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Distribution of *Phytolacca americana* in a coastal sand dune

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Abstract

This study examined the main factors affecting the distribution of *Phytolacca americana*, an exotic plant species in Korea, in coastal sand dunes. The areas examined from June 2004 to February 2006 were in Sindusagu where was located on Sin-du-ri, Wonbuk-myen, Taean-gun, Chungcheongnam-do. The vegetation, sediment properties, sizes and ages of *Robinia pseudoacacia, P. americana* and *Pinus thnunbergii* and spatial distribution of *P. americana* were assessed. Firstly, correlation coefficients (CC) between *P. americana*'s root biomass and sediment properties were not significant. Secondly, of the four community types, *P. americana* was not in the mixed herbaceous community and its density was the highest in the *P. thunbergii–R. pseudoacacia* and *R. pseudoacacia* community The Poisson distribution analysis revealed the distribution of *P. americana* to be severely clumped. The root biomass of *P. americana* and the basal area of *R. pseudoacacia* were significantly correlated, but the CCs between *P. thunbergii* and other two species were not significant. The ages of *P. americana* and *R. pseudoacacia* in a quadrat were significantly correlated. Thirdly, *P. americana's* ages in a quadrat were mostly similar to each other. Therefore, the spatial distribution of *P. americana* was largely influenced by *R. pseudoacacia* but not by the sediment properties, and plants in a narrow area were concurrently germinated.

Key words: age, coastal sand dune, *Phytolacca americana, Robinia pseudoacacia*, spatial distribution, vegetation

INTRODUCTION

Coastal sand dunes are formed by the movement of sand from the sea to land. At this time, the energy enforcing sand movement is derived from waves and wind. The physical environment for plant growth in coastal sand dunes is different from terrestrial ones; sand soil has good soil aeration but poor holding capacity of water and inorganic nutrients. In particular, coastal sand dunes shows a high soil surface temperature and low water content in summer, which is an unstable surface, as well as inadequate inorganic nutrients for plant growth. A small amount of salt is inputted continuously from sea water but it is easily leached by rainfall and the levels of nitrogen or phosphorus are inadequate (Chapman 1964, Rozema et al. 1985). In addition, soil nitrogen content is very low and it is main limiting factor to plant growth (Kachi and Hirose 1983, Berendse 1990, Olff 1992, Olff et al. 1993). For these reasons, plant species that can grow in coastal sand dunes are specific and limited.

Phytolacca americana is an exotic foreign species that was introduced into Korea in the 1950s and spread rapidly into the diverse vegetation after 1990 (Park 1995). This species was originally thought to acidify the soil, but this was later proven to be false (Park et al. 1999). Because of its adverse effects on the ecosystem, the Ministry of Environments of Korea designated *P. americana* to be a harmful species. *Phytolacca americana* tolerates strong acidic soil better than other species, and prefers strong sunlight. Moreover, its germination rate is high under sunny condi-

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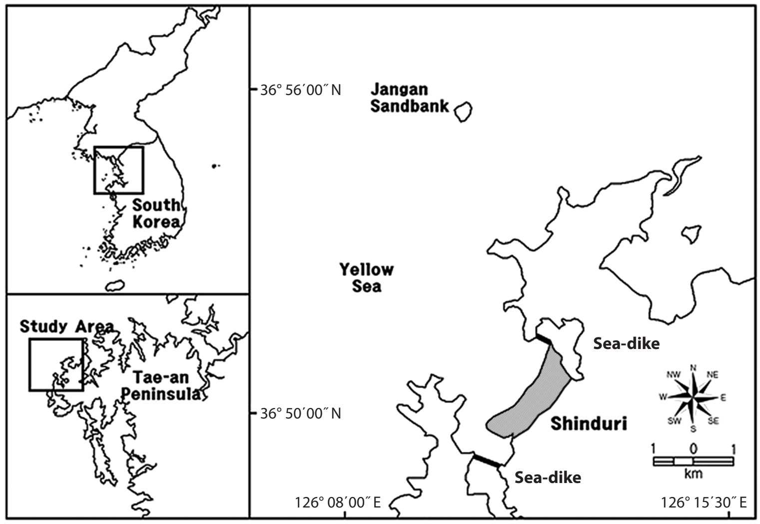

Fig. 1. Map showing the study area (shaded area).

tions (Joo and Cho 1995, Park et al. 1997, 1998). Park et al. (1998) reported that the growth of *P. americana* is dependent more on the sunlight than on the inorganic nutrient condition, and decreases significantly under 8% of the full sunlight, regardless of the inorganic nutrient content. Leaf area growth of *P. americana* increases conspicuously and the lowered net assimilation rate is compensated for by the increased leaf area under 33% full sunlight. The specific leaf weight is depended on the irradiation amount on the leaves. Joo and Cho (1995) reported that *P. americana* preferred intense sunlight. However, the small amount of inorganic nutrients acted as limiting factors for *P. americana* to grow in coastal sand dunes. Based on the fact that *P. americana* is commonly observed under a *Robinia pseudoacacia* canopy, inorganic nutrients, particularly nitrogen, as well as sunlight are believed to be important factors for the growth of this species (Joo and Cho 1995). *Robinia pseudoacacia* belongs to the Leguminosae family and supplies fixed nitrogen to the soil. As a result, these two species can be distributed together in the same area where the nutrient level is insufficient (Joo and Cho 1995).

In Korea, *P. americana* has threatened other peripheral plants as well as *P. esculenta*, which is a similar species, but is used as a pharmacological material. Therefore, many studies of *P. americana* have been carried out. These studies include its pharmacological effect and chemical composition (Woo and Kang 1975), main environmental factors controlling its growth (Joo and Cho 1995,Ri and Chun 1996, Park et al. 1998, 1999a, Park 2003, Kim et al. 2008), allelopathic activity (Bae et al. 1997, Kim et al. 2005a, 2005b), seed germination properties (Kang et al. 1997), effects on soil acidification (Kim 1996, Jang and Kim 1996, Park et al. 1999b). However, although *P. americana* has extended its distribution rapidly and was designated a harmful species by the Korean government, there is insufficient ecological information on the natural population of this species. As other coastal sand dune, Sindu sand dune is poor in soil nutrients but *P. americana* which prefers much nitrogen in soil is distributed in high density in a some area.

The aim of this study was to determine the main factors on the spatial distribution of *P. americana* in coastal sand dunes. For this, the sediment properties as a physical environment, vegetation as a biotic factor, and the age composition of *P. americana* at the same area at a population level were analyzed in the Sindu sand dune (Sindusagu), where the Cultural Heritage Administration of Korea has reserved it as a natural monument.

MATERIALS AND METHODS

The study area was located at Sindu sand dune, Sindu-ri, Wonbuk-myeon, Taean-gun, Chungnam Province (36°50′ N, 126°16′ E) (Fig. 1). The Sindu sand dune is 2 km in length and 500 m in width. North-East area of Sindu sand dune is reservation area designated Natural Monument No. 431 by Cultural Heritage Administration of Korea (Taean-gun 2004). Previously, only the sand dunes of the South-Western small area were used as cultivated land and a residential quarter. However, with the exception of the reservation area, almost all areas on the seaside and forest have been seriously disturbed by the increase automobile roads. In particular, automobile roads are covered with gravel and soil from other areas, or are paved by cement. Therefore, studies of the sand dune vegetation have been carried out mainly in the reservation area (Ahn 2003, Song et al. 2005, Kahng 2006, Song and Cho 2007).

A field survey from June 2004 to February 2006 was accomplished in three ways. In 2004, the vegetation survey program for the coastal sand dune was carried out by Ministry of Environment. At this time, the distribution pattern of *P. americana* was outlined. Next, the relationship between fluting and plant size was surveyed in autumn of 2005. Nutrients of sediment were stable in winter, therefore, surveyed from November 2005 to February 2006. Firstly, to clarify the relationship between vegetation and *P. americana*, and spatial distribution of this species, the vegetation and density of *P. americana* in all areas was surveyed from June to August 2004. The vegetation was first grouped into the two communities: herbaceous (including *Rosa rugosa* and *Vitex rotundifolia* community) and woody communities. The latter was divided repeatedly into three groups: *Pinus thunbergii*, *P. thunbergii-R. pseudoacacia* and *R. pseudoacacia* communities. Of these, for the three communities (two woody and one herbaceous community), two representative sites were chosen and surveyed in 10 m × 10 m quadrat, respectively. Community structures were analyzed by Braun-Blanquet (1964). Woody community was classified into tree, subtree, shrub and herb layers. Next, height, dominant species and total coverage of each layer were checked. Coverage was grouped into 10% unit (5% unit in herb layer). The density of *P. americana* was checked by ordinary sight and in 10 m × 10 m quadrat. The data was divided into three categories of no, low density (under 0.1 plants/m^2) and high density areas (over 0.1 plants/m^2). To test the Poisson distribution of *P. americana*, 150 quadrats, 2 m × 2 m in size, were set up continuously along the 3 lines, 100 m in length. All shoots of *P. americana* were checked in a quadrat. Secondly, to clarify the relationship between *R. pseudoacacia* and *P. americana*, sixty four circular quadrats, 5 m in diameter, were randomly set up at woody community, and woody plants and *P. americana* were surveyed from November 2005 to February 2006. In the winter, there are two advantages in field sampling. Firstly, the decomposition rate of organic matter is low and the nutrient content leached from the sediment by precipitation is small, so that the sediment nutrient content is relatively constant for long time. Secondary, the biomass of herbaceous plant is limited in underground part and the exchange of organic matter between shoot and root is not, so that the datum for plant size is definite. At this time, the center of each quadrat was located on the largest *R. pseudoacacia* plant in a quadrat. The perimeters and ages of *R. pseudoacacia* and *P. thunbergii* were checked at 50 cm height from the sediment surface. The roots of *P. americana* were dug out, age-counted, dried at 80°C in a dry oven and weighed. A sediment sample in a quadrat was collected at a 10 to 20 cm depth. The sediment samples were air-dried in the shade. The quadrats where stumps of *P. thunbergii* or *R. pseudoacacia* were present were omitted in statistical analysis of the relationship between *P. americana* and the former two species. Thirdly, to clarify the factor of the two, age and size, more affecting on flowering, the 230 plants which heights were in the range of 30-60 cm were sampled on September 2005. Sampled *P. americana* plants were grouped into fruiting plants (120 plants) and non-fruiting ones (110 plants). Age and root dry weight for all plants were checked. This survey could reveal that there was relationship between the age distribution of *P. americana* and the seed input at the same area or not.

In sediment samples, the total nitrogen, organic matter and available phosphorus were analyzed using the micro-Kjeldahl method, loss on ignition method, and spectrophotometric method at 660 nm after molybdophosphoric blue coloring, respectively. The K, Na, Mg and Ca contents in the sediment samples were analyzed by inductively coupled plasma-atomic emission spectroscope (ICP) after water extraction. The spatial distribution of *P. americana* was analyzed using a Poisson distribution test. All correlation coefficients between the two factors were examined using the formula, $y = ax + b$.

RESULTS

Sediment properties

The mean and range (in sixty four quadrats) of sediment organic matter were 0.987 ± 0.378 and 0.44 to 1.51, respectively (Table 1). The total nitrogen content of sedi-

Table 1. Sediment properties of 64 quadrats of 5 m in diameter

Soil properties	Mean ± SD	Range*
Organic Matter (%)	0.978 ± 0.378	0.44–1.51
Total Nitrogen (mg/g)	0.919 ± 0.095	0.047–0.612
Available Phosphorus (%)	9.46 ± 4.76	2.77–24.41
Potassium (K, μg/g)	72.1 ± 39.4	21.6–144.87
Sodium(Na, μg/g)	11.1 ± 4.9	5.3–30.4
Calcium (Ca, μg/g)	143 ± 46	63.2–242.4
Magnesium (Mg, μg/g)	48.9 ± 11.7	26.2–87.8

SD, standard deviation.
*Data of the minimum and the maximum.

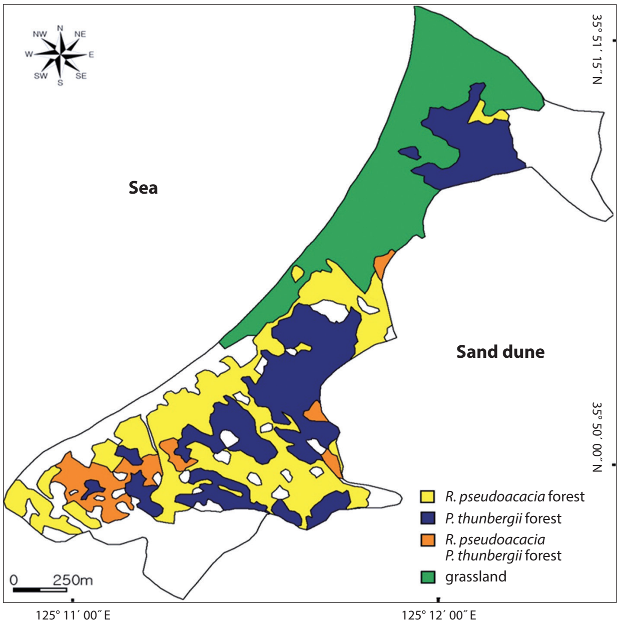

Fig. 2. Vegetation map of the study area.

ment was 0.189 ± 0.095 mg/g ranging from 0.047 to 0.612 mg/g. The available phosphorus content in sediment was 9.46 ± 4.76 μg/g ranging from 2.77 to 24.41 μg/g. The sediment nutrient content ranged from 21.6 to 153.3 μg/g in K, 5.3 to 30.4 μg/g in Na, 63.2 to 287.0 μg/g in Ca and 26.6 to 80.4 μg/g in Mg. The nutrient content differed according to the sites. Five correlation coefficient (CC) values were significant at a 1% level (Table 2). The organic matter and total nitrogen, organic matter and Ca, total nitrogen and Ca, Ca and Mg, Mg and K showed a positive relationship. Four CCs were significant at a 5% level. Almost of the CCs between sediment properties and basal area or biomass of three plant species were not significant (Table 3). However, the CC between basal area of *R. pseudoacacia* and Na or K was significant at a 1% or 5% level.

Vegetation and other species

The Sindu sand dune was composed of vegetation and non-vegetation areas. The non-vegetation area was road, pension, resident and cultivated land. The vegetation area was divided into three communities: *P. thunbergii, P. thunbergii–R. pseudoacacia, R. pseudoacacia* and mixed herbaceous communities (Fig. 2). The *P. thunbergii* community was formed in the broadest area except for herbaceous vegetation. The canopy heights were 7 m and 17 m in the two typical *P. thunbergii* stands (Table 4). *Pinus thunbergii* or *R. pseudoacacia* grew in the shrub layer but coverage of these species was <10%. In the *P. thunbergii* community, the coverage of *R. pseudoacacia* varied ac-

Table 2. Correlation coefficients (r) between two sediment properties (n = 64)

	Organic Matter	Total Nitrogen	Available Phosphorus	Potassium	Sodium	Calcium
Total Nitrogen	0.720**					
Available Phosphorus	0.181	0.068				
Potassium	0.107	0.320*	-0.093			
Sodium	0.106	0.270*	-0.203	0.302*		
Calcium	0.417**	0.394**	0.254*	0.011	0.210	
Magnesium	0.162	0.219	-0.013	0.366**	-0.017	0.358**

*significant at a 5% level; **significant at a 1% level.

Table 3. Correlation coefficients (r) between soil property and plant biomass (n = 49)

	P. americana (DW)	*R. pseudoacacia* (BA)	*P. thunbergii* (BA)
Total Nitrogen	0.041	0.150	0.256
Organic Matter	-0.083	-0.222	0.001
Available Phosphorus	-0.026	-0.045	0.075
Potassium	0.108	0.367*	-0.255
Sodium	0.202	0.440**	-0.083
Calcium	-0.019	-0.190	0.196
Magnesium	-0.036	0.032	-0.125

DW, dry weight; BA, basal area; *significant at a 5% level; **significant at a 1% level.

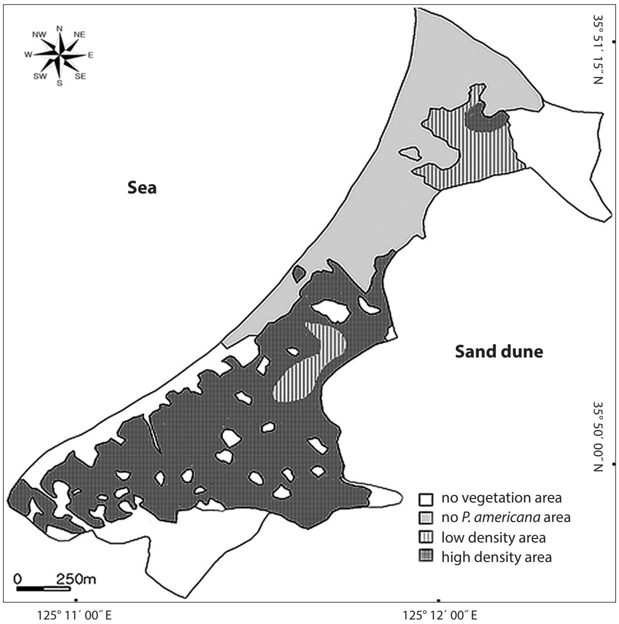

Fig. 3. Density of the three zones (no *Phytolacca americana* area, low and high density areas).

cording to the location. *Robinia pseudoacacia* community distributed in small fragments along roadsides or cultivated areas. Coverage of the canopy layer was relatively low with a value of 50–60%. *Robinia pseudoacacia* was the dominant species in the subtree or shrub layer, and the coverage was <10%. The dominant species and coverage of the herb layer were *P. americana* and 10–20%, respectively. In the herb layer, the dominant species was *Carex lanceolata* in two sites but the coverage was different. The mixed herbaceous community was distributed in the largest area and was composed of a range of species. In the *I. cylindrica* var. *koenigii* community and *C. epigeios* community, the coverage was 100% and 90%, respectively, and heights of the dominant species were 110 cm and 40 cm, respectively.

Distribution types of *P. americana* were divided into three groups according to the density (Fig. 3). As a result, firstly, the high density areas over 0.1 plants/m^2 were all of the *R. pseudoacacia* community, the *P. thunbergii-R. pseudoacacia* community and a part of the *P. thunbergii* community. Secondly, the low density areas below the 0.1 plants/m^2 were mainly the *P. thunbergii* community. There was virtually no *P. americana* in the *P. thunbergii* community bordering the herbaceous community. Thirdly, there were no *P. americana* areas in the herbaceous community. By the Poisson distribution analysis, dispersion pattern of *P. americana* was severely clumped and significant at a 0.001% level at the two communities - *P. thunbergii–R. pseudoacacia* community and *R. pseudoacacia* one (Table 5). The CC between the biomass of *P. americana* and basal

Table 4. Outline of the community structure of six representative sites

	Site No.					
	1	2	3	4	5	6
Latitude (N)	36°50′11″	36°50′32″	36°50′19″	36°51′01″	36°50′36″	36°50′09″
Longitude (E)	126°11′13″	126°11′41″	126°11′43″	126°12′06″	126°11′50″	126°11′16″
Tree layer						
Height (m)	13			17		
Coverage (%)	60			80		
Dominant species	*R. pseudoacacia*			*P. thunbergii*		
Subtree layer						
Height (m)	5	7	7	5		
Coverage (%)	10	50	90	10		
Dominant Species	*R. pseudoacacia*	*R. pseudoacacia*	*P. thunbergii*	*P. thunbergii*		
Shrub layer						
Height (m)	1.5	2	1.0	2.0		
Coverage (%)	5	10	5	10		
Dominant species	*P. thunbergii*	*R. pseudoacacia*	*R. pseudoacacia*	*P. thunbergii*		
Herb layer						
Height (m)	1.0	0.8	0.3	0.8	1.1	0.4
Coverage (%)	20	10	5	70	100	90
Dominant species	*P. americana*	*P. americana*	*C. lanceolata*	*C. lanceolata*	*C. epigeios*	*I. cylindrica* var. *koenigii*

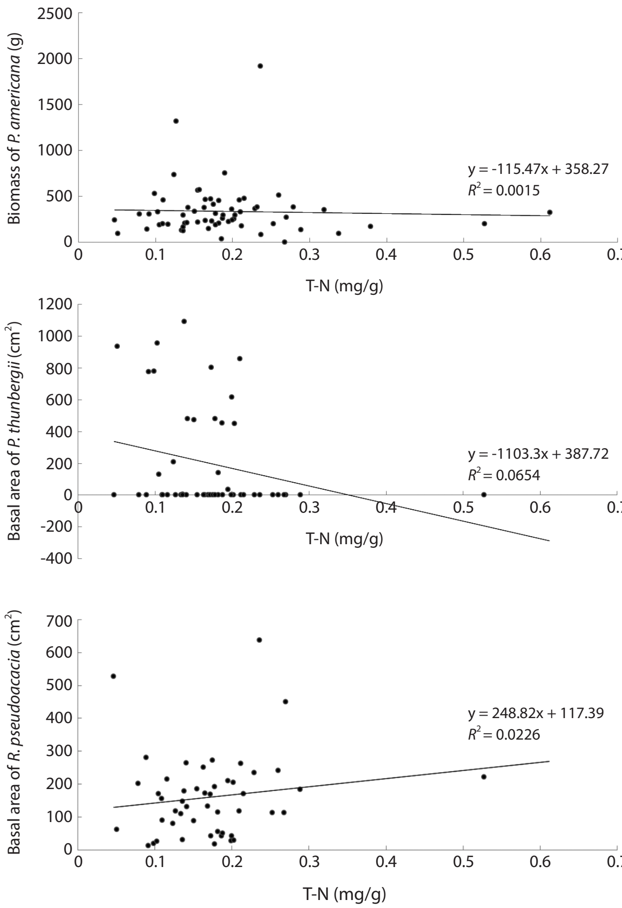

Fig. 4. Relationships among the root biomass of *Phytolacca americana*, basal areas of *Robinia pseudoacacia* and *Pinus thunbergii*. T-N indicates the total nitrogen.

area of *R. pseudoacacia* was significant at a 1% level (R^2 = 0.138, n = 49) (Fig. 4). However, the CC between the biomass of *P. americana* and basal area of *P. thunbergii* was not. The ages of *P. americana* and *R. pseudoacacia* of the total area ranged from two to thirteen (mainly 3-11 years) and from three to twenty (mainly 4-15 years), respectively, except for one site. The CCs between the age and the density of two species (*P. americana* and *R. pseudoacacia*) were significant or not (Fig. 5). That was, the CC between the *P. pseudoacacia*'s age and *P. americana*'s one was significant at a 0.1% level (R^2= 0.5713, n = 50), and its regression curve was $y = 0.6568x + 1.5744$. The CC between the age of *P. pseudoacacia* and the density of *P. americana* was significant at a 5% level (R^2= 0.1003). However, the other two CCs were not significant.

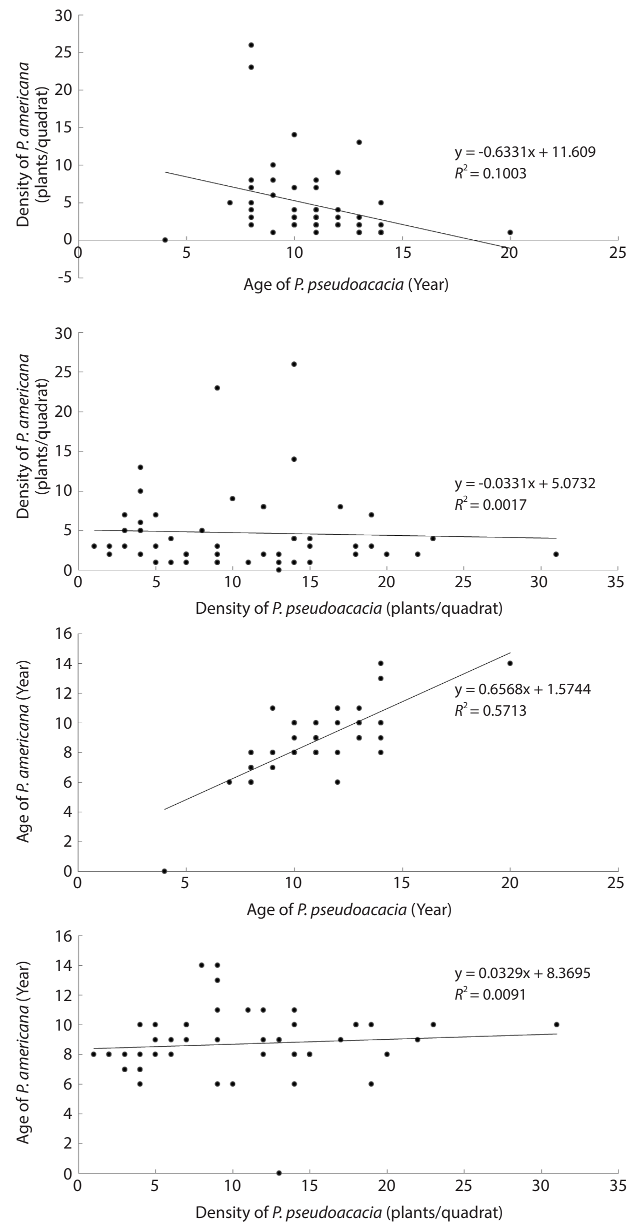

Fig. 5. Relationships between the ages and densities of *Phytolacca americana and Robinia pseudoacacia*.

Table 5. The frequency along the number of *Phytolacca americana* in 2 m × 2 m quadrats.

No. of plant	No. of quadrat	Total
0	70	0
1	32	32
2	18	26
3	12	24
4	11	44
5	4	20
over 6	3	19
Total	150	165

χ^2 = 129.036, df = 5, P < 0.001

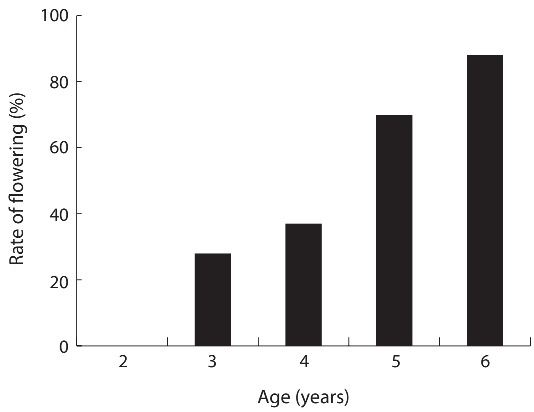

Fig. 6. Flowering rate along the age of *Phytolacca americana*.

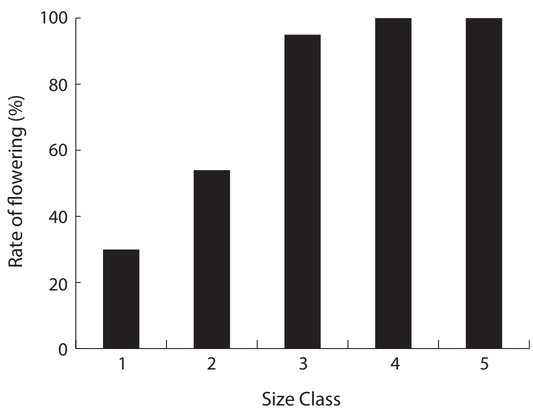

Fig. 7. Flowering rate along the root size of *Phytolacca americana*. Size class 1, below 2.00 g; 2, 2.01-4.00 g; 3, 4.01-6.00; 4, 6.01-8.00 g; 5, over 8.01 g.

Population properties at the same area

The CVs of a total area and a quadrat were 1.061 and 0.196, respectively (Table 6). The ages of *P. americana* in the total area were quite diverse but those in a quadrat (in 5 m diameter circle) were uniform. The other hands, only *P. americana* over 3 years old flowered and its rate generally increased with age (Fig.6). In particular, the flowering rates in a 3- and 6-year plant were 25% and 82%, respectively, so that plants of all age could flower, except for 2-year plants. Flowering rates were 28% at <2.0 g, 95% at 6 to 8 g, and 100% at >8.0 g (Fig. 7). The trend of the flowering rate was similar to age's one. The difference between the smallest class and the largest one was more in the root dry weight than in age.

DISCUSSION

Many factors affected on spatial distribution of *P. americana*. Among these factors, sediment properties, vegetation and population properties were important. Firstly, in sediment nutrient content, this result was similar to that reported by Song et al. (2005), who surveyed the same area but only herbaceous vegetation area. That was, the organic matter content of this study area was lower than that 1.73% in the B layer, which was the lowest value in inland soil (Jeong et al. 2003). This showed that the organic matter content of coastal sand dunes was quite low, which was believed to be a common phenomenon (Olff et al. 1993). The total nitrogen content of the sediment differed considerably according to the sites. This result was similar to that (0.011% to 0.050%) reported by Song et al. (2005), but much lower than that (0.9 to 1.0 mg/g) in inland soil (Jeong et al. 2003). Especially, total nitrogen is limiting factors to growth of sand dune plants (Olff et al. 1993). The order of sediment nutrient content at this study area was Ca > K > Mg > Na, whereas that of sea water was Na > Mg > Ca > K. Therefore, it was believed that sea water did not affect the sediment nutrient composition directly or leaching property (mobility) of each nutrient in sediment differed. The CCs which were positive and significant at a 1% level showed the two series. One was the organic matter-total nitrogen-calcium and it was related to the organic substance group. The other was calcium-potassium-magnesium and inorganic substance group. The reason why sodium and available phosphorus were excluded was thought to be needed more studies.

Sediment nutrient contents were not related to plant sizes. Therefore, the relative biomass was not indicator of the sediment nutrient contents. This was attributed to the very low sediment nutrient content and the complex state among plants, rainfall and sediment. Generally, the nitrogen level in sediment increased with increasing *R. pseudoacacia*'s biomass. The lack of a relationship be-

Table 6. Coefficient of variation in ages of *Phytolacca americana* between the total and sum of each quadrat

No. of Plants/quadrat	Mean	Standard Deviation	Coefficient of variation
Each, 312/27	5.8373	1.1201	0.196
Total, 312/1	5.6978	6.0480	1.061

Each, among the 27 quadrats; Total, among the 312 *Phytolacca americana* samples.

tween the total sediment nitrogen content and the basal area of *R. pseudoacacia* was attributed to decomposition of the dead part of this species during the growth season and the leaching and reuse under the insufficient condition. The correlation coefficient between the *P. americana*'s root biomass and the basal area of *R. pseudoacacia* was significant at a 1% level but there was no correlation between the other two species. Therefore, it was thought that *R. pseudoacacia* affected on the growth and distribution of *P. americana*. Generally, soil nitrogen fixed by symbiotic bacteria with legumes affects the seed size and C/N ratio of *P. americana* (He et al. 2005), as well as shoot growth (Olff et al. 1993). Therefore, soil nitrogen is indispensable for the growth of *P. americana*. However, there was no positive relationship between the biomass of *P. americana* and the total nitrogen of sediment. To clarify this fact, more studies were needed.

Secondary, the vegetation of Sindu sand dune had been mainly studied at herbaceous area (Ahn 2003, Min 2004, 2006, Song et al. 2005, Kahng 2006, Song and Cho 2007), and by these reports, *Elymus mollis, Carex kobomugi, Ischamum anthephoroides, Imperata cylindrica* var. *koenigii, Calamagrostis epigeios* and *Calystegia soldanella* formed a pure stand in several areas. As mentioned above, the height and coverage of the canopy layer in woody communities were more than 7 m and 50%, respectively. However, the height of the dominant species in the herbaceous community was ≤1.1 m, as shown in this study and others (Song et al. 2005, Song and Cho 2007). Therefore, the irradiance that *P. americana* could receive was more in the herbaceous community than in the woody community. Park et al. (1998) reported that the growth of *P. americana* was affected by light rather than the nutrient environment. The growth of *P. americana* decreased conspicuously under 8% natural irradiance, even though there were sufficient nutrients. *P. americana* compensated for the low net assimilation rate by the increase in leaf area under the 33% natural irradiance. None the less, *P. americana* was no in herbaceous community, as shown in this study and other (Kahng 2006). The density of *P. americana* was high in the *R. pseudoacacia* community or *P. thunbergii–R. pseudoacacia* one. Therefore, factors rather than light that affected the growth of this species might explain why *P. americana* was absent in the herbaceous community. One of the several factors might be no seed dispersal to this area or unsuitable sediment environments. However, *P. americana*'s seed dispersal to the herbaceous community was possible because this community was in contact with the *R. pseudoacacia* community. Therefore, the environment of the herbaceous community was unsuitable for seed germination or growth of *P. americana*. In particular, the sediment nutrient contents of the study area were quite low as mentioned above. This sediment property was reported in other coastal sand dunes (Olff et al. 1993, Song et al. 2005). However, this study failed to clarify that sediment total nitrogen content affected on the distribution of *P. americana*, and *R. pseudoacacia* raised the sediment total nitrogen content, although in inland the former was reported to be the dominant species of the herb layer in areas where the latter was dead (Joo and Cho 1995). Moreover, the CC between the root biomass of *P. americana* and the basal area of *R. pseudoacacia* was significant at a 1% level and the ages of two species were correlated at a 0.1% level of significance. By this result, it was thought that *R. pseudoacacia* affected on distribution of *P. americana* in a certain way. The way that *R. pseudoacacia* affected the distribution of *P. americana* needed more studies. The fact that two species have something in common with invasion to the disturbed area might be a reason. Moreover, sediment nitrogen content was low at a time but could be continuously inputted from *P. pseudoacacia*'s litter. In relation to vegetation or succession, *P. americana* was reported to be a pioneer species of the early successional stage (Hyatt 1998). However, in this study, there was no *P. americana* in the herbal vegetation. Instead, *P. americana* was found only in the woody vegetation of the middle successional stage. Therefore, *P. americana* was not always a pioneer species of the early successional stage. In *R. pseudoacacia* and *P. thunbergii-R.pseudoacacia* communities, the dispersion pattern of *P. americana* was seriously clumped. In the temperate zone, most species appeared to be clumped. The reason for this was that the seeds or fruits tend to fall close to a parent (Barbour et al. 1980). The seed of *P. americana* is dispersed by bird or rodent feces (Orrock et al. 2003). A spike of *P. americana* is composed of 10-30 fruits, with each containing six seeds. However, a field survey showed that distance between two plants was >20 cm. Therefore, several plants in a site had germinated from the seeds in a feces pallet. In the time that a spike rolled with the wind, the fruit parted from the spike and was buried by sand in winter. In this time, only the seed properly buried in sand could germinate. In particular, the seeds on the soil surface could be easily eaten by herbivores and the germination rate of those at a 10-cm depth increased (Orrock and Damschen 2007). In coastal sand dunes, the movement of sand is important for *P. americana* seed's burial, and this may be happened a fruit. Therefore, the fact that only one plant among the six seeds located in a fruit had survived requires more study. However, the diverse factors -light, soil water and nutrients- affected on seed germination. Especially, *P. americana* preferred abundant light.

Thirdly, only *P. americana* over 3 years old flowered and its rate generally increased with age. Considering these properties, seeds could be introduced yearly after three years at the site which a plant germinated at the first, so a seed bank could form in an area where *P. americana* was distributed. Regardless of this, the ages of *P. americana* in a quadrat (5.0 m-diameter circle) were similar. However, large plants did not have an allelopathic effect on seed germination (Kim et al. 2005a, 2005b). Moreover, the ages of *P. americana* ranged from two to seven years in a quadrat. Therefore, a large plant might suppress the young one rather than germination during growth from seedlings, so plants of a similar age remained in a small area unit. Accordingly, more study of *P. americana* in coastal sand dunes would be needed. The other hands, in relation to flowering and plant size or age, the difference between the smallest and largest classes was more in the root dry weight than in age. Therefore, plant size was related more to the flowering of *P. americana* than the plant age. Generally, many authors reported a strong positive correlation between the plant size and reproductive output (Klinkhamer et al. 1992). Of the two plant size factors, the flowering of field plants was positively correlated with the shoot size (Verburg et al. 1996, Min 2000). However, the flowering rate in other plant species was strongly related to the root system biomass (Fortanier 1973, Kawano 1975, Barkham 1980, Min 2003). Therefore, the main factor affecting flowering differed according to the plant species but flowering was related to the plant size rather than age. Hence, *P. americana* was similar to other plant species in the fact that plant size affected more than its age in flowering.

LITERATURE CITED

Ahn YH. 2003. Phytosociological study on the vegetation of sand dune in Shindoori seashore. J Korean Env Res Reveg 6: 29-40.

Bae CH, Nou IS, Kang KK, Koh YJ. 1997. *In vitro* test on allelopathic effects of leaf extracts from *Phytolacca americana* and *Armoracia rusticana*. Korean J Crop Sci 42: 652-665.

Barbour MG, Burk JH, Pitts WD. 1980. Terrestrial plant ecology. The Benjamin/Cummings Publishing Company, Inc., Menlo Park, CA.

Barkham JP. 1980. Population dynamics of the wild daffodil (*Narcissus pseudonarcissus*). In clonal growth, seed reproduction, mortality and the effects of density. J Ecol 68: 607-633.

Berendse F. 1990. Organic matter accumulation and nitrogen mineralization during secondary succession in heathland ecosystems. J Ecol 78: 413-427.

Braun-Blanquet J. 1964. Pflanzensoziologie. Springer-Verlag, Wien.

Chapman VJ. 1964. Coastal vegetation. Pergamon Press, Oxford.

Fortanier EJ. 1973. Reviewing the length of the generation period and its shortening, particularly in tulips. Sci Hort 1: 107-116.

He J-S, Flynn DFB, Wolfe-Bellin K, Fang J, Bazzaz FA. 2005. CO_2 and nitrogen, but not population density, alter the size and C/N ratio of *Phytolacca americana* seeds. Funct Ecol 19: 437-444.

Hyatt LA.1998. Spatial patterns and causes of overwinter seed mortality in *Phytolacca americana*. Can J Bot 76: 197-203.

Jang H, Kim J. 1996. Distribution of American pokeweed (*Phytolacca americana*) and soil acidity of Mt. Bonglae. Kosin Univ Nomumngib 23: 197-206. (In Korean with English abstract)

Jeong JH, Kim CS, Goo KS, Lee CH, Won HG, Byun JG. 2003. Physico-chemical properties of Korean forest soils by parent rocks. Jour Korean For Soc 92: 254-262.

Joo SH, Cho JH. 1995. Effect of environment factors on growth of *Phytolacca americana*. J Environ Sci 9: 137-144.

Kachi N, Hirose T. 1983. Limiting nutrients for plant growth in coastal sand dune soil. J Ecol 71: 937-944.

Kahng TG. 2006. The landforms and vegetation of coastal sand dune natural monument at Sindu-ri, Taean-gun, South Chungcheong Province. J Kor Geomorphol Assoc 13: 35-44.

Kang JH, Ryu YS, Kim DI, Lee OS, Kim SH. 1997. Effect of priming, temperature and light quality on germination of pokeweed (*Phytolacca americana*) seed. Korean J Crop Sci 42: 153-159.

Kawano S. 1975. The productive and reproductive biology of flowering plants: II. The concept of life history strategy in plants. J Coll Lib Arts Toyama Univ Japan 8: 51-86.

Kim JH. 1996. Distribution of American pokeweed (*Phytolacca americana*) and soil acidity of Mt. Hwangryung. Kyeongsung Univ Nonmungib 17: 65-79. (In Korean with English Abstract)

Kim YO, Johnson JD, Lee EJ. 2005a. Phytotoxic effects and chemical analysis of leaf extracts from three Phytolaccaceae species in South Korea. J Chem Ecol 31: 1175-1186.

Kim YO, Johnson JD, Lee EJ. 2005b. Phytotoxicity of *Phytolacca americana* leaf extracts on the growth, and physiological response of *Cassia mimosoides*. J Chem Ecol 31: 2963-2974.

Kim YO, Rodriguez RJ, Lee EJ, Redman RS. 2008. *Phytolacca americana* from contaminated and noncontaminated soils of South Korea: Effects of elevated temperature, CO_2 and simulated acid rain on plant growth response. J Chem Ecol 34: 1501-1509.

Klinkhamer PGL, Meelis E, de Jong TJ, Weiner J. 1992. On the analysis of size-dependent reproductive output in plant. Functional Ecol 6: 308-316.

Min BM. 2000. Population dynamics of *Heloniopsis orientalis* C. Tanaka (Liliaceae) in natural forests - Sexual reproduction. J Plant Biol 43: 208-216.

Min BM. 2003. Seed production of Pes-gallinaceua (*Corydalis*, Fumariaceae) group. Korean J Ecol 26: 189-197.

Min BM. 2004. Growth properties of *Carex kobomugi* Ohwi. Korean J Ecol 27: 49-55.

Min BM. 2006. Morphological adaptations by *Glehnia littoralis* to the biomass and heights of peripheral herbaceous plants in coastal sand dunes. J Plant Biol 49: 123-132.

Olff H. 1992. Effects of light and nutrient availability on dry matter and N allocation in six successional grassland species: testing for resource ratio effects. Oecologia 89: 412-421.

Olff H, Huisman J, Van Tooren BF. 1993. Species dynamics and nutrient accumulation during early primary succession in coastal sand dunes. J Ecol 81: 693-706.

Orrock JL, Damschen EI. 2007. The effect of burial depth on removal of seeds of *Phytolacca americana*. Southeastern Naturalist 6: 151-158.

Orrock JL, Danielson BJ, Burns MJ, Levey DJ. 2003. Spatial ecology of predator-prey interactions: Corridors and patch shape influence seed predation. Ecol 84: 2589-2599.

Park BJ, Choi KR, Park YM. 1998. Effects of light and nitrogen on the growth of Pokeberry. Korean J Ecol 21: 329-335.

Park SH. 1995. Colored illustrations of naturalized plants of Korea. Ilchokak, Seoul, pp 112-113. (in Korean)

Park TG, Song EJ, Song SD. 1999a. Effect of Cd on the growth pattern of *Phytolacca americana* seedlings. J Environ Sci 13: 15-21.

Park YM. 2003. Response of pokeberry (*Phytolacca americana*) to water stress. J Ind Sci Chongju Univ 20: 15-21.

Park YM, Choi KR, Ko JK, Park BJ. 1997. An ecological study on the distribution of *Phytolacca americana*. KOSEF Report, Seoul.

Park YM, Park BJ, Choi KR. 1999b. pH changes in the soil of pokeberry. Korean J Ecol 22: 7-11.

Ri CU, Chun JI. 1996. Adapted environmental factors for a neophyte pokeweed (*Phytolacca americana*). Korean J Life Sci 6: 87-93.

Rozema J, Bijwaard P, Prast G, Broekman R. 1985. Ecophysiological adaptations of coastal halophytes from foredunes and salt marshes. Vegetatio 62: 499-521.

Song HK, Park GS, Park HR, Seo EK, So SK, Kim MY. 2005. Vegetation and soil properties of the coastal sand dune in Sinduri, Taean-gun. J Korean Env Res & Reveg Tech 8: 59-68.

Song HS, Cho W. 2007. Diversity and zonation of vegetation related microtopography in Sinduri coastal dune, Korea - Focused on the natural monument area. Kor J Env Eco 21: 290-298.

Taeangun. 2004. Conservation and management strategies for Sindu coastal dune. Taeangun. (in Korean)

Verburg RW, Kwant R, Werger MJA. 1996. The effect of plant size on vegetative reproduction in a pseudo-annual. Vegetatio 125: 185-192.

Woo WS, Kang SS. 1975.The occurrence and chemistry of *Phytolacca* triterpenoids. J Pharm Soc Kor 19: 189-208.