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Research Article

DISTRIBUTION AND MANAGEMENT OF THE INVASIVE EXOTIC SPECIES *AMBROSIA TRIFIDA* AND *SICYOS ANGULATUS* IN THE SEOUL METROPOLITAN AREA

Kee Dae Kim[1]

[1] Department of Environmental Education, Korea National University of Education, Cheongju 361-892, Republic of Korea, e-mail: kdkim@knue.ac.kr

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ABSTRACT

We investigated the status of invasive exotic plants disturbing the ecosystem of the Seoul metropolitan area and examined the management of such plants. We selected our study sites based on those used in previous studies and on information in databases. All flora were classified into 57 families and 211 species; we evaluated 253 plant communities. The representative, invasive exotic species were *Sicyos angulatus, Lactuca scariola, Ambrosia trifida, Ambrosia artemisiifolia,* and *Eupatorium rugosum*. Stands of *A. trifida* ranged in area from 214 to 16,882 m^2 and were present in riparian zones, road and forest edges, slopes, and other open habitats at all sites, covering an average of 37.87% of all study areas. In Gwangju, Ansan, and Anyang cities and in Yeoncheon-gun, *A. trifida* coverage was >50%; the total mean coverage was near-continuous along the Han and the South Han rivers, broken only by cliffs in some riparian zones, and anthropogenic constructions. *A. trifida* and *S. angulatus* require careful management because of extensive growth, shading, and twining. The biodiversity of native species may be conserved by physical eradication of these plants. We describe the extents and distribution patterns of these two representative invasive exotic species in the enormous urban ecosystem of Seoul.

Keywords: *Ambrosia trifida*, exotic, invasive, management, *Sicyos angulatus*, spreading, urban ecosystem

INTRODUCTION

Humans have either deliberately or accidentally dispersed many exotic species outside their native ranges. Exotic species compete with native species and threaten ecosystem stability. Exotic species have greatly weakened ecosystems worldwide, as they are associated with diseases that spread among crops and forests [Krebs 2009]. We use "exotic" to define a species of foreign origin that has invaded the Korean Peninsula.

Many countries have listed their exotic species and study and manage them extensively. The Korean Ministry of Environment has created rules for the control of exotic species. However, ecological studies are very few in number, and evaluations of present ecological conditions and the impacts of exotic species on ecosystems are needed. The Korean Ministry of Environment has listed a total of 1,109 problematic species, of which exotic plants number 309 [NIE 2016]. The Ministry has identified 12 exotic species as legally disturbing ecosystems; these are noxious species. When animals are included, the problematic exotic species total 18.

Plants in this category include *A. trifida* (from North America) and *S. angulatus*. *A. trifida* grows to >2 m in height and have high population densities. This species was first recorded in northern Kyounggi during the 1970s and is now widely distributed in the riparian zones of streams and rivers and on road edges. Local officials report that *A. trifida* is expanding from forest edges into forest interiors in northern Kyounggi. *A. trifida*

occurs nationwide, including in northwest Gangwon, adjacent to the Seoul metropolitan area [Choi et al. 2007]. Even in North America, *A. trifida* is recorded as a problem weed, outcompeting crops [Page and Nurse 2015].

S. angulatus (from North America; annual dendril grass) is dominant in the riparian zone, establishing areas of monoculture. This species has dispersed rapidly along the riparian zone of the Han river and its tributaries. *S. angulatus* grows well in soil, with about 10% (w/w) water, under high or moderate shade conditions (60%) [Oh et al. 2015].

Our objective was to explore the distribution of *A. trifida* and *S. angulatus* in the Seoul metropolitan area and to suggest how these very invasive exotic species might be managed.

MATERIALS AND METHODS

Study area

We analyzed databases and the relevant literature to determine the distribution, spread, and damage caused to ecosystems identified by the Ministry of Environment by exotic plants. We analyzed reports prepared by the Ministry and local governments in the Seoul metropolitan area and selected 197 potential study sites. We reduced this number to 52 by considering local administrative units, distribution areas, and site accessibility (Figure 1, Table 1). The 52 sites were located in 20 local administrative units of the Gyeonggi-do region: Goyang-si, Gwachon-si, Gwangju-si, Gunpo-si, Namyangju-si, Sungnam-si, Suwon-si, Siheung-si, Ansung-si, Ansan-si, Anyang-si, Yangpyeong-gun, Yeoju-si, Yeonchon-gun, Yongin-si, Ichon-si, Paju-si, Pyeongtaek-si, Hanam-si, Hwasung-si, and metropolitan Seoul. Most study sites were urban and rural streams. Demilitarized zones were included in the Paju-si study sites.

The *S. angulatus* study sites were riparian zones along the main Han River of Gangdong-gu and Seoul, running to the South Han River of Gwangju-si and Yeoju-si. The total distance studied was approximately 88 km. Of the *S. angulatus* study sites, 15 were beside the Han River, 2 were

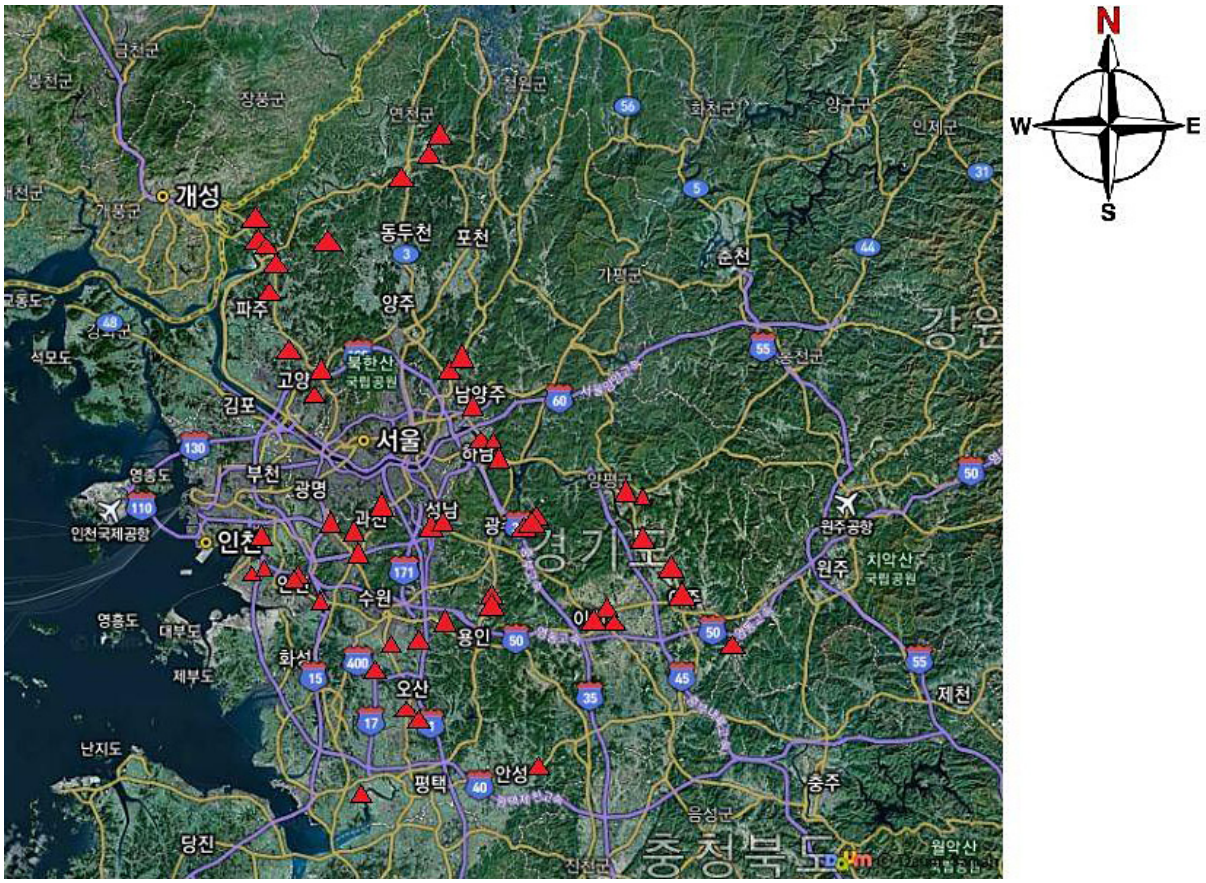

Figure 1. Study sites. The triangles indicate 52 study sites in Seoul metropolitan area where vegetation and cover survey were conducted (May 1, 2015 – Oct 31, 2016). Refer to Table 1 for details of 52 study sites

Table 1. Distribution area of exotic plants disturbing ecosystem in study sites (-: minimal area of exotic plants disturbing ecosystem)

#	Address	Exotic plants disturbing ecosystem	Distribution area (m^2)	Total survey area (m^2)
1	Gwangchang bridge, Sunbawei station parking lot Gwacheon-dong Gwacheon-si Gyeonggi-do	*Lactuca scariola*, *Ambrosia trifida*	-	9,482
2	Jiwol-ri Chowol-up Gwangju-si Gyeonggi-do (Jiwol bridge)	*Ambrosia trifida*, *Ambrosia artemisiifolia* var.	-	3,480
3	Songjung bridge Songjung-dong Gwangju-si Gyeonggi-do	*Ambrosia artemisiifolia* var. *elatior*	-	8,795
4	24–0 Jiwol-ri Chowol-up Gwangju-si Gyeonggi-do (Shinwol-2-bridge)	*Ambrosia trifida*	*Ambrosia trifida*: 2,903	32,998
5	Near Samsin APT, Gunpo bridge Geumjung-dong Gunpo-si Gyeonggi-do	*Lactuca scariola*, *Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*	-	10,962
6	Yatap elementary school, Yatap-10-bridge Yatap-dong Bundang-gu Seongnam-si Gyeonggi-do	*Ambrosia trifida*	-	4,385
7	Yeosu grand bridge Sasong-dong Sujung-gu Seongnam-si Gyeonggi-do	*Ambrosia trifida*	-	15,691
8	Daehwang bridge Daehwanggyo-dong Gwonsun-gu Suwon-si Gyeonggi-do	*Lactuca scariola*, *Ambrosia trifida*	-	12,338
9	1959 Jungwang-dong Siheung-si Gyeonggi-do (Gunja-2-bridge, Gunja stream)	*Lactuca scariola*, *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	-	16,166
10	2154 Jungwang-dong Siheung-si Gyeonggi-do (Weigwak-4-bridge, Siheung stream)	*Lactuca scariola*, *Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*	-	13,800
11	Po-dong Siheung-si Gyeonggi-do (Po-ri Sluice)	*Sicyos angulatus*, *Lactuca scariola*, *Ambrosia trifida*, *Aster pilosus*	*Ambrosia trifida*: 805	11,020
12	Wolpi-dong Sangrok-gu Ansan-si Gyeonggi-do (Ansan bridge, Ansan stream)	*Lactuca scariola*, *Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	-	11,609
13	Choji-dong Danwon-gu Ansan-si Gyeonggi-do (Hwajung-1-bridge, Hwajung stream)	*Ambrosia trifida*	*Ambrosia trifida* : 2846	23,261
14	590–1 Palgok-2-dong Sangrok-gu Ansan-si Gyeonggi-do (Palgok bridige, Banwol stream)	*Lactuca scariola*, *Ambrosia trifida* , *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	*Ambrosia trifida*: 214	13,674
15	Naebang bridge Naebang-ri Bogae-myeon Ansung-si Gyeonggi-do	*Ambrosia trifida*	*Ambrosia trifida* : 356	11,324
16	Bisan grand bridge Bisan-dong Dongan-gu Anyang-si Gyeonggi-do	*Ambrosia trifida*	-	14,688
17	Near Seoksu station, Yeonhyun middle school Seoksu-dong Manan-gu Anyang-si Gyeonggi-do	*Sicyos angulatus*, *Lactuca scariola*, *Ambrosia trifida* , *Ambrosia artemisiifolia* var. *elatior*	-	25,133
18	Wondeog bridge Gongsae-ri Gaegun-myeon Yangpyeong-gun Gyeonggi-do	*Ambrosia trifida* , *Ambrosia artemisiifolia* var. *elatior*	-	34,377
19	Infobox of Ipo-bo Ipo-ri Geumsa-ri Yangpyeong-gun Gyeonggi-do	*Sicyos angulatus*, *Ambrosia artemisiifolia* var. *elatior*	*Sicyos angulatus* : 404	30,932
20	Hoeihyun-ri Yangpyeong-up Yangpyeong-gun Gyeonggi-do	*Sicyos angulatus*, *Ambrosia trifida* , *Ambrosia artemisiifolia* var. *elatior*	*Ambrosia trifida* : 2,496	34,641
21	Hupo bridge Hupo-ri Daeshin-myeon Yeoju-si Gyeonggi-do	*Ambrosia artemisiifolia* var. *elatior*	-	10,876
22	Ha-ri Yeoju-up Yeoju-si Gyeonggi-do	*Ambrosia artemisiifolia* var. *elatior*	-	18,609
23	Near Nungnum fields Do-ri Jeomdong-myeon Yeoju-si Gyeonggi-do	*Sicyos angulatus*	-	26,287
24	A bridge before confluence of Osan stream, Sangha-dong Giheung-gu Yongin-si Gyeonggi-do (Near Sangha elementary school)	*Lactuca scariola*, *Ambrosia trifida*	-	2,031
25	447–9 Chobu-ri Mohyun-myeon Yongin-si Gyeonggi-do (Shinchobu bridge)	*Ambrosia trifida*	*Ambrosia trifida* : 1,066	4,290
26	A forked road in front of Supo bridge Cheoin-gu Yongin-si Gyeonggi-do (Near Dunjeon station)	*Ambrosia trifida*	-	10,653
27	Bokha-2-bridge Galsan-dong Ichon-si Gyeonggi-do	*Ambrosia trifida* , *Ambrosia artemisiifolia* var. *elatior*	-	23,762
28	Byeolmyeong bridge Jangrok-dong Ichon-si Gyeonggi-do (Jangrok bridge)	*Ambrosia artemisiifolia* var. *elatior*	-	10,962
29	Yousan-2-bridge Jangrok-dong Ichon-si Gyeonggi-do	*Ambrosia trifida* , *Ambrosia artemisiifolia* var. *elatior*, *Rumex acetocella*	*Ambrosia trifida* : 1,793	16,965

30	Geumam bridge Geumam-ri Seotan-myeon Pyeongtaek-si Gyeonggi-do	*Ambrosia trifida*, *Aster pilosus*	-	13,705
31	Near lake Kileum-ri Osung-myeon Pyeongtaek-si Gyeonggi-do	*Lactuca scariola*, *Sicyos angulatus*	-	3,470
32	Bongnam bridge Jinwe-myeon Pyeongtaek-si Gyeonggi-do (Intersection of local road 314)	*Lactuca scariola*, *Ambrosia trifida*	-	24,469
33	Near Korea Water Resources Corporation Baealmi-dong Hanam-si Gyeonggi-do	*Eupatorium rugosum*	-	6,741
34	Shinjang-dong Hanam-si Gyeonggi-do (Deogpung stream)	*Ambrosia trifida*	*Ambrosia trifida*: 975	20,338
35	Near Shinan APT, Sangok-2-bridge Chanwoo-dong Hanam-si Gyeonggi-do (Sangok stream)	*Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*	*Ambrosia trifida* : 8,323	25,786
36	Seokwoo bridge Seokwoo-ri Dongtan-myeon Hwasung-si Gyeonggi-do	*Ambrosia trifida*	-	20,334
37	Yongsu bridge Goji-ri Jungnam-myeon Hwasung-si Gyeonggi-do	*Ambrosia trifida*	-	92,977
38	205–5 Samsong-dong Deogyang-gu Goyang-si Gyeonggi-do	*Ambrosia trifida*	*Ambrosia trifida*: 7,851	39,188
39	450–8 Shinwon-dong Deogyang-gu Goyang-si Gyeonggi-do	*Sicyos angulatus*, *Lactuca scariola*, *Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	*Ambrosia trifida*: 2,730	49,364
40	228–27 Sunghyun-ro Ilsandong-gu Goyang-si Gyeonggi-do	*Sicyos angulatus*	*Sicyos angulatus*: 1,181	11,724
41	273–5 Ilpae-dong Namyang-si Gyeonggi-do	*Sicyos angulatus*, *Ambrosia trifida*	*Sicyos angulatus*: 2,076; *Ambrosia trifida*: 771	8,470
42	567–24 Naegok-ri Jinjeop-up Namyang-si Gyeonggi-do (Wangsuk stream)	*Sicyos angulatus*, *Lactuca scariola*, *Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	*Sicyos angulatus*: 648; *Ambrosia trifida*: 2,561	5,295
43	Shinwol bridge, Shinwol-ri Jinjeop-up Namyang-si Gyeonggi-do	*Sicyos angulatus*, *Ambrosia trifida*	*Sicyos angulatus*: 1,452; *Ambrosia trifida*: 2,125	5,884
44	518 Gomun-ri Yeoncheon-up Yeoncheon-gun Gyeonggi-do	*Ambrosia trifida*, *Aster pilosus*	*Ambrosia trifida*: 3,412	3,412
45	San 35–10 Goneung-ri Jeongok-up Yeoncheon-gun Gyeonggi-do	*Sicyos angulatus*, *Ambrosia trifida*, *Aster pilosus*	*Sicyos angulatus*: 2,191; *Ambrosia trifida*: 7,586	14,869
46	13–1 Shindap-ri Jeongok-up Yeoncheon-gun Gyeonggi-do	*Ambrosia trifida* , *Aster pilosus*	*Ambrosia trifida*: 15,725; *Aster pilosus*: 2,963	18,688
47	336–9 Bongseo-ri Munsan-up Paju-si Gyeonggi-do	*Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	*Ambrosia trifida*: 5,105	18,954
48	687 Jikcheon-ri Bupwon-up Paju-si Gyeonggi-do	*Ambrosia trifida*	*Ambrosia trifida*: 11,991	11,991
49	741–1 Bongam-ri Paju-up Paju-si Gyeonggi-do	*Sicyos angulatus*, *Ambrosia trifida*, *Aster pilosus*	*Ambrosia trifida*: 11,019	75,539
50	DMZ1, Deokjinsansung	*Sicyos angulatus*, *Ambrosia trifida*, *Aster pilosus*	*Ambrosia trifida*: 16,882	16,882
51	DMZ2	*Ambrosia trifida*	*Ambrosia trifida*: 14,763	15,202
52	DMZ3, Sunae stream	*Ambrosia trifida*, *Ambrosia artemisiifolia* var. *elatior*, *Aster pilosus*	*Ambrosia trifida*: 4,511	4,511
	Total		139,724	970,984

in Lake Paldang, and 26 were along the South Han river (Table 3).

Vegetation and cover analyses

The GPS locations, physical addresses, study areas, dominant species, and areas covered by the species were recorded in detail. We selected reference points and performed vegetation surveys in circles of radii 500 m from such points. We established plant community quadrats at all sites. If the area occupied by a problematic species were >100 m^2, we considered that the species formed a plant community. All species in each quadrat were recorded, and coverages were visually estimated (in terms of the dominant

class) using the Braun–Blanquet scale [Fuller and Conard 1932].

GIS analyses

We downloaded recent geomorphological maps at a 1:25,000 scale and recorded each study site, the area thereof, and geomorphological data. We noted the proportions of annuals, perennials, shrubs and trees, exotic plants, waterways, open lots, artificial structures, forest vegetation, housing and business development, arable land, and the following 12 problematic plants: *A. trifida*, *A. artemisiifolia* var. *elatior*, *E. rugosum*, *A. pilosus*, *H. radicata*, *S. altissima*, *L. scariolia*, *P. distichum* var. *distichum*, *P. distichum* var. *indutum*, *S. carolinense*, *S. angulatus,* and *R. acetosella*. All areas <100 m^2 were amalgamated with adjacent areas. We used Q-GIS ver. 2.2.0 to define the areas [QGIS 2016]. All plant coverages were calculated using Q-GIS data.

Statistical analyses

All problematic plant coverages recorded were pooled to estimate and rank total mean *A. trifida* coverages in local administrative units. We employed the Kruskal–Wallis rank test of SPSS software ver. 12.0.

Spread rates

We calculated *A. trifida* and *S. angulatus* spread rates [Kil et al. 2012; Kil et al. 2013] using the following equation: Spread rate (m^2/year) = (area of plant species in a certain year–area in year 1)/(Arabic number of test year–Arabic number in year 1). The spread rates in similar ecosystems (open lots, riparian zones, and road edges) were averaged.

RESULTS AND DISCUSSION

Vegetation analysis

On the 197 study sites, the frequencies (in decreasing order) of exotic plants disturbing the ecosystem were: *A. trifida* (65%), *A. artemisiifolia* var. *elatior* (54%), *A. pilosus* (30%), *S. angulatus* (23%), *L. scariolia* (8%), and *E. rugsom* (3%) (n = 197). The quadrat survey showed that 211 species of 57 families were involved. We recorded 50 problematic plant communities among the 253 communities (Table 2). The dominant problematic species were *S. angulatus*, *L. scariola*, *A. trifida*, *A. artemisiifolia* var. *elatior*, and *E. rugosum*. The most frequent species encountered in the vegetation survey was *A. trifida,* whereas the most common native species were *Pragmites communis* and *Pragmites japonica*. The dominant exotic species of plant communities that did not disturb the ecosystem were *Ailanthus altissima*, *Erigeron annuus*, *Oenothera biennis*, *Helianthus tuberosus*, *Erigeron canadensis*, *Bromus richardsonii*, *Robinia pseudoacacia*, *Amorpha fruticose*, *Chenopodium serotinum*, *Lepidium virginicum*, *Coreopsis lanceolate*, *Festuca ovina*, *Trifolium repens,* and *Chenopodium album*. Among native species, perennials and annuals dominated; most exotic and problematic exotic species were adaptable annuals (Figure 2), particularly in the riparian zones of the Han and South Han Rivers (Figure 3).

Distributional status of *A. trifida* and *S. angulatus*

The ratio of the area of exotic plants disturbing the ecosystem to that of all study sites was ca. 14% (Table 1). The *A. trifida* distributional areas ranged from 214 (590–1 Palgok-2-dong Sangrok-gu Ansan-si Gyeonggi-do; Palgok Bridge, Banwol Stream) to 16,882 m^2 (DMZ, Deokjinsansung) (Table 1). We recorded 37 *S. angulatus* communities on the principal streams of the Han and South Han Rivers (Tables 3, 4). Quadrat vegetation analysis revealed 44 species in 24 families among 3 plant communities. The areas of all but the principal *S. angulatus* communities ranged from 20.53 m^2 to 244,248.89 m^2 (Table 3). The largest area of *S angulatus* was 434,903 m^2, constituting an epicenter of *S. angulatus* propagation. This community was located at the largest cape of the Han River; upstream *Sicyos angulatus* seeds are delivered when the water velocity is low; they then germinate and grow. *S. angulatus* propagation is influenced by the direction of upstream flow [Osawa et al. 2013]. The plant communities recorded along the Han and South Han Rivers were *S. angulatus*, *A. princeps* var. *orientalis,* and *Humulus japonicas* (Table 4); *S. angulatus* was the most common (95%).

Spread rates of *A. trifida* and *S. angulatus*

The *A. trifida* spread rate ranged from 4,972 m^2/year to 337,500 m^2/year (Table 6), and it was

Table 2. Status of plant communities appeared in study sites. The number in parenthesis indicates frequency recorded. No number represents one frequency

Name of plant community	Number of plant community	Locations(Refer to number of locations in Table 1)
Sicyos angulatus[a]	14	11, 19, 20(2), 31, 39(3), 40(3), 43, 45, 49
Lactuca scariola[a]	5	10, 12, 14(2), 31
Ailanthus altissima	1	8
Phragmites communis	16	3, 8, 10, 11, 15, 21, 26, 27, 28, 29, 30, 31, 32(2), 36, 37
Phalaris arundinacea	3	5, 14, 25
Setaria viridis	2	41, 42
Erigeron annuus	7	2, 4, 5, 7, 8, 29, 35
Agropyron tsukushiense var. *transiens*	2	1, 37
Salix gracilistyla	2	6, 23
Persicaria thunbergii	12	1(2), 2, 3, 4, 5, 12, 13, 21, 24, 43, 49
Salix pseudolasiogyne	4	5, 16, 26, 37
Ambrosia trifida[a]	39	1, 2, 4(2), 5, 7, 8(2), 12(2), 13(3), 14(4), 16, 17(2), 18, 20(2), 24(2), 25(3), 26, 27, 29, 34, 35(2), 36, 37(3), 38(5), 39(2), 41(1), 42(2), 44(2), 45(1), 46(2), 47(3), 48, 49(6)
Oenothera biennis	3	23, 26(2)
Phragmites japonica	22	1, 2, 4, 6, 7, 9, 11, 12, 13, 14, 16, 17, 18, 19, 20, 23, 34, 35, 39, 42, 43, 45
Glycine soja	1	38
Echinochloa crusgalli	1	41
Ambrosia artemisiifolia var. *elatior*[a]	3	10, 14, 19
Helianthus tuberosus	1	30
Erigeron canadensis	2	12, 35
Scirpus fluviatilis	1	22
Artemisia selengensis	2	22, 26
Miscanthus sacchariflorus	12	1, 5, 7, 11, 12, 16, 17, 18(2), 34, 47, 49
Aster pilosus	1	47
Digitaria sanguinalis	1	36
Salix koreensis	5	1, 20, 30, 32, 36
Lespedeza cuneata	2	19, 38
Bromus richardsonii	5	9, 15, 16, 30, 37
Rubus crataegifolius	1	25
Umbelliferae spp.	1	31
Eupatorium rugosum[a]	2	33(2)
Salix subfragilis	5	1, 16, 17, 18, 34
Agropyron ciliare	1	17
Equisetum arvense	5	6, 21, 27, 28, 30
Artemisia princeps var. *orientalis*	8	4, 6, 10, 14, 32, 39, 45(2)
Robinia pseudoacacia	13	4, 14, 15, 17, 20, 27, 28, 29, 32, 37, 38, 39, 42
Chelidonium majus var. *asiaticum*	5	2, 15, 20, 27, 29
Salix chaenomeloides	1	7
Amorpha fruticosa	1	36
Chenopodium serotinum	1	7
Zizantia latifolia	3	6, 7, 14
Pueraria thunbergiana	11	1, 3, 14, 18, 19, 26, 35, 40, 42, 45, 47
Lepidium virginicum	2	16(2)
Persicaria nodosa	2	3, 14
Coreopsis lanceolata	2	19, 34
Festuca ovina	7	6, 9, 13, 16, 35, 37(2)
Trifolium repens	1	30
Poa spp.	1	29
Platanus occidentalis	1	16
Humulus japonicus	7	1, 5, 9, 19, 27, 28, 40
Chenopodium album	3	22, 24, 25
Total	253	

[a]: Exotic plants disturbing ecosystem.

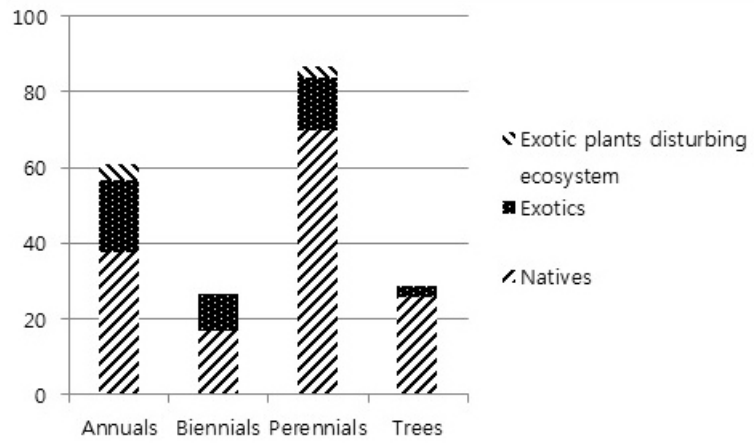

Figure 2. Life forms of flora in study sites

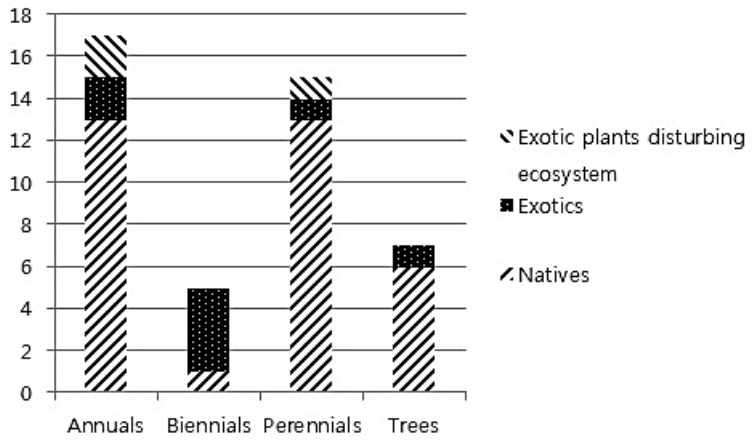

Figure 3. Life forms of flora in the Han and the South Han river

lowest in the riparian zone. However, *A. trifida* is spread by flowing water [Kim and Choi 2008] and may invade adjacent sites. The spread rate was higher along road edges than in riparian zones, although the species disturbs and damages Korean river ecosystems [Seo et al. 2012]. *S. angulatus* was found principally along riversides and on small mountains, roadsides, and open and cultivated areas [Moon et al. 2008; Kim et al. 2014]. The coverages of these two species fell over time at some sites, possibly due to construction and changes in land use.

Management of *A. trifida* and *S. angulatus*

We used the species coverage data to analyze the distribution densities of exotic plants disturbing the ecosystem. However, not all the 12 such species were represented in the vegetation survey. Only *A. trifida* was found at all study sites (37.87% mean coverage; Table 5). Coverage was >50% in Gwangju-si, Ansan-si, Anyang-si, and Yeoncheon-gun. The Kruskal–Wallis test showed that the *A. trifida* coverage differed significantly from that of other plants ($p < 0.05$; Table 5).

A. trifida was the most common exotic species and was found in small or large patches in the Seoul metropolitan area. This species can invade forest edges and interiors, the riparian zones of urban streams, and disturbed sites. The shading effect of *A. trifida* negatively affects native species; in the Seoul metropolitan area, *A. trifida* can grow to about 3 m in height prior to September/October. *A. trifida* dominated the DMZ of Paju City, forming monocultures in fields by road edges, abandoned paddy fields, and military training areas. This may be explained by the fact that the seeds are spread by the transportation of soldiers and equipment. We recommend that military transports and uniforms be cleaned after training exercises.

The distance between *S. angulatus* patches downstream near Hanam-si was shorter that that upstream near Yeoju-si (Figure 4), which is ex-

Table 3. Study sites for *Sicyos angulatus* in the Han river and The South Han river of the distance about 88.75 km along Gangdong-gu to Samhap-ri Jumdong-myeon Yeoju-si (8–1 to 8–7 sites represents one connected patches dominated by *Sicyos angulatus*)

No.	Address	Longitude	Latitude	Name of river	Area of *Sicyos angulatus* (m^2)
1	351–1 Chonho-2-dong Gandong-gu Seoul	127 07 12E	37 32 50N	Han	230.53
2	508–2 Chonho-2-dong Gandong-gu Seoul	127 07 08E	37 32 53N	Han	67,294.18
3	661–1 Amsa-2-dong Gangdong-gu Seoul	127 07 23E	37 33 23N	Han	998.23
4	660 Amsa-2-dong Gangdong-gu Seoul	127 07 25E	37 33 27N	Han	12,471.49
5	166–8 Amsa-2-dong Gangdong-gu Seoul	127 07 39E	37 33 41N	Han	4,444.93
6	148–13 Amsa-2-dong Gangdong-gu Seoul	127 07 46E	37 33 44N	Han	10,377.04
7	378 Godeug-dong Gangdong-gu Seoul	127 09 18E	37 34 13N	Han	1251.91
8–1	14 Gangil-dong Gangdong-gu Seoul	127 10 07E	37 34 42N	Han	10,229.28
8–2	399 Sun-dong Hanam-si Kyeonggi-do Gyeonggi-do	127 11 09E	37 34 57N	Han	244,248.89
8–3	78 Misa-dong Hanam-si Gyeonggi-do	127 12 49E	37 33 53N	Han	4,413.47
8–4	Dangjung-dong Hanam-si Gyeonggi-do	127 13 06E	37 33 30N	Han	74,801.58
8–5	2–9 Misa-dong Hanam-si Gyeonggi-do	127 13 15E	37 33 09N	Han	1,362.99
8–6	516 Changwoo-dong Hanam-si Gyeonggi-do	127 13 36E	37 32 55N	Han	99,846.91
8–7	San 2–22 Baealmi-dong Hanam-si Gyeonggi-do	127 14 40E	37 32 23N	Han	1897.44
9	159–18 Baealmi-dong Hanam-si Gyeonggi-do	127 15 07E	37 32 15N	Han	2436.71
10	657–2 Bunwon-ri Namjong-myeon Gwangju-si	127 18 14E	37 30 03N	Lake Paldang	1347.77
11	198–3 Sucheong-ri Namjong-myeon Gwangju-si	127 22 43E	37 30 10N	South Han	1475.78
12	285–2 Unsim-ri Gangha-myeon Yangpyeong-gun Gyeonggi-do	127 23 27E	37 29 35N	South Han	2690.89
13	68–5 Unsim-ri Gangha-myeon Yangpyeong-gun Gyeonggi-do	127 24 30E	37 29 49N	South Han	749.90
14	1049–2 Jeonsu-ri Gangha-myeon Yangpyeong-gun Gyeonggi-do	127 24 55E	37 30 02N	South Han	1243.36
15	1038–1 Jeonsu-ri Gangha-myeon Yangpyeong-gun Gyeonggi-do	127 24 52E	37 29 54N	South Han	600.03
16	41–6 Geumsa-ri Geumsa-myeon Yeoju-si Gyeonggi-do	127 31 42E	37 25 16N	South Han	9917.70
17	241 Geumsa-ri Namjong-myeon Gwangju-si Gyeonggi-do	127 18 20E	37 29 18N	Lake Paldang	319.56
18	350–2 Gyopyeong-ri Gangsang-myeon Yangpyeong-gun Gyeonggi-do	127 29 16E	37 29 05N	South Han	2417.94
19	232 Byeongsan-ri Gangsang-myeon Yangpyeong-gun Gyeonggi-do	127 28 06E	37 29 44N	South Han	175.51
20	San166–5 Byeongsan-ri Gangsang-myeon Yangpyeong-gun Gyeonggi-do	127 27 11E	37 30 03N	South Han	1990.28
21	479 Jeonsu-ri Gangha-myeon Yangpyeong-gun Gyeonggi-do	127 25 54E	37 30 19N	South Han	1531.23
22	San 23 Sangbaek-ri Heungchon-myeon Yeoju-si Gyeonggi-do	127 33 41E	37 21 36N	South Han	25.48
23	177–3 Sangbaek-ri Heungchon-myeon Yeoju-si Gyeonggi-do	127 33 20E	37 21 43N	South Han	839.73
24	164 Sangbaek-ri Heungchon-myeon Yeoju-si Gyeonggi-do	127 33 10E	37 21 54N	South Han	20.53
25	36–10 Gyeshin-ri Heungchon-myeon Yeoju-si Gyeonggi-do	127 32 17E	37 23 10N	South Han	732.02
26	318–2 Dangnam-ri Daeshin-myeon Yeoju-si Gyeonggi-do	127 32 09E	37 23 26N	South Han	1559.16
27	2 Samhap-ri Jumdong Yeoju-si Gyeonggi-do	127 44 49E	37 13 26N	South Han	130.53
28	132 Do-ri Jumdong Yeoju-si Gyeonggi-do	127 42 33E	37 13 37N	South Han	5586.18
29	202–1 Uman-ri Yeoju-up Yeoju-si Gyeonggi-do	127 40 50E	37 15 05N	South Han	219.76
30	49–3 Danhyun-ri Yeoju-up Yeoju-si Gyeonggi-do	127 40 58E	37 16 26N	South Han	219.76
31	305 Yeonyang-ri Yeoju-up Yeoju-si Gyeonggi-do	127 40 07E	37 17 43N	South Han	129.67
32	39 Janae-ro Yeoju-up Yeoju-si Gyeonggi-do	127 39 2.96E	37 17 36N	South Han	844.05
33	136–10 Sang-ri Yeoju-up Yeoju-si Gyeonggi-do	127 38 52E	37 17 43N	South Han	3055.97
34	3–108 Ha-ri Yeoju-up Yeoju-si Gyeonggi-do	127 37 10E	37 18 19N	South Han	199.00

35	1–1 Wangdae-ri Neungseo-myeon Yeoju-si Gyeonggi-do	127 37 03E	37 18 50N	South Han	314.26
36	397–10 Wangdae-ri Neungseo-myeon Yeoju-si Gyeonggi-do	127 35 58E	37 19 46N	South Han	864.38
37	59–1 Naeyang-ri Neungseo-myeon Yeoju-si Gyeonggi-do	127 34 23E	37 21 16N	South Han	814.97

Table 4. Status of plant communities at riparian zones of the Han and the South Han river

Name of plant communities	Number of plant communities	Sites(refer to name of sites in Table3)
Sicyos angulatus[a]	35	1, 2, 3, 4, 5, 6, 7, 8–1, 8–2, 8–3, 8–4, 8–5, 8–6, 8–7, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37
Artemisia princeps var. *orientalis*	1	22
Humulus japonicus	1	14
Total	37	

[a] Exotic plants disturbing ecosystem

Table 5. Total mean cover of exotic plant disturbing ecosystem in local cities of Seoul metropolitan area (±SD; – means no data). The different superscript numbers represent significant rank of means by Kruskal-Wallis Test

Cities	*Sicyos angulatus*	*Lactuca scariola*	*Ambrosia trifida*	*Ambrosia artemisiifolia* var. *elatior*	*Aster pilosus*	*Rumex acetocella*
Goyang-si	20.71±31.28	-	24.77[17)]±32.26	0.00±0.02	2.00±6.93	-
Gwacheon-si	-	-	26.18[13)]±19.99	-	-	-
Gwangju-si	-	-	67.51[1)]±32.27	17.5	-	-
Gunpo-si	-	0.05	30.76[12)]±40.84	-	-	-
Namyangju-si	13.08±29.83	0.15±0.55	18.85[19)]±34.89	-	0.38±1.39	-
Seongnam-si	-	-	26.67[11)]±7.64	-	-	-
Suwon-si	-	-	70[2)]	-	-	-
Siheung-si	38.75±22.5	55	32.89[16)]±34.95	15±9.35	18	-
Ansan-si	-	18.91±17.61	60[3)]±31.21	46.7	7.68	-
Anseong-si	-	-	45[10)]	-	-	-
Anyang-si	20	-	55.83[5)]±26.72	-	-	-
Yangpyeong-gun	19.72±28.83	-	34.04[15)]±41.74	35.03	-	-
Yeoju-si	-	-	0.05[20)]	0.05	-	-
Yeoncheon-gun	12.73±28.67	-	55.45[4)]±32.97	-	4.12±10.67	-
Yongin-si	-	-	49.42[7)]±37.62	-	-	-
Icheon-si	0.1	10	49.5[6)]±42.79	4.68	-	40
Paju-si	4.33±16.78	-	48.80[8)]±28.60	0.01±0.03	10.60±18.53	-
Pyeongtaek-si	70	60	10.03[18)]±14.11	-	-	-
Hanam-si	-	-	32.02[14)]±35.38	40	-	-
Hwasung-si	-	-	45[9)]±34.93	-	-	-
Total mean cover	8.75±22.22	1.98±8.91	37.87±34.67	2.50±11.14	1.95±7.74	40

plained by the fact that construction affected the former riparian zone. Under such circumstances, *S. angulatus* may spread from the principal streams along tributaries, including the waterways of paddy fields and ditches. Thus, tributary populations must be managed. In terms of biodiversity conservation, *A. trifida* and *S. angulatus* must be eliminated; the former plant grows rapidly and densely, and the latter is associated with shading and dendrilling. Exotic plants disturbing ecosystems can be harvested and turned into biological resources, such as nitrogen fertilizers [Kim et al. 2016]. Also, they may serve as educational materials in terms of plant classification and observation. Exotic plants should be sustainably used rather than dumped as organic waste.

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Table 6. Status of spreading of *Ambrosia trifida* and *Sicyos angulatus* (Value ± SD)

EPDE	Ecosystem type	Spreading rate (m^2/y)
Ambrosia trifida	Open lots	337,500
	Road edge	23,333
	Riparian zone	4,972±3,354
Sicyos angulatus	Road edge	3,125±2,839
	Riparian zone	262

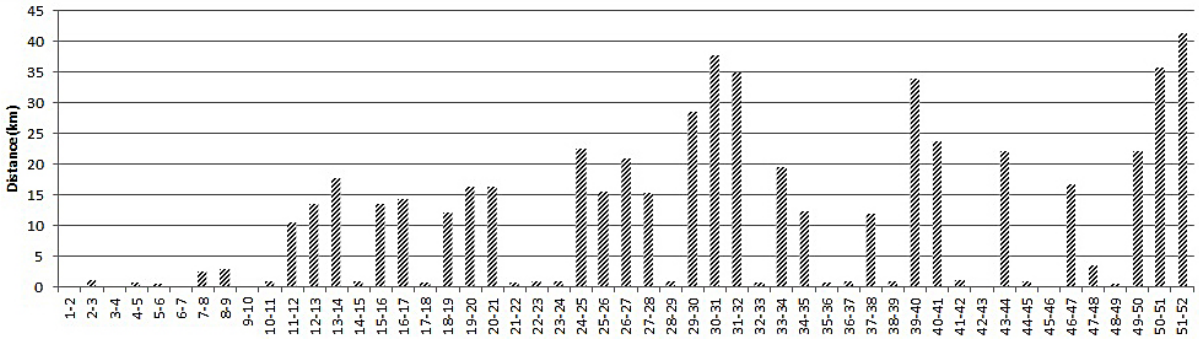

Figure 4. The distances between patches of *Sicyos angulatus* at the riparian zones of the Han and the South Han river. The number indicates study sites (1–2: Gangdong-gu, Seoul ~ 51–52: Jumdong-myeon, Yeoju-si)

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