Chapter

Forest Decline Under Progress in the Urban Forest of Seoul, Central Korea

Chang Seok Lee, Songhie Jung, Bong Soon Lim, A Reum Kim, Chi Hong Lim and Hansol Lee

Abstract

Vegetation in the urban area showed not only a difference in species composition but also lower diversity compared with that of the natural area. Successional trend was normal in natural area, but that in urban areas showed a retrogressive pattern. Korean mountain ash (*Sorbus alnifolia* (Siebold & Zucc.) K.Koch), a shade intolerant species, dominated such a retrogressive succession. The vegetation decline is due to changes of mesoclimate and soil properties that imbalanced distribution of green space induced as the result of urbanization. In recent years, new environmental stress due to climate change is imposed additively to this forest decline. Drought is the very environmental stress. Drought-induced plant damage started from withering of leaves of plants introduced for landscaping in the urban area. Over time, branches died and death of the whole plant body followed. In particular, damage of Korean mountain ash, the product of retrogressive succession, was remarkable. As retrogressive succession has already progressed much, thus such phenomenon could be recognized as crisis of urban forest.

Keywords: drought, forest decline, retrogressive succession, Seoul, urban forest

1. Introduction

Urbanization expanding globally is recognized as a major causing environmental change [1]. Reduction of habitat size, fragmentation, and imbalanced distribution of green space due to urbanization led to influences on dynamics of vegetation remaining in urban area [2, 3]. Increases of temperature, precipitation, and nitrogen deposition due to urbanization also altered abiotic conditions of habitat patches remaining in urban area [1, 4]. These changes influence habitat quality, and, consequently, the species composition, species diversity, and functional diversity of vegetation remaining there [3, 5, 6], which in turn affect the ecosystem functions [7].

Forests are the typical types of urban green space [8]. Urban forests function as habitat of native species as well as recreation site for citizens [9, 10]. Urban forests can play a role of refugia of rare and threatened species and thus can display high conservation value [11, 12]. Among urban landscape elements, forest has substantially different site history, intensity of management and disturbance, and consequently different species composition from other landscape elements [3, 12, 13].

Urban forests are remnants of former continuous forests, a result of succession or artificial plantation [14]. They can also include urban orchards, urban park, cemeteries overgrown by trees, or residential garden [12, 13].

Land transformation and increase of impervious surface cover affect forests throughout the landscape through increased local temperatures and altered ecosystem processes. Anthropogenic drivers of global change, i.e., land-use change, introduction of exotic species, pollution, and climate change, affect forest composition and function across the landscape [15]. In particular, change of land-use pattern including urbanization and their effects on remaining vegetation constitute one of the major factors influencing on natural ecosystems [16, 17]. In the case of forests, about 70% of remaining forest around the world is within 1 km from the forest's edge [18]. Therefore, it is very difficult that they maintain integrate structure and healthy function. As land is transformed into urbanized area, the effects of the transformation on the remaining vegetation are getting more apparent. Increased local temperature and altered hydrologic and nutrient cycle, land transformation, and increased impervious surface cover have been recognized as elements affecting forest health and resilience to other stress factors [19–21]. Those remaining natural forest patches are still critical in terms of air quality improvement, flooding reduction, urban heat island effect mitigation, and supply of other ecosystem services that are important to both human societies and natural environment [22–24]. Therefore, understanding how urbanization affects structure and function of remnant forest ecosystems is critical to both conservation and management of this ecological resource.

One of the principal changes that urbanization induced is the increase of land covered by impervious surfaces such as asphalt and concrete pavement, concrete buildings, and tightly compacted soils. Percentage-paved land surface is an appropriate proxy for urban heat island effects as a main factor increasing the land surface temperature [25, 26]. Urban heat islands develop around areas with high heat absorptive capacity such as asphalt, concrete buildings, bare ground, and other developed lands, which heat up rapidly and increase local temperature greatly compared with surrounding natural areas [27, 28]. In an area that natural forest is conserved to urbanized area, land surface temperature increased more than 70% and soil moisture decreased about 15%. These changes of the microclimate in urbanized areas can affect vegetation remaining there [29]. Trees growing in areas covered by impervious surface densely represented low drought resilience compared with trees in forested areas [30] and experienced severer moisture stress and insect damage compared with trees in intact forests [31]. In general, increased impervious surface cover increases water stress and vulnerability to drought and thus makes trees in intensively urbanized landscapes more sensitive to cavitation and lower protection from embolism formation [32].

Increasing urbanization could aggravate the impact of climate change on forest. Increasing temperature accompanies severer and more frequent droughts that could increase tree mortality [33, 34]. Even though most forest species can tolerate changes in mean climatic conditions, it is not clear that they could withstand the extreme weather events like drought [35, 36].

Thus, the synergistic effects of extreme weather events, like drought and temperature increase in relation to urbanization, could influence severely on the health and resilience of forests remaining in urban areas [37, 38]. A decline of forest health and the following changes in species composition and vegetation structure would lead to change of ecosystem function and ultimately alter ecosystem services in those ecosystems [39, 40].

In Korea, forest began to show decline symptoms around the industrial complexes and large cities [41, 42]. Further, change of mesoclimate due to excessive land use in urban area led to changes of vegetation structure and dynamics as well as soil properties [39, 42–48]. In addition, new environmental stress due to climate change is imposed additively to this forest decline and thereby incites degradation of urban forest in recent years.

This chapter addresses the following: (1) landscape structure in Seoul, (2) changes of mesoclimate and soil due to imbalanced distribution of greenery space, (3) retrogressive succession due to such environmental changes, and (4) drought-induced tree mortality.

Forest decline here includes deforestation, forest degradation, or a combination of both based on the definition of FAO [49].

2. Study area

Seoul, the capital of South Korea, is located in the Central Korean Peninsula and covers 605 km^2 of land (126°46′15″ to 127°11′15″ E longitude, 37°25′50″ to 37°41′45″ N latitude; **Figure 1**). Topography of Seoul is the typical basin that Han River runs through the center and is backed by mountains. The elevation of the study area ranges from 20 to 800 m above sea level. The parent rock of the mountainous areas around Seoul is usually composed of granite and gneiss, and the flat land beside rivers and streams is consisted of alluvium. Soil in these areas was classified into the Suam, Osan, Asan, and Anryong series, which developed on gneiss and granite bedrock [39, 50]. The climate of Seoul is continental, with warm and moist summers and cold and dry winters. From 1981 to 2010, the mean annual temperature was 12.5°C and the mean annual precipitation was 145.1 cm [51].

The mountainous vegetation of Seoul is consisted of four major plant communities distributed along an elevation gradient: the Korean red pine (*Pinus densiflora*

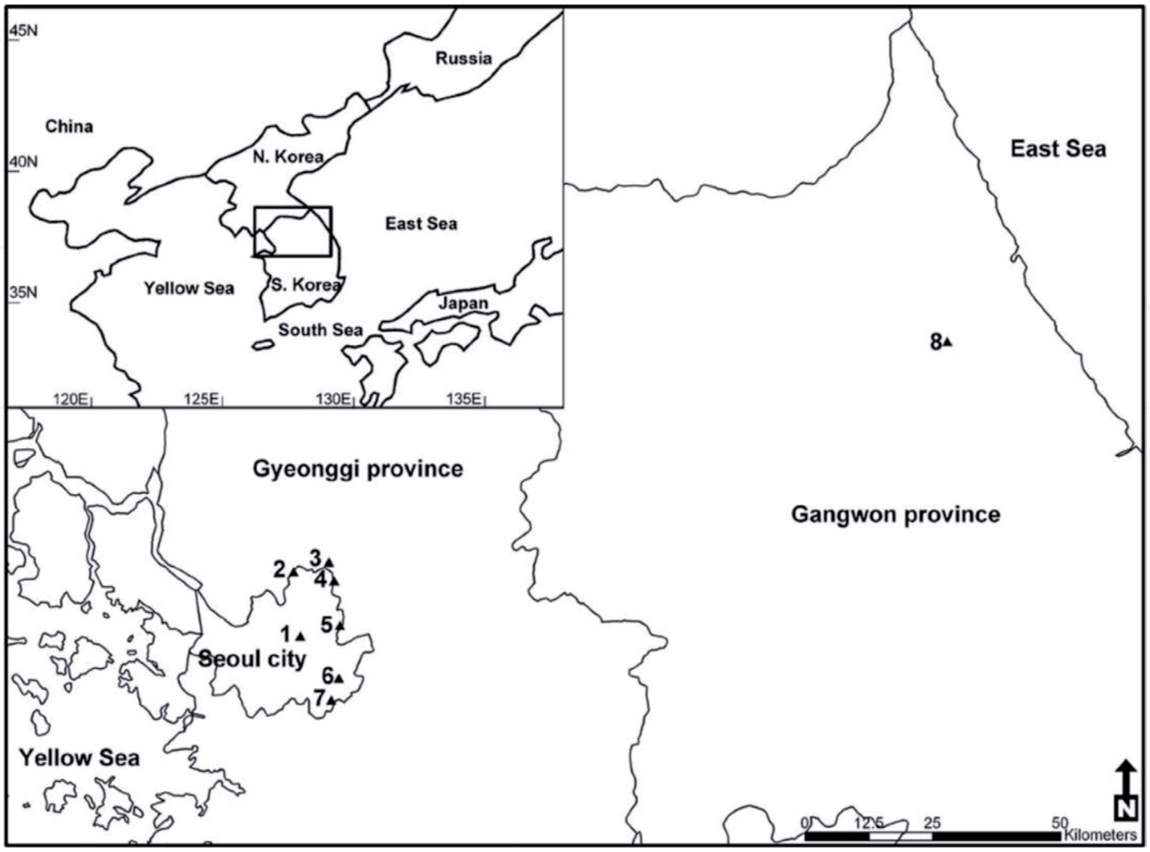

Figure 1.
A map showing the study area, Seoul, the capital of South Korea. (1) Mt. Nam, (2) Mt. Bukhan, (3) Mt. Surak, (4) Mt. Bulam, (5) Mt. Acha, (6) Mt. Daemo, (7) Mt. Cheonggye, (8) Mt. Jeombong.

Siebold & Zucc.) community in the mountain peaks and around the residential area, the Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.) community in the upper slopes, the hornbeam (*Carpinus laxiflora* (Siebold & Zucc.) Blume) community in the lower slopes, and the sawleaf zelkova (*Zelkova serrata* (Thunb.) Makino) community in the mountain valleys [52]. East Asian alder (*Alnus japonica* (Thunb.) Steud.) stands remained in the plains and valleys of lowlands that escaped from urbanization [53–55]. Much of the natural forest in the Seoul metropolitan area disappeared due to extensive deforestation for fuel, building material, and other purposes during the twentieth century [56]. The human population of Seoul has increased from 2.4 million in 1960 to 9.8 million as of 2010 [57]. During this period, the percentage of green space decreased from 70% in 1960 to 29% in 2015, mostly to accommodate residential area [54, 56, 58]. Korean government designated most of the forested mountains in suburban areas of Seoul as greenbelt zones in order to prevent further loss of green space. Under the current greenbelt ordinance, no commercial, industrial, or urban development is permitted in those forests [58].

3. Methods

An ecological map to grasp landscape structure was obtained from Seoul City [59]. Landscape ecological analyses of the maps were determined with ArcGIS program (ver. 10.0).

Soil samples were collected from 150 grids, dividing 2 km × 2 km intervals, throughout the entire area of Seoul (all 605 km^2). Soil properties were measured for pH, Ca^{2+}, Mg^{2+}, and Al^{3+} contents, which can explain acidification and its effects. Soil pH was measured with a benchtop probe after mixing the soil with distilled water (1:5 ratio, weight per volume) and filtering the extract through Whatman No. 44 paper. Exchangeable Ca^{2+}, Mg^{2+}, and Al^{2+} concentrations were measured after extraction with 1 N ammonium acetate (pH = 7.0 for Ca^{2+} and Mg^{2+} and pH = 4.0 for Al^{3+}) and using inductively coupled plasma (ICP) atomic emission spectrometry (Shimadzu ICPQ-1000) described in Allen [60].

Vegetation data were collected in the urban areas (Mts. Nam, Daemo, Bulam, Acha, Surak, Bukhan, and Cheonggye) and a natural area (Mt. Jeombong) (**Figure 1**). Vegetation survey was conducted in 66 plots, with 8, 10, 7, 8, 10, 4, 10, and 9 plots in each of the following sites: Mts. Nam (Mt. N hereafter), Daemo (Mt. D), Bulam (Mt. Bl), Acha (Mt. A), Surak (Mt. S), Bukhan (Mt. Bk), Cheonggye (Mt. Cg), and Jeombong (Mt. J), respectively. The size of each plot was 20 m × 20 m. All the plant species in each plot were identified using the Korea Plant Name Index [61]. For major tree species, stem diameters (at breast height for mature trees or at stem base for seedlings and saplings) were measured and sorted by diameter classes. The vegetation survey was conducted by applying the phytosociological procedure of Braun-Blanquet [62]. Dominance of each species in each plot was estimated by ordinal scale (1 for ≤5% up to 5 for ≥75%), and each ordinal scale was converted to the median value of percent cover range in each cover class. Relative coverage was regarded as the importance value of each species. Relative coverage was determined by dividing the cover fraction of each species by the summed cover of all species in each plot and then multiplying by 100. A matrix of importance values for all species in all plots was constructed and used as data for ordination using detrended correspondence analysis (DCA) [63]. To describe and compare species diversity and dominance among sites, rank abundance curves [55, 64, 65] were plotted. The Shannon-Wiener diversity index (H′) [65] was also calculated for each stand in each site.

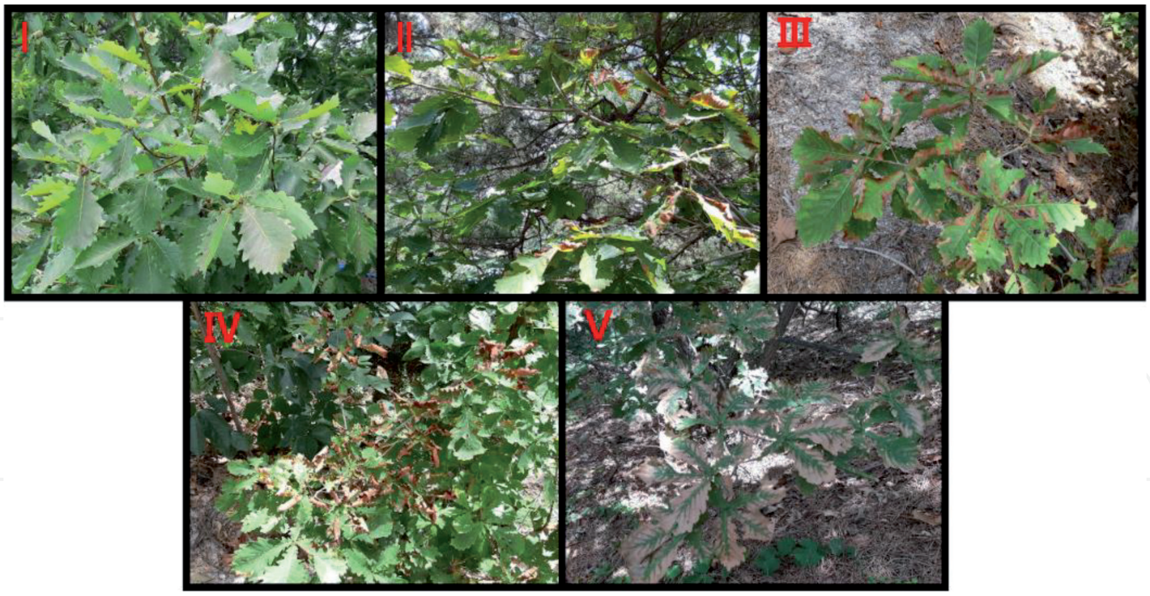

Figure 2.
Photos showing the grades for assessing drought-induced plant damage. I, none damaged; II (slight), less than 25% damaged; III (moderate), 25–50% damaged; IV (severe), 50–75% damaged; V (very severe), more than 75% damaged.

Meteorological data to confirm drought state were obtained from the Korea Meteorological Administration (https://data.kma.go.kr). The amount of evapotranspiration and evaporative demand was obtained by applying a method of Blaney and Criddle [66].

Field survey for investigating drought-induced plant damage was carried out from May to early July before rainy season in 2017 and from July to August in 2018. Survey in 2018 focused on verifying the result assessed in 2017 survey.

Field survey was conducted by recording degree of leaf surface injury of all plants appearing along the trampling path. Damage degree was classified into five groups based on the percentage of injury showed on leaf surface: very severe (V, more than 75% of total leaf area damaged), severe (IV 50–75% damaged), moderate (III, 25–50% damaged), slight (II, less than 25% damaged), and none (I, 0%) (**Figure 2**). We regarded the plant that all leaves were withered as dead individual in survey of 2017 and confirmed the result in the survey of 2018. The length of trampling path where field survey was conducted was about 4.0 km, and horizontal range was within 10 m in both sites.

4. Landscape structure

As the result of analysis on the landscape ecological map generated for Seoul, urban area occupied the widest as 60.8% of total area, secondary forests (12.7%), plantations (8.6%), river and reservoir (5.6%), landscape architectural plantation (4.5%), agricultural fields (2.5%), grasslands (2.4%), inaccessible area (2.3%), and bare ground (0.7%) followed (**Figure 3**). Forests composed of secondary forests and plantations and agricultural fields were usually concentrated to the city's fringe, and the urban center has little vegetation. Moreover, vegetation in the urban center was of low ecological quality, as most were fragmented into small patches and consisted of species introduced by landscape architects without ecological consideration or exotic plants [39, 40]. Therefore, green space showed severe imbalanced spatial distribution (**Figure 3**).

Figure 3.
A map showing spatial distribution of vegetation and land-use types in the Seoul metropolitan area (redrawn from Seoul City [59]).

5. Spatial structure of urban heat island

Spatial structure of the urban heat island in Seoul was investigated based on temperature data measured at 23 automatic weather stations (AWSs) in the Seoul metropolitan area.

Figure 4 shows the average spatial distribution of air temperature in the Seoul metropolitan area for each season and the whole year for 20 years from 1998 to 2017. A relative warm area extends in the east-west direction, and warm cores are pronounced in residential and commercial area with high-story buildings and heavy traffics. A relative cold area is observed in mountainous areas, which is near the borderline of Seoul except the southwestern and southeastern borderlines where the sprawling expansion of urbanization has already progressed.

Cities are often referred to as urban heat islands, with the urban center having the highest temperatures. This is primarily due to the low amount of vegetation in urban center compared to the suburbs and beyond (**Figure 1**). Cities also use large amounts of energy, and emit this energy as waste heat, further exacerbating the urban heat island effect.

On the other hand, forests and other vegetation types use large amounts of solar energy and evaporate water by means of transpiration to cool leaf surfaces. Evaporative water used through transpiration also contributes in reducing air temperatures in urban areas. Forests and other vegetation can also contribute indirectly to temperature reduction by reducing urban energy consumption

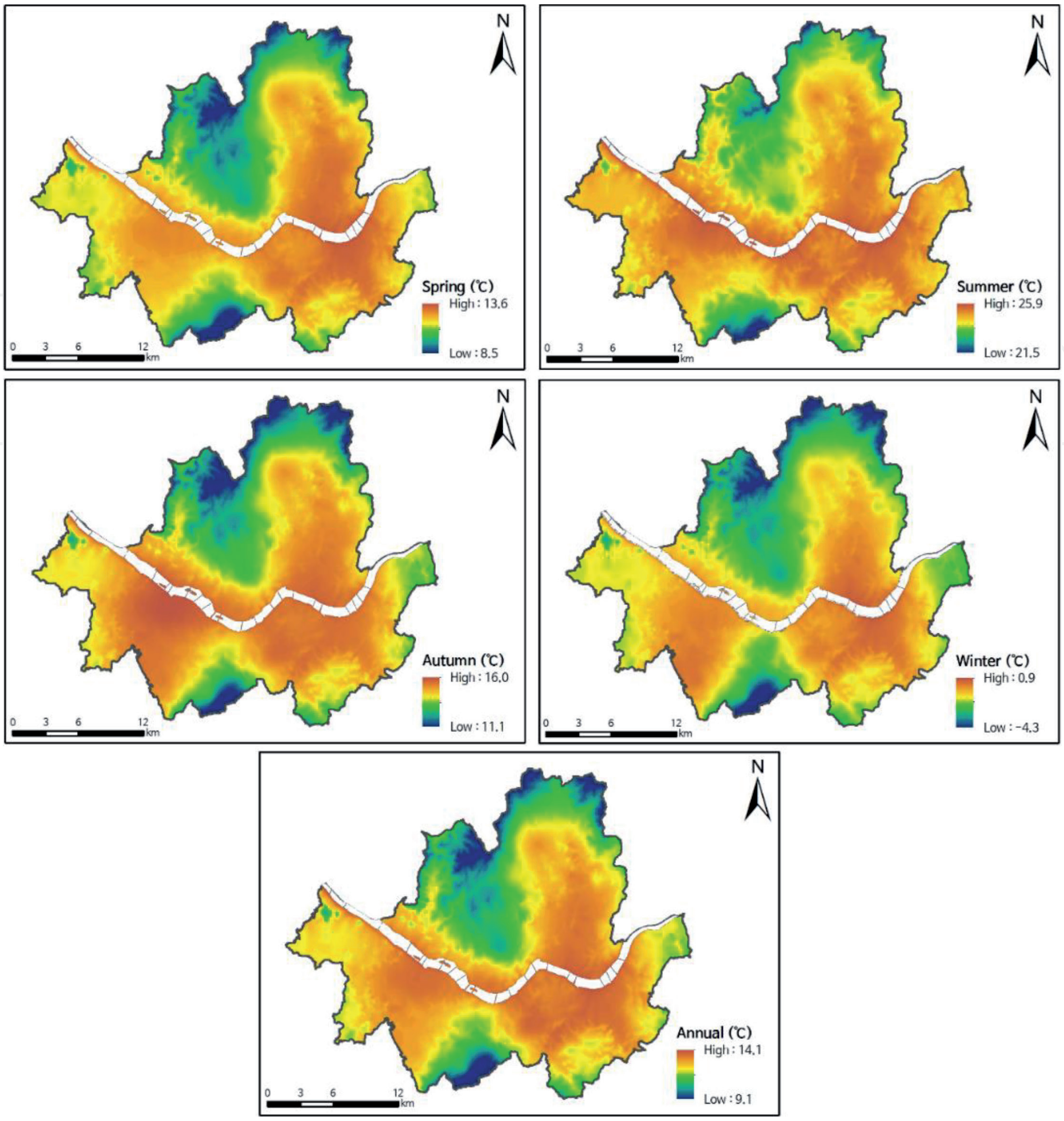

Figure 4.
Spatial distribution of air temperature in the Seoul metropolitan area averaged for each season and year.

through intercepting and using solar energy and by reducing building energy demand through shading and reducing wind speed. Therefore, low vegetation coverage in urban center results in larger temperature gradients between urban center and urban fringe or beyond [67–69]. Indeed, Seoul's heat island effect is very large [27, 70], as the temperature difference between the urban center and boundary was about 5°C (**Figure 4**).

The urban heat island is closely linked to the land-use pattern (**Figure 3**). Buildings, asphalt, and concrete pavement absorb solar radiation and emit long-wave radiation that warms the atmosphere [71–73]. Moreover, those artificial structures hold heat for extended periods. This heat moves from buildings, asphalt, and concrete pavement to the cool air as the air temperature decreases after sunset to form atmospheric temperature inversion (warm air over cold air) [74–77]. Therefore, many cities located in basins with limited ventilation like Seoul experience serious air pollution problems. The ventilation of an urban basin can be limited not only by orographic barriers but also by urban heat island-induced circulations and/or the capping effect of temperature inversions. Furthermore, land-use and land-cover changes caused by urbanization alter the dynamics of temperature inversions and urban heat islands, thereby affecting air quality in an urban valley [78].

Temperature inversions are frequently observed in most urban areas including Seoul. Temperature inversion results in poor dispersion of pollutants. Strong thermal inversion induces pollutant accumulation and thereby become a primary cause of the heavy air pollution. In addition, Seoul is backed by mountains, which intensified the accumulation of pollutants generated in the city itself and blown from other regions, particularly China, which is relatively closely located to Seoul.

In recent decades, East Asia has been significantly industrialized and urbanized through its rapid economic growth. The industrialization and urbanization have resulted in adverse effect on air quality not only in this region but also in neighboring countries [78].

6. Effects of urban mesoclimate on soil physicochemical properties

Temperature gradient between urban center and suburbs results in a local circulation of air. As air heated in urban center rises and relatively cool air of suburbs flows into urban center, a micro-current is formed. In this air circulation process, temperature inversion layer formed in the urban air inhibits the vertical movement of air, and thereby the polluted air from urban center comes down on the urban fringe [77]. Such an air circulation occurring through interaction of temperature differences between urban and suburban areas and temperature inversion can transport light gaseous air pollutants from the urban center to the urban fringe [74, 79].

Spatial distribution of soil properties reflected the effects of such an air circulation. Soil pH tended to be lower in grids in the urban fringe than in grids within the urban center (**Figure 5**). Ca^{2+} and Mg^{2+} concentrations of soil followed the pH

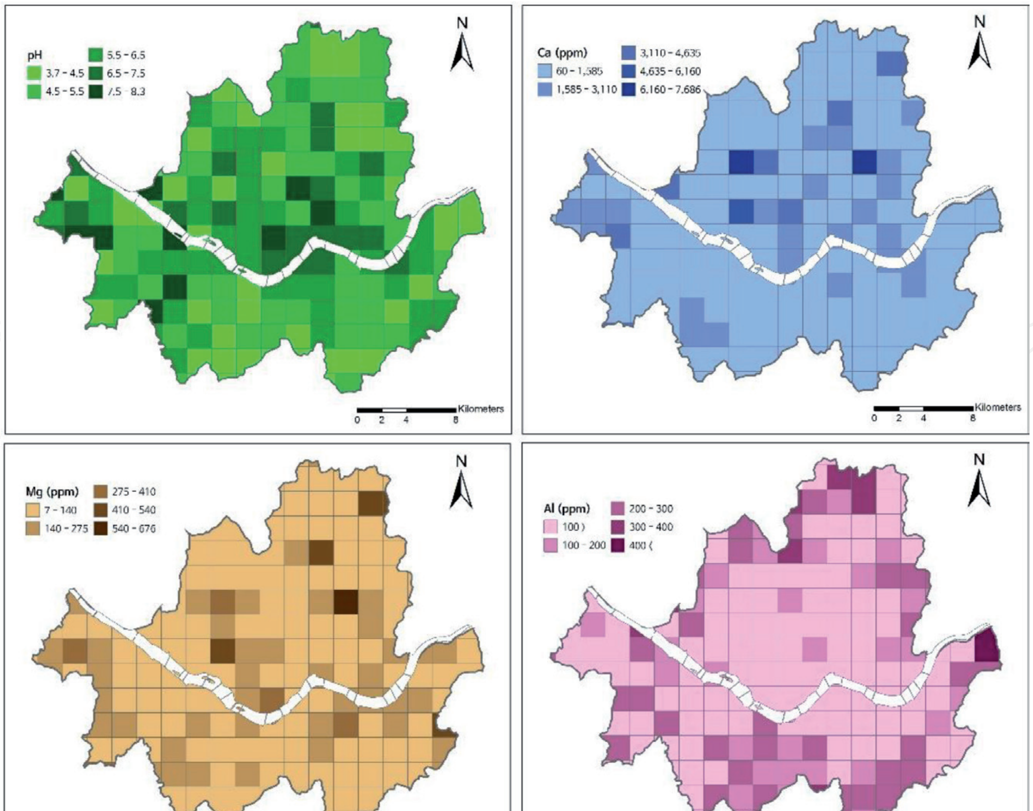

Figure 5.
Spatial distribution of physicochemical properties of soil, such as pH, Ca^{2+}, Mg^{2+}, and Al^{3+}, in the Seoul metropolitan area.

trends (**Figure 4**), but Al^{3+} concentration was the vice versa as it was higher in the urban fringe than in the urban center (**Figure 4**). Most of these chemical properties of soil are strongly related to soil acidification and to each other (**Figure 5**).

Soil acidification in those sites was due to deposition of acid precipitates, such as SO_x and NO_x [46]. Gaseous SO_x and NO_x are transformed to sulfuric acid (H_2SO_4) and nitric acid (HNO_3) as they interact chemically with water in the air and soil and are deposited in dry and wet form on soil [80, 81].

Acidified soils of the urban periphery contained lower concentrations of basic cations, such as Ca^{2+} and Mg^{2+}, than soils in the urban center, because they were leached through cation exchange mechanisms [82]. But higher concentrations of Ca^{2+} and Mg^{2+} in soils in the urban center are also related to deposition of heavy particulate probably from building materials (e.g., cement concrete; [83]) or to direct applications of calcium chloride ($CaCl_2$) used for melting snow. In addition, acidified soil releases the Al^{3+} ion when soil is particularly acidified to below pH 4.5. Such an Al^{3+} ion inhibits plant cell division and consequently retards plant growth as a toxic ion [84]. These serial changes in soil chemistry are known to cause forest decline [82].

Changes of those soil properties tend to be intensified compared with the result of the former research [39].

7. Responses of urban forest on the changed mesoclimate and soil properties

Mongolian oak (*Quercus mongolica*) forests are the most widely distributed and dominant forest of the late successional stage in Korea [85]. The DCA ordination (**Figure 6**) showed that stands in the urban area (Mts. Nam, Acha, Daemo, Bulam,

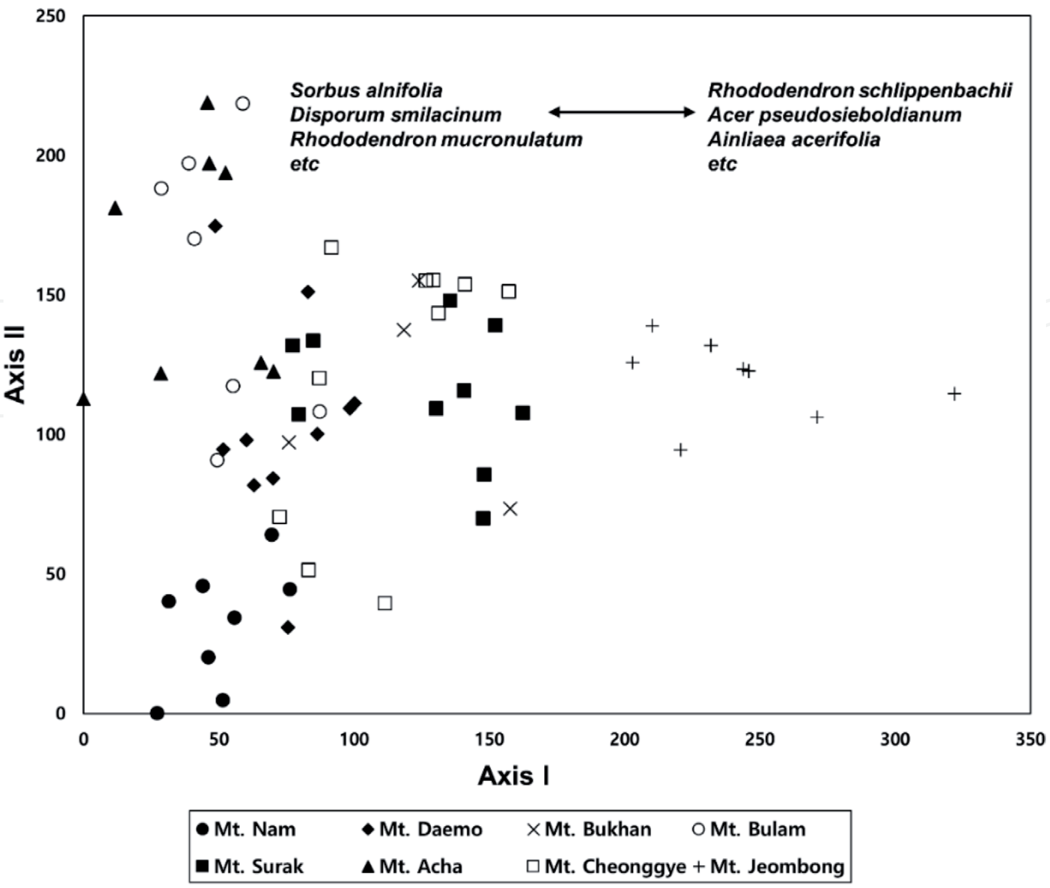

Figure 6.
Stand ordination of the Mongolian oak forest established in urban and suburban areas around Seoul.

Bukhan, Cheonggye, and Surak) were clustered in the left corner of the graph, with stands in the natural area (Mt. Jeombong) on the opposite end of axis I. This result shows that species composition in the urban forest was differed from that in the natural forest.

Species richness was usually lower in the urban areas than that in natural areas although a few exceptional areas exist such as Mts. Surak, Bukhan, Bulam, and Cheonggye (see x-axis in **Figure 7**). The slope of species rank-dominance curve was steeper in sites with low species richness than that in sites with high species richness and thereby showed lower evenness (**Figure 7**).

Mongolian oak stands established in urban area showed a difference even in successional trend from those in natural area. In mountains located on urban area, the diameter class distribution of major trees in these Mongolian oak stands revealed that oaks dominated the larger diameter classes, while *Sorbus alnifolia* dominated the smaller diameter classes. On the other hand, Mongolian oak dominated all diameter classes in natural areas (**Figure 8**).

Size distributions of trees are useful indicators for understanding the structure of tree populations and for predicting dynamics of them [86–88]. The diameter class distribution of plant populations has generally been computed as frequency histograms [89]. Frequency distribution patterns of each diameter class indicate the potential change of the population in a plant community. A plant population, where young individuals are numerous and mature ones are fewer, is recognized as having a reverse J-shaped diameter distribution pattern [90, 91]. It is recognized that the population that shows a reverse J-shaped distribution pattern can persist continuously [90–93]. On the other hand, the normal population pattern with fewer

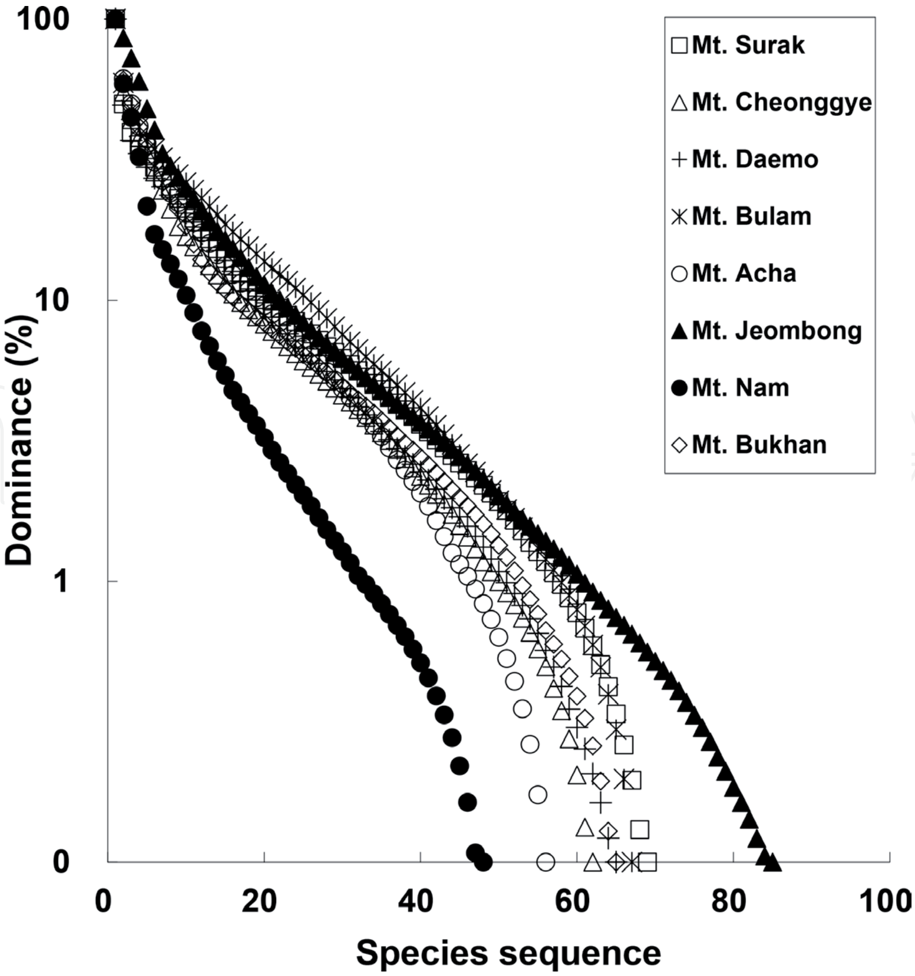

Figure 7.
Rank-abundance curves of the Mongolian oak forests established in 10 study areas.

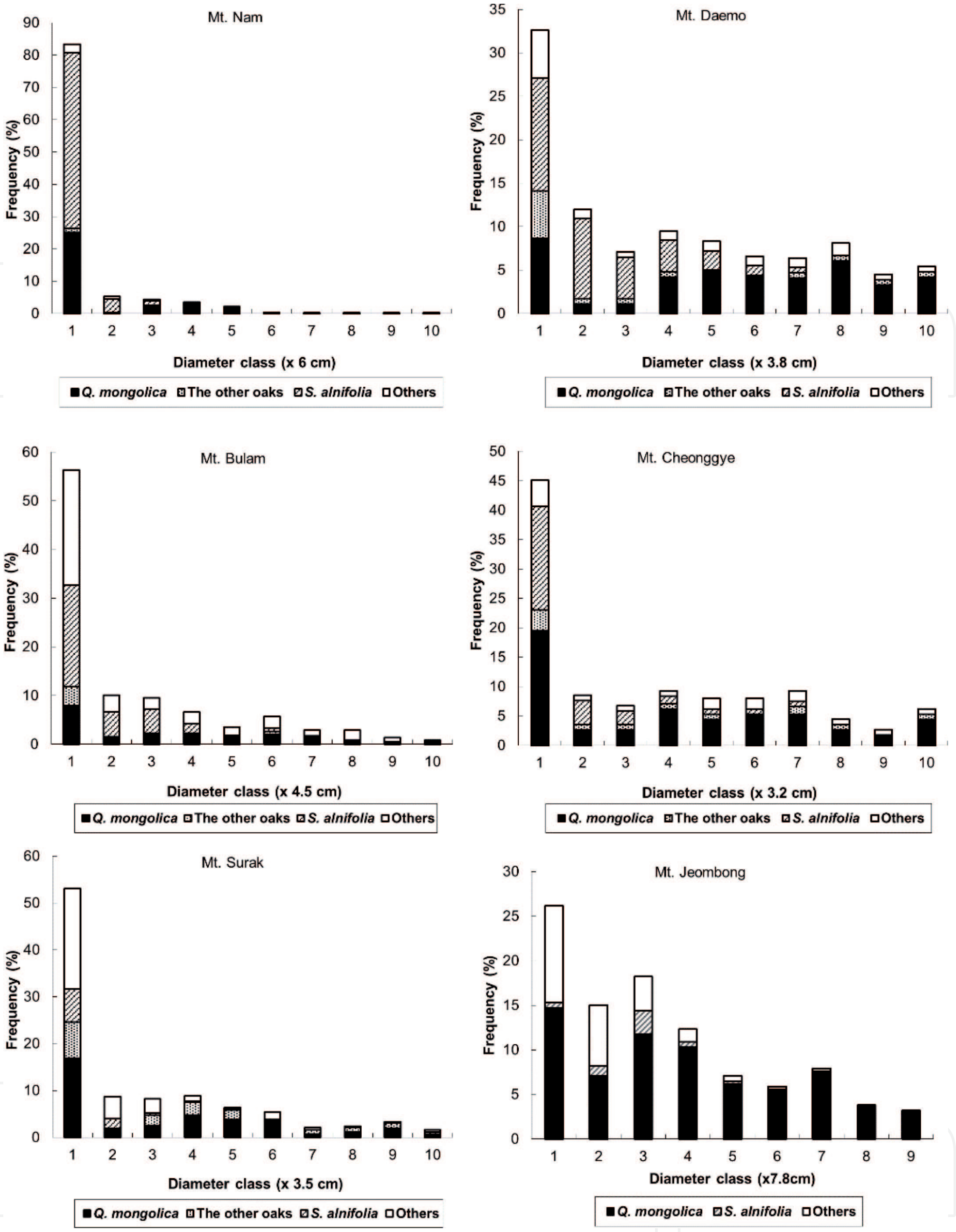

Figure 8.
Frequency distribution of diameter classes of major tree species composed of the Mongolian oak forests established in several mountains of Seoul and in Mt. Jeombong as a natural area.

juveniles relative to adults is typically replaced by another population in the future [92, 93], but a bimodal pattern is shown in a population that is regenerated with periodic disturbance [94, 95].

Based on this principle, it is expected that Mongolian oak stands in the natural area could be maintained continuously, whereas urban oak stands would be replaced by Korean mountain ash. Considered that Mongolian oak stands are the representative vegetation of the late successional stage in the Korean peninsula [85], this successional trend could be interpreted as being retrogressive [95].

As was mentioned above, the Mongolian oak forests in urban area of Seoul had different species composition, lower diversity, and retrogressive successional trends compared to those in natural area (**Figures 6–8**). These differences are likely due to the development of thin canopy crowns in overstory composed of Mongolian oaks, which have been exposed to severe air pollution stress over long years [39, 47, 48]. By increasing the supply of light and precipitation to the forest floor, thin crowns of canopy trees cause dense growth of subcanopy trees, such as the Korean mountain ash. Therefore, vegetation structure and successional trends change over time [96–99]. Once the subcanopy layer becomes denser, light again decreases, and species richness can be expected to decline, a pattern we observed in our urban forests (**Figure 7**).

Retrogressive succession, signs of which appeared in our urban oak communities, is usually caused by frequent or intense disturbance [100, 101]. Although such situations have been frequently observed in the vicinity of industrial complexes exposed to severe air pollution [102–107], it is a very rare phenomenon in urban areas. Retrogressive succession would be expected where pollution damage to forests is usually intense and acute. However, pollution in most urban areas is less severe than near industrial sites but is chronic [106]. Although we could observe signs of severe air pollution damage from analyzing the vegetation structure in Seoul, severe visible damage on vegetation surface was not found as observed in forests near the industrial areas [50, 108]. Therefore, our results in Seoul could be explained as resulting from synergistic interactions between chronic air pollution and urban climate, rather than resulting solely from severe pollution [109]. Air circulation specific to urban area from interaction of atmospheric temperature inversions and microcurrents occurred due to local temperature differences, and soil acidification due to air pollutants transported along the air circulation interact to cause a change in vegetation structure and consequently change vegetation dynamics. From these results, we can recognize a new type of forest decline in Mongolian oak stands as a general phenomenon occurring on the upper slopes surrounding the Seoul basin [39, 53, 54].

8. Occurrence of drought due to climate change

Although annual precipitation showed a variation, precipitation when the amount was low, for example, 2014 and 2015, fell short of the threshold that temperate forest can be persisted in this region (**Figure 9**). Considering that annual mean temperature in Seoul is 12.2°C, precipitation more than 100 cm is required to maintain temperate forest [110, 111]. But precipitations in 2014 and 2015, 80.89 cm and 79.21 cm, did not fulfill the level.

Trends of monthly mean precipitation and potential evapotranspiration also showed very dangerous pattern (**Figure 9**). Gaps between precipitation and potential evapotranspiration during spring and fall seasons in 2017 when drought-induced plant damage was investigated were far bigger than that between mean values of them. In 2018, rainfall during spring season is far more than that of normal year, while that during rainy season, usually July to August, was very short (**Figure 10**). Consequently, rainfall pattern was deviated greatly from the normal pattern. Patterns in 2014 and 2015 when precipitation was very short resembled that in 2018. Water budget in 2014 and 2015 evaluated based on relationship between precipitation and potential evapotranspiration was more severe. Potential evapotranspiration exceeded precipitation.

From those results we can deduce that plants would endure severe water deficiency during growing season particularly. In fact, drought-induced plant damage investigated in urban forest of Seoul reflects those results.

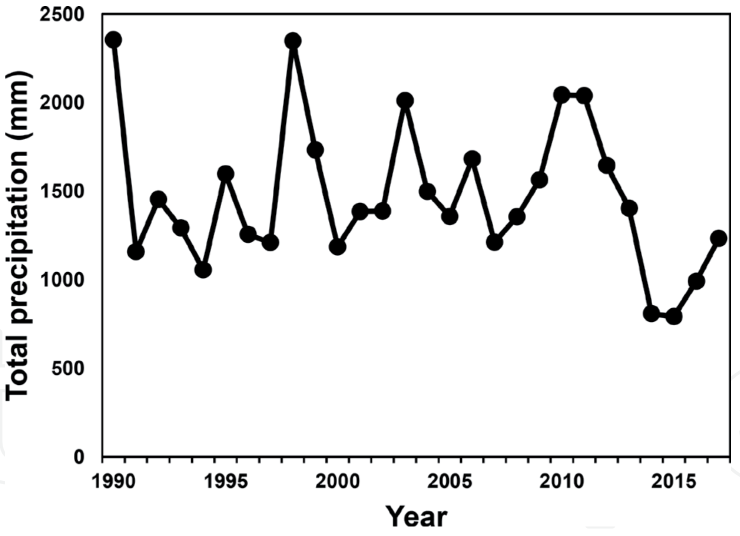

Figure 9.
Changes of annual precipitation for recent 30 years in Seoul. Considered annual mean temperature is 12.2°C; precipitation more than 100 cm is required to maintain temperate forest. But years, which is not fulfill the level, for example 2014 (80.89 cm) and 2015 (79.21 cm) appear in recent years due to climate change.

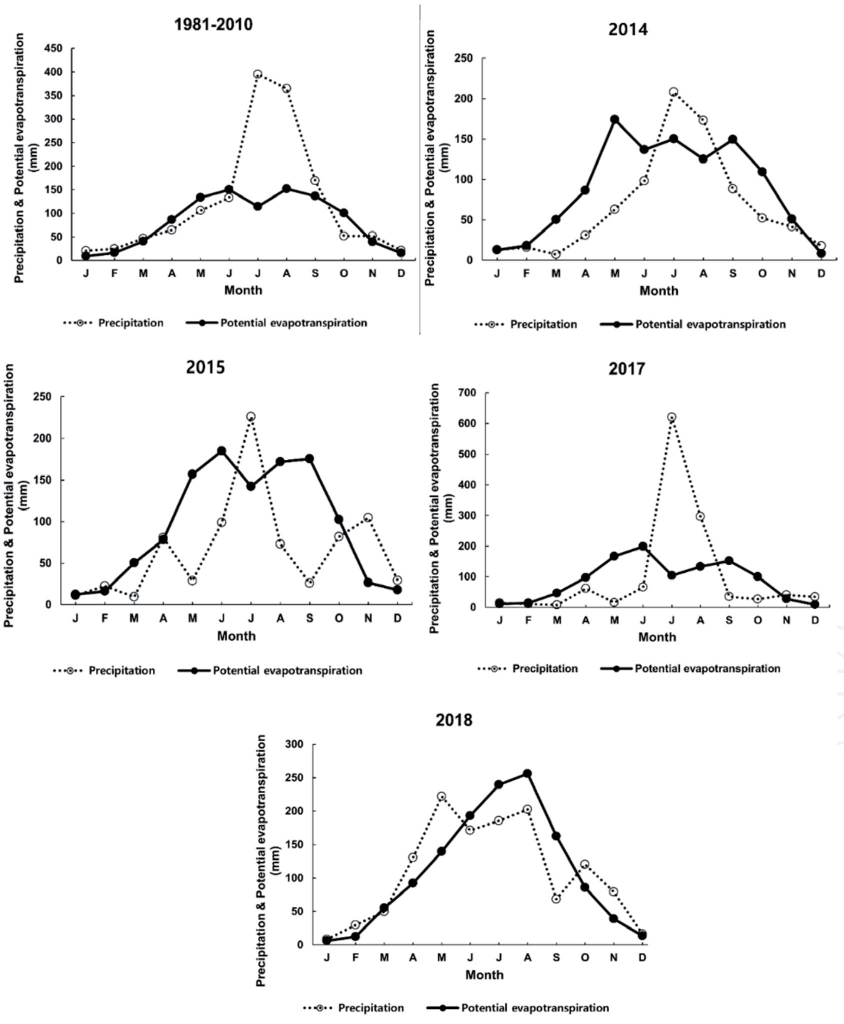

Figure 10.
Mean monthly trends of precipitation and potential evapotranspiration in 2014, 2015, 2017, and 2018 compared with mean values for recent 30 years from 1981 to 2010 in Seoul. Seoul, which is attributed to Asian monsoon climate zone, usually shows water balances with deficits in the spring season of the year, but the phenomenon was severer in 2017 and showed very different pattern in 2018. Patterns in 2014 and 2015 when precipitation was very short resembled that in 2018. Potential evapotranspiration exceeded precipitation in 2014 and 2015. Potential evapotranspiration was obtained applying a method of Blaney and Criddle [66]. Data were derived from Korea meteorological agency (https://data.kma.go.kr).

9. Drought-induced plant damage

Drought-induced plant damage was shown in **Table 1**. Among canopy trees and understoried trees, *S. alnifolia* showed very severe damage (**Table 1**). *C. scabrida*, *P. sargentii*, and *Crataegus pinnatifida* showed severe damage, and *Q. mongolica*, *Q. serrata*, and *Q. variabilis* showed severe damage depending on site. *R. pseudoacacia*, *Q. acutissima*, *Q. dentate*, and *P. rigida* showed moderate damage, and *P. densiflora*, *Alnus hirsuta* var. *sibirica*, *Carpinus laxiflora*, and *Styrax obassia* showed moderate damage depending on site. *Fraxinus rhynchophylla*, *F. mandshurica*, and *Lindera obtusiloba* showed slight damage. On the other hand, *Sorbus commixta* and *Acer pseudosieboldianum* did not show any visible damage. Among shrubs, *Parthenocissus tricuspidata* showed very severe damage depending on site. *S. incisa* showed severe damage, and *Juniperus rigida*, *Symplocos chinensis* for. *Pilosa,* and *Weigela florida* showed severe damage depending on site. *Callicarpa japonica*, *R. mucronulatum*, *Lespedeza cyrtobotrya*, *Viburnum erosum*, and *Smilax sieboldii* showed moderate damage. On the other hand, *Corylus heterophylla* showed slight damage.

Around 310 damaged plants in 34 species were observed (**Table 1**). *Sorbus alnifolia*, *Robinia pseudoacacia*, *Q. mongolica*, *P. densiflora,* etc. were the most damaged plants.

Around 107 plants in 7 species died due to drought (**Table 1**). *Sorbus alnifolia, Castanea crenata*, *Robinia pseudoacacia*, *Q. mongolica*, etc. were the plants that died the most.

Life form	Species	Damage degree	No. of damaged individuals	No. of dead individuals
Tree and understory tree	*Sorbus alnifolia*	V	100	96
	Castanea crenata	IV	3	
	Robinia pseudoacacia	III	50	
	Prunus sargentii	IV	9	1
	Quercus mongolica	I – IV	27	6
	Pinus densiflora	I – III	23	
	P. rigida	III	1	
	Quercus serrata	II – IV	15	
	Sorbus commixta	I	1	
	Q. variabilis	II – IV	8	1
	Q. acutissima	III	2	
	Alnus hirsuta var. *sibirica*	II - III	2	
	Fraxinus mandshurica	II	1	
	Acer pseudosieboldianum	I	1	
	F. rhynchophylla	II	2	
	Carpinus laxiflora	I- III	2	
	Q. aliena	I - V	2	1
	Q. dentata	III	1	
	Lindera obtusiloba	II	2	
	Styrax obassia	II - III	3	

Life form	Species	Damage degree	No. of damaged individuals	No. of dead individuals
Shrub	*Fraxinus sieboldiana*	I	1	
	Juniperus rigida	III - IV	4	1
	Indigofera kirilowii	II	1	
	Stephanandra incisa	IV	20	
	Rhododendron mucronulatum	III	8	
	Viburnum erosum	III	1	
	Smilax sieboldii	III	1	
	Rhododendron schlippenbachii	III	3	
	Lespedeza cyrtobotrya	III	2	
	Symplocos chinensis for. *pilosa*	III - IV	2	
	Corylus heterophylla	II	1	
	Parthenocissus tricuspidata	I - V	2	
	Weigela florida	III - IV	7	
	Callicarpa japonica	III	2	1

Table 1.
Degree of leaf surface damage, the number of damaged plants, and the number of dead plants due to drought in an urban forest (Mt. Bulam) of Seoul, central Korea.

Drought-induced plant damage started from withering of leaves of plants introduced for landscaping in the urban area. Over time, branches died and death of the whole plant body followed. We regarded these phenomena due to that they were introduced without ecological consideration at this time. But die-off of *Ligustrum obtusifolium*, *Callicarpa japonica*, *Euonymus japonicas*, etc., which were introduced by reflecting potential natural vegetation, and/or *Pinus densiflora*, *Buxus koreana* etc., which are familiar with present concrete ground or changes of Anthropocene, began to be observed.

As drought continues, plant damage spreads toward the urban forest beyond the residential area in the urban center. Damage of exotic plants, such as *Robinia pseudoacacia*, *Crataegus scabrida*, etc., or plants introduced for landscaping such as *Prunus serrulata* var. *spontanea*, *Rhododendron yedoense* for. *Poukhanense*, etc. was observed first of all. But damage of the native plants began to appear soon after. In particular, damage of *Sorbus alnifolia*, the product of retrogressive succession [39], was remarkable. As retrogressive succession has already progressed much and thus the number of individuals of *Sorbus alnifolia* increased greatly (**Figure 7**), it can be recognized as crisis of urban forest.

Retrogressive succession from forests of stable late successional stage such as *Quercus* or *Carpinus* dominated forests to *Sorbus alnifolia* or *Styrax japonica* dominated forests, which favor infertile and instable environment of early successional stage, has progressed in urban area of Seoul by complex interactions of chronic air and soil pollution, and urban microclimate regime is changed by excessive land use [39]. Not only biodiversity decreases remarkably but also vegetation stratification became simple, and thus both ecological diversity and ecosystem stability deteriorated severely in the place that retrogressive succession occurred [39].

In this situation, severe drought due to climate change continued for several years and threatened ecological stability of the region substantially. Annual precipitation of the region, which experiences severe drought at present, falls short to the level, about 1000 mm, that temperate forest can establish in this region [110].

In addition, aggravation of spring drought, which comes from reduction of snow fall due to temperature rise during winter season and temperature rise and evaporation increase due to climate change, incites vegetation damage [37, 38].

Climate change does not induce temperature rise only simply but accompanies diverse and complex environmental changes likewise drought that we experience now. Moreover, vegetation damage spreads into various native plants beyond several sensitive plants. Environmental change due to climate change may cause additive retrogressive succession into poor vegetation near to open woodland rather than simple change from the deciduous broad-leaved forest to the evergreen broad-leaved forest as the general public think.

The damage of *Castanea crenata* and *Prunus sargentii* was severe, and damage of *Q.mongolica* and *Carpinus laxiflora*, which composes late successional vegetation, was also found. Of more concern is that most plants without any relation with species and life form over all layers composing vegetation stratification such as canopy tree, understory tree, shrub, and herb layers were injured or died. For example, *P. densiflora* and *Q. variabilis*, which composes vegetation of the representative dry land and *Juniperus rigida*, *Weigela florida*, *Rhododendron mucronulatum*, etc., which forms their undergrowth, were damaged or died. Indeed, serious phenomenon progressed around us. Continuous monitoring and synthetic consideration for preparing on climate change are urgently required.

10. Conclusion

In Seoul, the capital of South Korea, most flat plains and hilly terrain were transformed from the natural land surface to the artificial impervious one with the increase of population due to both birth and influx from the rural area. Consequently, green space shows imbalanced spatial distribution as it is restricted to the urban fringe, where the land is mountainous and thus development is difficult topographically and deficient in urban center. This imbalanced distribution of green space led to severe urban heat island effect, and the effect was followed by temperature inversion. Subsequently, this change produced altered air circulation patterns specific to city, particularly city with basin-type topography like Seoul [77, 79]. Movement of air pollutants from urban area is likely dominated by this air circulation. In this process, relatively heavy particulates are felled in urban center, while light gaseous pollutants are transported to the forested area in urban boundary. Spatial distribution of physicochemical properties of soil reflects the trends. Forest of this area experiences retrogressive succession from Mongolian oak forest of the late successional stage to Korean mountain ash forest of the earlier successional stage as it is continuously exposed to air pollutants blowing from urban center, and soil is acidified due to the effect. As the results of such changes, urban Mongolian forest shows decline symptom that species composition is different and species diversity is lower than that in natural landscape. Further, the result increases vulnerability to environmental stresses related to climate change including drought.

Plant damage due to drought begun from withering of leaves of plants introduced for landscaping in the urban park. Over time, branches died and death of the whole plant body followed. As drought continues, plant damage spreads toward the urban forest beyond the residential area in the urban center. Damage of exotic plants or plants introduced for landscaping was observed first of all. But damage of the native plants began to appear soon after. In particular, damage of *Sorbus alnifolia*, the product of retrogressive succession, was remarkable. As retrogressive succession has already progressed much and thus the number of individuals of *Sorbus alnifolia* increased greatly, it was surmised as the level so that this phenomenon can be recognized as crisis of urban forest. In this situation, severe drought due to climate change is being continued for several years; annual precipitation of the region, which experiences severe drought at present, records less than 1000 mm; the level approaches the threshold of ecological condition that forest can be established. In this respect, continuous monitoring and synthetic measure based on the results for coping with drought due to climate change are urgently required.

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Conflict of interest

This paper was prepared by supplementing and reediting papers that prof. C.S. Lee had published [39, 40, 46, 47, 99].

Author details

Chang Seok Lee[1]*, Songhie Jung[1], Bong Soon Lim[1], A Reum Kim[1], Chi Hong Lim[2] and Hansol Lee[3]

1 Seoul Women's University, Seoul, Korea

2 National Institute of Ecology, Seocheon, Korea

3 Miami University, Ohio, USA

*Address all correspondence to: leecs@swu.ac.kr

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