *Commelina communis* | Annual | Native | 3 |
| *Chenopodium album* | Annual | Exotic | 3 |
| *Portulaca oleracea* | Annual | Native | 4 |
| *Stellaria aquatica* | Biennial | Native | 4 |
| *Cardamine flexuosa* | Biennial | Native | 26 |
| *Potentilla paradoxa* | Perennial | Native | 1 |
| *Oxalis corniculata* | Perennial | Native | 22 |
| *Euphorbia supina* | Annual | Exotic | 1 |
| *Oenothera biennis* | Biennial | Exotic | 1 |
| *Mosla dianthera* | Annual | Native | 1 |
| *Mazus pumilus* | Annual | Native | 3 |
| *Ambrosia artemisiifolia* | Annual | Exotic | 11 |
| *Galinsoga ciliata* | Annual | Exotic | 3 |
| *Aster subulatus* var. *sandwicensis* | Annual | Exotic | 8 |
| *Erigeron canadensis* | Biennial | Exotic | 2 |
| *Artemisia princeps* var. *orientalis* | Perennial | Native | 2 |
| *Cosmos bipinnatus* | Annual | Exotic | 1 |
| *Ixeris dentate* | Perennial | Native | 7 |

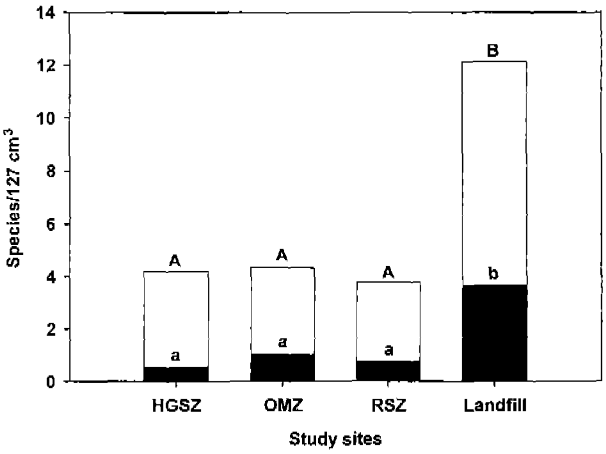


**Fig. 2.** Mean species number of exotics (black rods) and natives (white rods) germinated in the top 10 cm of less than 1-year-old urban soils according to zones and 7-year-old landfill soils in Incheon. The different letters above rods means significant difference among zones ($P < 0.05$). HGSZ, OMZ and RSZ mean housing green space zone, open miscellaneous zone and road slopes zone, respectively.

clonally in soils as bud banks.

### 2. Comparison of native and exotic species

In study sites, *Panicum dichotomiflorum*, *Aster subulatus* var. *sandwicensis* and *Ambrosia artemisiifolia* var. *elatior* as exotics were much more frequent than any other species (Table 1) whereas *Digitaria ciliaris, Cardamine flexuosa* and *Oxalis cormiculata* as natives dominated. The ratio of exotic species number to total species number in study sites and the landfill control site was 0.29 and 0.39, respectively. The mean exotic and native species number per unit soil volume of zones was not significantly different among each other from GT2-method. But, there were significantly differences between zones and the landfill site (Fig. 2).

### 3. Soil characteristics

Mean pH of soils in study sites was 7.98±0.14 (average±S.E.; $n = 39$). Mean organic matter and total-N content of those were 0.58%±0.09 and 0.14%±0.01 ($n$ = 39). P, K, Ca and Mg contents of those were 7.5 mg $kg^{-1}$ ±0.5, 138.9 mg $kg^{-1}$±12.3, 1711.8 mg $kg^{-1}$±112.3 and 194.3 mg $kg^{-1}$±13.8. The percentage by weight of sand, silt and clay was 70.4, 14.5 and 15.1%. The analysis of soil characteristics showed that soils of study sites are sandy loamy, basic and saline.

### 4. Total seeds transported by anthropogenic activities

Analyzed on conditions that all plots were pooled, total mean seedling density per $m^2$ in the top 10 cm of soil were 8037±221 (average±S.E.). Mean seedling density per $m^2$ in the top 10 cm of soil on zones ranged 231 to 2308 seeds. Mean seedling density (number per $m^2$) of each site was as follows. Mean seedling density of NIER Boundary Slopes and Sangsan APT categorized as HGSZ were 979±195 (average±S.E.) and 1369±287, respectively. Mean seedling density of City Railway 1 Line, Dongmak Crossroad, Gyeyang-Gu Soil Storage and Namchon-Dong Namdong Industrial Complex in OMZ were 2308±514, 780±240, 231±73 and 2188±1650, respectively. Mean seedling density of Incheon International Airport Expressway, Seochang Pedestrian Overpass and Yongjongdo-Outside Circulation Expressway Ramp as RSZ were 271±99, 1783±760 and 669±185, respectively. The each mean seedling density of HGSZ, OMZ and RSZ was 1173±174, 1376±443 and 907±279. But, the mean seedling density in Kyong Seo landfill was much higher than in other newly constructed zones (Fig. 1). The mean seedling densities of zones were not significantly different among each other, but, significantly different from that of the landfill site from GT2-method (Fig. 1).

By calculating total seed bank transferred, total seeds moved by humans in Incheon were estimated to be 53 thousand million $m^{-2}$ $yr^{-1}$ in 10 cm depth.

## DISCUSSION

This studies indicated that the seed bank of soils is small as a result of the subsoil having been totally mixed with topsoil. In general, the mean seed numbers show a linear decline with depth (Rahman *et al.* 2001) and the major part of the seed reserve is contained within the litter and the top 5 cm of the soil profile (Smith *et al.* 2000). So, seed numbers in topsoil are higher than that in subsurface soil. However, if topsoil are mixed with seed-poor subsurface soil during construction and transportation, total amount of seeds store are diluted and decreased, initially reducing species richness (Kotanen 1997).

Classification and quantification of seed bank flora using germination is generally regarded as the most satisfactory approach (Thompson *et al.* 1997). But, not all viable seeds present will germinate under any given conditions. However, most weeds of urban area will have characteristics of good germination. The soils used for construction were topsoil and subsurface soil in some area. Consequently, they have scarce seed bank and bud bank in situations which soils were mixed altogether. This trend will give weak landscape in urban area. This is unintentional introduction of plants by soil movement contaminated by seed and bud bank. If soil or gravel is brought to a secluded area like an island for gardens or construction, then alien species are more likely to be introduced than such is not the case (Heatwole and Walker 1989). As constructed artificial open lands in urban area are separated from outer ecosystem like an island, alien species invade as soil movements proceed. These recycled soils normally contain at least a few propagules, as its origin is mostly from previously vegetated areas (Rebele 1992). All the species found are associated with urban area, as would be expected given the source of the soils.

Soils function in the urban landscape by supplying plant nutrients, serving as a plant growth medium and substrate for soil fauna and flora and contributing to the hydrologic cycle through absorption, storage and supply of water (Effland and Pouyat 1997). Additions of earthy fill materials (excavated from either natural or disturbed soils) or human-derived artifacts (e. g. broken bricks and glass, ashes, crushed stone) during housing construction may influence the rate and extent of soil formation across a wide range from the limited fill placement to marked soil disturbance from excavation of foundations (Effland and Pouyat 1997). Many urban soils are lacking in organic matter and available nutrients and may be contaminated by various harmful constituents such as heavy metals. They have physical problems such as shallow solum, excessive contents of stones and construction debris, limiting texture and structure, shortage of available water capacity, sharply demarcated layering and compaction (Jim 1998). The principal changes to soil are decreases in soil porosity due to the compaction and shearing forces imparted during handling while its movement and care (Harris *et al.* 1996). These inadequacies of urban soils would make the colonization of plants restrictive. Above all, the perturbation caused by excavated and filled soils is instability of soil structure, lowing in bulk density after leveling and infertility from nutrient leaching. It leads to severe soil alteration and degradation. In special, filled -excavated sites have poor soil conditions with low soil nitrogen and high pH (Stylinski and Allen 1999).

The soil seed bank, if managed correctly, is a valuable resource in the restoration of disturbed areas within natural vegetation communities (Iverson and Wali 1982) and the propagule pool of seed bank and vegetative plant parts are important for succession management (Luken 1990). Such a case seems to be the same in disturbed areas within urban region. The initial vegetation from seed bank is very important to cover the open disturbed area at first and overcome the degraded condition such as scarce nutrients and soil erosions. But, later, a need for weed control is demanded as necessary due to management for specific area. Study results lead to the conclusion that the initial floristic composition from seed bank is an important factor in determining urban landscape and can alter the composition of vegetation, although new plant seeds are added to the soil surface continuously through seed rain processes and the landscape enriches floristically. But, consequently, through many soil transport chain action in random lines, gene pool summing seed pool in soils will be limited and is being homogenized. It contributes homogenization of Earth's flora regionally and globally (Vitousek *et al.* 1997). Reduction of genetic potential impedes recolonization of disturbed areas. In the end, the convergence toward increasingly similar states decreases both soil and vegetation landscape complexity (Phillips *et al.* 1999). Its development depends on the selection of two managements, clinically managed under intensive regimes or managed based on neglect (Baines 1995).

## CONCLUSIONS

The soil movement process by human activities caused plant seeds to disperse at areas landfilled. From seed bank analysis of less than 1-year-old soil, total seeds moved by humans in urban area such as Incheon were estimated to be 53 thousand million $m^{-2}$ $yr^{-1}$ in 10 cm soil depth. Seedlings from these seeds will make up spontaneous urban vegetation and affect city landscape.

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## REFERENCES

Baines C. 1995. Urban areas. pp. 362-380. In Managing Habitats for Conservation (Sutherland WJ and DA Hill eds.). Cambridge University Press, Cambridge.

Bekker RM, GL Verweij, REN Smith, R Reine, JP Bakker and S Schneider. 1997. Soil seed banks in European grasslands: does land use affect regeneration perspectives? J. Appl. Ecol. 34:1293-1310.

Carter MR. 1993. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton.

Child L and M Wade. 1999. *Falloba japonica* in the British isles: the traits of an invasive species and implications for management. pp. 200-210. In Biological Invasion of Ecosystem by Pests and Beneficial Organisms, Ser. 3 of NIAES (Yano E, K Matsuo, M Shiyomi and DA Andow eds.). NIAES, Tsukuba.

Effland WR and RV Pouyat. 1997. The genesis, classification, and mapping of soils in urban areas. Urban Ecosyst. 1:217-228.

Harper JL. 1977. Population Biology of Plants. Academic Press, New York.

Harris JA, P Birch and JP Palmer. 1996. Land Restoration and Reclamation: Principles and Practice. Addison Wesley Longman, Singapore.

Hayashi I and M Numata. 1971. Viable buried-seed population in the *Miscanthus*- and *Zoysia*-type grasslands in Japan-ecological studies on the buried-seed population in the soil related to plant succession VI. Jap. J. Ecol. 20:243-252.

Heatwole H and TA Walker. 1989. Dispersal of alien plants to coral cays. Ecology 70:787-790.

Hooke RL. 1994. On the efficacy of humans as geomorphic agents. GSA Today 4:224-225.

Incheon Metropolitan City. 2001. Incheon Statistical Yearbook. Incheon Metropolitan City, Incheon.

Iverson LR and MK Wali. 1982. Buried, viable seeds and their relation to revegetation after surface mining. J. Range. Manage. 35:648-652.

Jackson ML. 1967. Soil Chemical Analysis. Prentice-Hall of India Private Limited, New Delhi.

Jim CY. 1998. Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosyst. 2:171-181.

Kalamees R and M Zobel. 1998. Soil seed bank composition in different successional stages of a species rich wooded meadow in Laelatu, western Estonia. Acta Oecol. 19: 175-180.

Kolar CS and DM Lodge. 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16:199-204.

Kotanen PM. 1997. Effects of experimental soil disturbance on revegetation by natives and exotics in coastal Californian meadows. J. Appl. Ecol. 34:631-644.

Le Bayon RC, S Moreau, C Gascuel-Oduox and F Binet. 2002. Annual variations in earthworm surface-casting activity and soil transport by water runoff under a temperate maize agroecosystem. Geoderma 106:121-135.

Leck MA, VT Parker and RL Simpson. Ecology of Soil Seed Bank. Academic Press, INC., San Diego.

Lee TB. 1999. Illustrated flora of Korea. HyangMunSa, Seoul.

Lodge DM. 1993. Biological invasion: Lessons for ecology. Tree 8:133-137.

Luken JO. 1990. Directing Ecological Succession. Chapman and Hall, New York.

Page AL, RH Miller and DR Keeney. 1982. Methods of Soil Analysis, part 2, Chemical and Microbiological Properties. American society of agronomy, Inc. and Soil science society of America, Inc., Wisconsin.

Park SH. 1995. Colored Illustrations of Naturalized Plants of Korea. IlChoKak, Seoul.

Park SH. 2001. Colored Illustrations of Naturalized Plants of Korea: Appendix. IlChoKak, Seoul.

Perez SJ, SS Waller, LE Moser, JL Stubbendieck and AA Steuter. 1998. Seedbank characteristics of a Nebraska sandhills prairie. J. Range. Manage. 51:55-62.

Phillips JD, PA Gares and MC Slattery. 1999. Agricultural soil redistribution and landscape complexity. Landscape Ecol. 14:197-211.

Rahman A, TK James and N Grbavac. 2001. Potential of weed seedbanks for managing weeds: a review of recent New Zealand research. Weed Biol. Manage. 1:89-95.

Rebele F. 1992. Colonization and early succession on anthropogenic soils. J. Veg. Sci. 3:201-208.

Roberts HA. 1981. Seed banks in soils. Adv. Appl. Biol. 6:1-56.

Smith MA, WA Loneragan, CD Grant and JM Koch. 2000. Effect of fire on the topsoil seed banks of rehabilitated bauxite mine sites in the jarrah forest of Western Australia. Ecol. Manage. Restor. 1:50-60.

Sokal RR and FJ Rohlf. 1995a. Biometry. W.H. Freeman and Company, New York.

Sokal RR and FJ Rohlf. 1995b. Statistical Tables. W.H. Freeman and Company, New York.

Soulé ME. 1991. Conservation: tactics for a constant crisis. Science 253:744-750.

Stylinski CD and EB Allen. 1999. Lack of native species recovery following severe exotic disturbance in southern Californian shrublands. J. Appl. Ecol. 36:544-554.

ter Heerdt GNJ, GL Verweij, RM Bekker and JP Bakker. 1996. An improved method for seed-bank analysis: seedling emergence after removing the soil by sieving. Funct. Ecol. 10:144-151.

Thompson K, JP Bakker and RM Bekker. 1997. The Soil Seed Banks of North West Europe: Methodology, Density and Longevity. Cambridge University Press, New York.

Vitousek PM, HA Mooney, J Lubchenco and JM Melillo. 1997. Human domination of Earth's ecosystems. Science 277:494-499.

Worthington TR and DR Helliwell. 1987. Transference of semi-natural grassland and marshland onto newly created landfill. Biol. Conserv. 41:301-311.

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