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Evaluation of the Restoration Effects of Rooftop Greening Areas Created by Applying an Ecological Restoration Method

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Abstract: Green roofs provide various ecosystem services, including habitats for diverse organisms in urban areas where natural space is very scarce. This study aims to evaluate the restoration effects of green roofs created by applying an ecological restoration method to reinforce habitat function. The reference ecosystem selected for the ecological restoration of a roof was a Korean red pine stand established on Mt. Bulam, considering the soil depth, light, moisture conditions, etc., compared with the roof's environmental conditions. Ecological restoration was carried out by planting two-year-old pine seedlings and scattering surface soil collected from the pine stands. The pine trees showed geometrical growth in height and diameter and a high water-use efficiency. The ecological restoration of the green roofs demonstrated an ecological function for improving the urban climate through the mitigation of the urban heat island effect and high productivity, showing different functions depending on the greening method. The composition and diversity of vegetation and insects at the ecological restoration site were similar to those at the reference site, whereas the landscape architecture sites, which were created using the landscape architecture method, were different from the reference site. These results confirm that applying the ecological restoration method for rooftop greening resulted in better biological habitat function than applying existing landscape architecture methods.

Keywords: green roof; restoration; urban ecology; urban habitat; habitat template

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1. Introduction

Cities make up approximately 2% of the world's land area, but about 3.9 billion people, 54% of the world's population, live in cities [1]. The population concentration in cities has caused changes in land-use patterns; high-density building and the replacement of soil and vegetation by pavement cause adverse effects on the urban ecosystem, such as habitat loss, groundwater depletion, flooding, and the urban heat island effect [2–4]. It is difficult to secure additional green areas, as urbanized areas are continuously expanding into natural and rural areas [5–7]. However, efforts to expand green spaces in cities are being made to reduce their adverse effects [8].

In this context, rooftop greening, which creates green spaces in existing built-up areas, has attracted attention as an alternative to expanding green spaces in urban areas where it is difficult to secure additional green areas [9–11]. The expansion of green spaces through rooftop greening has become a concept to compensate for the loss of green spaces on Earth, with potential benefits including green-space amenities, air and water quality improvement, reduction in the urban heat island effect, and habitats for wildlife [12]. In this context, humans have long been introducing plants to their buildings, particularly on rooftops [12], and unexpected wildlife is sometimes observed on green roofs [13,14]. Although green roofs cannot fully replace natural areas, they are regarded as beneficial,

e.g., they can provide habitats for diverse biota, thereby helping to protect terrestrial and aquatic ecosystems [15].

Buildings built to support a wide range of activities, including the residences of many people concentrated in cities, change the flow of energy and matter through urban ecosystems, often causing environmental problems. These problems can be partially mitigated by altering the buildings' surficial properties [16]. Roofs can represent up to 32% of the horizontal surface of built-up areas [17] and are important determinants of the energy flux and water use of buildings. The addition of vegetation and soil to roof surfaces can lessen several negative effects of buildings on local ecosystems and reduce the energy consumption of buildings [18–20].

A green roof, i.e., a roof with a vegetative cover, is one passive technique that can be used to address environmental issues in an urban setting. Researchers have shown that green roofs can be used to mitigate problems associated with storm water runoff, the urban heat island effect, wildlife habitats, and air and water quality [13,21–23].

Although green roofs represent a distinct type of urban habitat, they have largely been treated as an engineering or horticultural challenge rather than as ecological systems. Nevertheless, the environmental benefits provided by green roofs are derived from their functioning as ecosystems. Rooftop conditions are challenging for plant survival and growth. Moisture stress and severe drought, extreme (usually elevated) temperatures, high light intensities, and high wind speeds increase the risk of desiccation and physical damage to vegetation and substrate [24]. Plants suitable for extensive green roofs share adaptations that enable them to survive in harsh conditions. These plants have stress-tolerant characteristics [25], including low, mat-forming, and compact growth; evergreen foliage or tough, twiggy growth; and other drought-tolerance or -avoidance strategies, such as succulent leaves, water storage capacity, or crassulacean acid metabolism (CAM) physiology [26]. However, some ruderal species [25] that can rapidly occupy gaps may also be favored due to frequent drought-related disturbances to green roof vegetation. Green roof communities are dynamic, and with time, their vegetation is likely to change from their original composition [27].

Since green roofs are gaining prominence as shelters for wildlife in urban ecosystems [13,14,28,29], practices, science, and theory are required to realize ecological restoration in urban settings [30]. Lundholm [31] suggested a way to mimic a habitat consisting of granite outcrops similar to rooftops, beyond simply planting drought-tolerant species for rooftop greening. Reflecting this trend, Nagase and Tashiro-Ishii [32] proposed a roof-greening scheme that mimics vegetation established on rocky coasts. Rocky areas are suitable as "habitat templates" for green roofs because the soil depth of these areas is shallower and the soil moisture condition is poorer than that in deep soil areas [31,33]. Green roofs created by applying an ecological restoration method that imitates such a habitat as a reference site can provide a life-supporting function as biological habitats [32,34,35]. They can also be created as self-sustaining ecosystems [36]. Di Miceli et al. [37] conducted a comparative study to identify better plant combinations, and Heim and Lundholm [38] tracked changes in community structure and functional traits after construction. Gourdji [39] conducted a study to select plants with high capacity to purify air pollutants such as particulate matter, ozone, and nitrogen dioxide as rooftop greening plants.

After implementing restoration practices by applying a habitat template as a reference, the achievement of the ecological restoration needs to be assessed for the development of future projects [40–42]. The Society for Ecological Restoration International [43] has provided a list of the nine key attributes of successful restoration that identify appropriate indicators of restoration success. The attributes cover three general ecological outcomes: vegetation structure, species diversity and abundance, and ecological processes [44,45]. Additionally, in recent years, studies have been carried out to determine whether ecosystem functions are restored by applying plant functional traits [46–48]. Assessing plant functional traits helps to identify the generalizable nature of an ecosystem, and therefore, makes it possible to interpret changes in the community composition and ecosystem function [48].

The results, which are compared between the restored and reference areas through these evaluation indices, are used to derive information on habitat suitability and ecosystem services in restored areas [49–51].

In this study, we executed a rooftop greening project by applying a habitat template. To evaluate the effects of the project, we compared the species composition and diversity of its plants and insects and some of its ecosystem service functions to those of a natural reference site and places created by applying landscaping methods. The ecosystem service functions were evaluated by focusing on the improvements in climate mitigation and biological habitat function.

2. Materials and Methods

2.1. Site Description

Seoul Women's University, where this study was carried out, is located in the north-eastern part of Seoul in central Korea (Figure 1). The green roofs were created on the fifth floor of the Humanities and Social Studies building, the fifth floor of the 50th Anniversary Memorial Hall, and the fourth floor of the Headquarters building. The green roof of the Humanities and Social Studies building had a soil depth of 50 cm, and trees, shrubs, and herbs were introduced, imitating the Korean red pine forest established on Mt. Bulam, which is located close to this site. This location is referred to as an ecological restoration site hereafter as an area where the ecological restoration method was applied; it is considered an 'intensive' green roof. The green roof of the 50th Anniversary Memorial Hall (hereafter referred to as landscape architecture 1) had a soil depth of 20–60 cm, and shrubs and herbs were introduced. The Headquarters building (hereafter referred to as landscape architecture 2) had a soil depth of 10 cm, and only herbs were introduced (Table 1). These roofs to which the landscaping method was applied are considered 'extensive' green roofs.

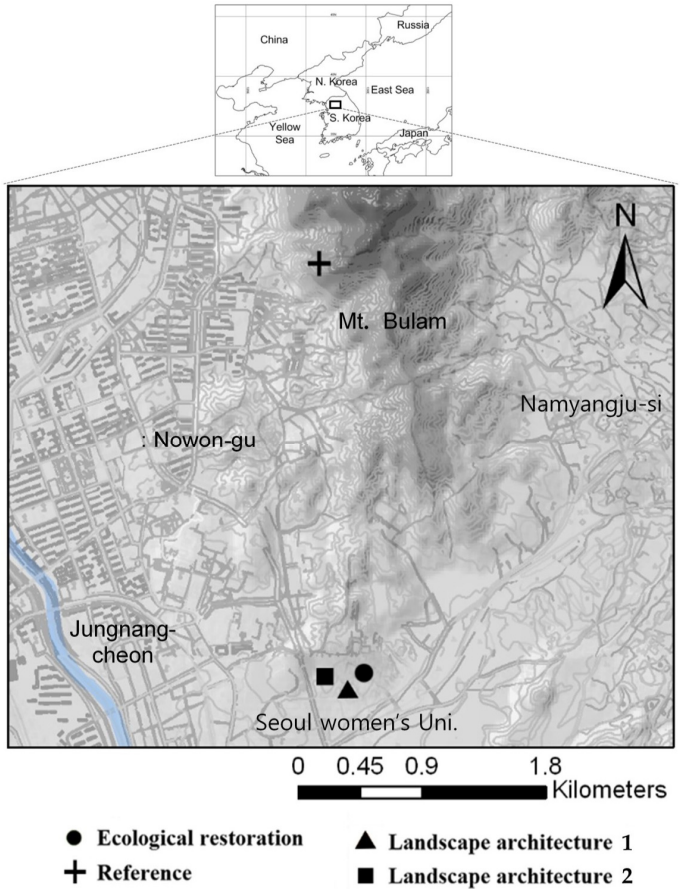


Figure 1. Geographic location of the study area.

Table 1. Configuration of the three green roofs selected for this study. The plants in parentheses indicate dominant species.

Restoration Method	Year of Completion	Vegetation Type	Area (m^2)	Percentage (%)
Ecological restoration	2006	Pine (*Pinus densiflora*) forest	328.5	57.5
		Pavement	243.3	42.5
		Total	571.8	100.0
Landscape architecture 1	2014	Grassland	505.3	38.1
		Shrubland (*Syringa dilatata*)	107.5	8.1
		Pavement	713.9	53.8
		Total	1326.6	100.0
Landscape architecture 2	2007	Grassland (*Phedimus kamtschaticus*)	458.9	50.7
		Pavement	446.5	49.3
		Total	905.4	100.0

The reference site was selected on Mt. Bulam, which is located near the green roof areas (Figure 1). Mt. Bulam was designated as an urban nature park in July 1977 by the central government of Korea. It is located on the border between Nowon-gu in Seoul and Namyangju-si in Gyeonggi-do and consists of mountainous terrain extending to the north and south. Daebo granite covers the summit and is scattered throughout the rock outcrop area, creating domes. The forest vegetation of this site is dominated by Mongolian oak (*Quercus mongolica*), Korean red pine (*Pinus densiflora*), sawtooth oak (*Quercus acutissima*), and cork oak (*Quercus variabilis*) [52]. Among these, the Korean red pine stand established on Mt. Bulam was selected as the reference site for restoring the rooftops, considering the soil depth, light, moisture conditions, etc., compared with the environmental conditions of the studied roofs. The individual trees that make up the pine forest are 40 to 50 years old and have not yet begun to senesce.

To compare the restoration effects, the green roof prepared by applying the landscaping method to an existing building was adopted as another reference site. Construction at the sites where ecological restoration, landscape architecture 1, and landscape architecture 2 methods were applied took place in 2006, 2014, and 2007, respectively. Field surveys were conducted between 2014 and 2015.

2.2. Rooftop Greening by Applying the Ecological Restoration Method

Ecological restoration on the fifth floor of the Humanities and Social Studies building was performed based on the vegetation information obtained from the reference site. Two-year-old Korean red pine saplings were planted on the green roof area with spacings of 50 cm. In addition, topsoil taken from the Korean red pine forest was dispersed to introduce understory vegetation.

2.3. Monitoring the Establishment of Vegetation

2.3.1. Diameter and Height Growth

To analyze the population structure of plants introduced for rooftop greening, the diameter and height of all trees $\geq$ 1 cm in diameter at breast height were measured. Ten individuals were randomly selected for measuring the radial and height growth. Radial growth was analyzed by measuring the tree rings. Tree ring samples were extracted at 30 cm above ground using an increment borer (Haglof, Stockholm, Sweden) and measured using a core measuring instrument (CORIM Maxi). The height growth was analyzed by measuring the length of the stem node.

2.3.2. Physiological Characteristics

Physiological characteristics of the plants, including photosynthetic rate, transpiration rate, and water-use efficiency, were analyzed [53]. The photosynthetic rate and transpiration

rate were measured using a Li-6400 portable photosynthetic analyzer (Li-6400, Li-COR, Lincoln, NE, USA). Based on the obtained values, the water-use efficiency was calculated as follows:

$$WUE = PN/Tr \quad (1)$$

$$WUE: \text{Water-use efficiency } (\mu mol\ CO_2\ mmol\ H_2O^{-1}) \quad (2)$$

$$PN: \text{Photosynthetic rate } (\mu mol\ CO_2\ m^{-2}\ s^{-1}) \quad (3)$$

$$Tr: \text{Transpiration rate } (mmol\ H_2O^{-1}\ m^{-2}\ s^{-1}) \quad (4)$$

2.4. Measurement of Abiotic Factors

2.4.1. Microclimate

We installed meteorological sensors (Model HOBO Pro v2 U23–001, U23–004, Onset company, Bourne, MA, USA) 1 m above ground and 10 cm below ground at each site to measure the air temperature during the summer season (June–August). Each sensor was protected from direct sunlight by a protective case, and observations were made at 30 min intervals.

2.4.2. Soil Respiration

Soil respiration was measured by applying the closed dynamic chamber method [54] using a portable closed-chamber infrared gas analysis system (SRC-1 with EGM-4, PP-Systems, Hitchin, Herts, UK). In order to measure the soil respiration rate, six cylindrical collars with diameters of 10 cm and heights of 8 cm were installed at each site. Caps with CO_2 concentration sensors were mounted on the collars to measure the amount of CO_2 in them. Soil respiration was calculated from the rate of increase in the CO_2 concentration over time with the caps closed for 2 s intervals for 2 min. The method of calculating the soil respiration rate from the increasing rate of CO_2 concentration emitted from soil surfaces is shown in Equation (5):

$$\text{Soil respiration } (mg\ CO_2\ m^{-2}\ h^{-1}) = a\rho VS^{-1} \quad (5)$$

where a is the increasing rate of the CO_2 concentration; ρ is the CO^2 density (mg m^{-3}); V is the volume of chamber (m^3); S is the surface area of the soil covered with collars (m^2).

The soil respiration rate was measured at monthly intervals for a year. The measurements were replicated four times from 10:00 to 13:00 h in all plots at each location.

2.5. Net Primary Productivity (NPP)

2.5.1. Herb Layer

Estimations of the biomass in the herb layers were made for each subplot by applying a harvesting method after a vegetation survey. We installed three plots of 0.5 m × 0.5 m at each site. All plants that appeared in each plot were harvested and divided into their aboveground and belowground parts. The plants were then oven-dried at 70 °C for 48 h to a constant mass (Drying Oven, Daeil Eng. DDO102, Seoul, Korea) and weighed using an electronic scale (SHIMADZU EB-3200HU, Kyoto, Japan). The amount of carbon stocks was converted by applying the IPCC's suggested carbon conversion factor of 0.5 [55].

2.5.2. Tree Layer

The diameters of all trees that appeared in the study plots were measured using diameter tape (KOBIC, Gwangju, Republic of Korea). The net primary production was estimated by applying the allometric equation after measuring the annual diameter growth (Table 2). Previously published species-specific allometric equations were available for *P. densiflora*, *Q. variabilis*, *Q. acutissima*, *Q. mongolica* [56], and *S. oblata* [57], and a family-specific allometric equation was available for *Juniperus rigida* [56]. Based on the equations, the biomass in 2014 (W1) and the biomass in 2015 (W2) were estimated, and the increase in

biomass (ΔW = W2 − W1) was calculated. The amount of carbon stocks was converted by applying the IPCC's suggested carbon conversion factor of 0.5 [55].

Table 2. Biomass equations used to calculate the total biomass of species in the ecological restoration area. These allometric equations were obtained from the results of Son et al. [56]. D: diameter at breast height measured in cm, H: height measured in m, BGB: belowground biomass. In the allometric equations, the coefficients of D appear in the order of stem, branch, leaf, and root.

Species	Equation (Total Biomass)
Pinus densiflora	$Y(kg) = 0.235 \times D^{2.071} + 0.004 \times D^{2.748} + 0.054 \times D^{1.561} + 0.031 \times D^{2.279}$
Quercus variabilis	$Y(kg) = 0.186 \times D^{2.184} + 0.035 \times D^{2.293} + 0.061 \times D^{1.454} + 0.077 \times D^{2.199}$
Quercus acutissima	$Y(kg) = 0.051 \times D^{2.724} + 0.012 \times D^{2.854} + 0.006 \times D^{2.478} + 0.46 \times D^{1.669}$
Quercus mongolica	$Y(kg) = 0.595 \times D^{1.766} + 0.007 \times D^{2.970} + 0.005 \times D^{2.362} + 0.691 \times D^{1.526}$
Syringa oblata	$\log Y(kg) = [\{0.4692 \log(D^2H) - 0.3576\} + \{0.5887 \log(D^2H) - 1.443\} + \{0.492 \log(D^2H) - 1.36\}] \times BGB$
Juniperus rigida	$Y(kg) = 0.165 \times D^{2.157} + 0.022 \times D^{2.277} + 0.136 \times D^{1.470} + 0.464 \times D^{1.404}$

2.6. Measurement of Biotic Factors

2.6.1. Vegetation

A vegetation survey was carried out based on the degree of cover of each species [58]. According to the plant heights, the plot sizes were 10 m × 10 m for the reference stands, 5 m × 5 m for the ecological restoration site, and 2 m × 2 m for the two landscape architecture sites.

To assess the restoration effects based on the plant functional traits, the species' functional traits were classified into their life forms, such as the dormancy form, radicoid form, disseminule form, growth form, and longevity.

The differences in the species compositions and plant functional traits among the stands were analyzed by applying the ordination method. For ordination, the cover degree of each species and plant functional trait were converted into the median value of the percent coverage in each cover class. The relative coverage was determined by dividing the cover fraction of each species and plant functional trait by the summed cover of all species and functional traits in each plot and then multiplied by 100 to. The relative coverage of each species and plant functional trait was then regarded as the importance value [59].

Finally, the differences in the species compositions and plant functional traits among the sites were analyzed with nonmetric multidimensional scaling (NMDS) stand ordination [59] based on the Euclidean distance. The species diversity was compared based on the species rank–dominance curves and the Shannon diversity index (H′) [60], which was calculated to evaluate changes in species diversity among sites using the package 'vegan' in R ver. 3.4.4. [61].

2.6.2. Insects

An insect survey was carried out four times in 2015 (May, June, July, and August) using a sweeping net (diameter: 30 cm, mesh size: 1 mm). The collected individuals were identified, and the insect composition was compared using nonmetric multidimensional scaling.

3. Results

3.1. Vegetation Establishment Monitoring

The diameters of the pine trees introduced to the restoration site showed a normal distribution forming a peak around the 3–6 cm class (Figure 2). Their height distribution was also normal around the 1.5–4.5 m class (Figure 3).

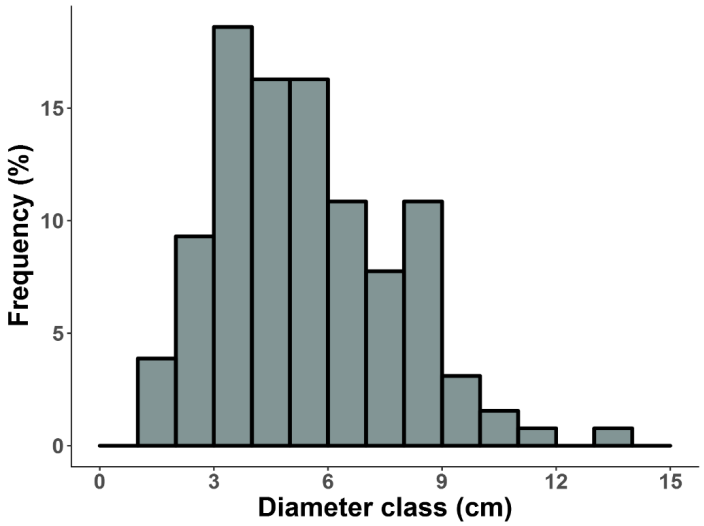


Figure 2. Frequency distribution of diameter classes of *Pinus densiflora* established at the ecological restoration site.

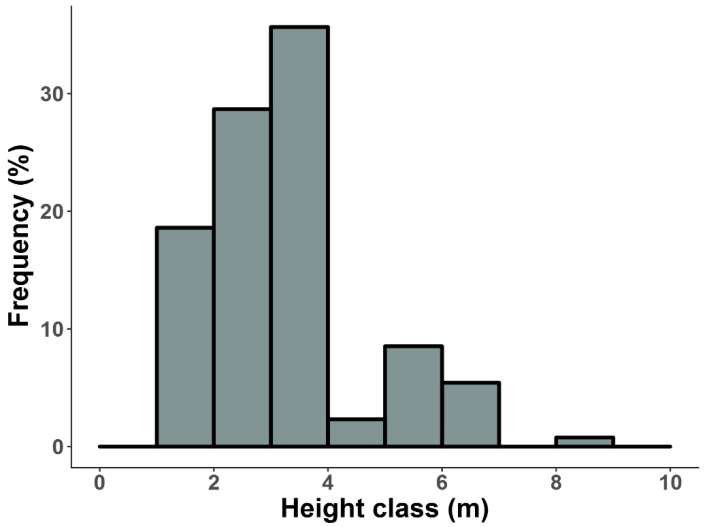


Figure 3. Frequency distribution of height classes of *P. densiflora* established at the ecological restoration site.

The cumulative radial growth of the Korean red pines at the ecological restoration site showed exponential growth over time after their introduction (Figure 4). Their cumulative height growth was moderate for two years after planting and then rapidly exponential thereafter (Figure 5).

The water-use efficiency curves of the pine trees at the ecological restoration site, measured from January to December 2014, are shown in Figure 6. The water-use efficiency at the light saturation point was 500–800 μmol CO_2 mmol H_2O^{-1}, and the average annual water-use efficiency was 2.76 (±0.30) μmol CO_2 mmol H_2O^{-1}.

The monthly mean water-use efficiency of the pine trees was the highest in October, at 9.22 (±1.67) μmol CO_2 mmol H_2O^{-1}, followed by 4.83 (±0.83) μmol CO_2 mmol H_2O^{-1} in June, 4.03 (±0.70) μmol CO_2 mmol H_2O^{-1} in September, 3.85 (±0.84) μmol CO_2 mmol H_2O^{-1} in April, and 3.05 (±0.71) μmol CO_2 mmol H_2O^{-1} in July. On the other hand, the water–use efficiency was low during the winter season at just 0.00–0.16 μmol CO_2 mmol H_2O^{-1} (Figure 6 and Table 3).

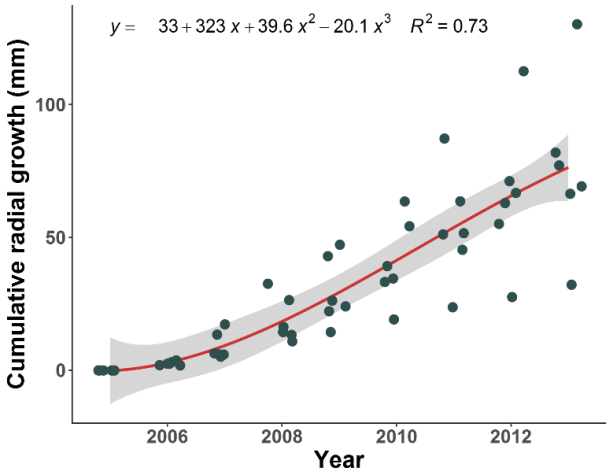


Figure 4. Cumulative radial growth of *P. densiflora* established at the ecological restoration site.

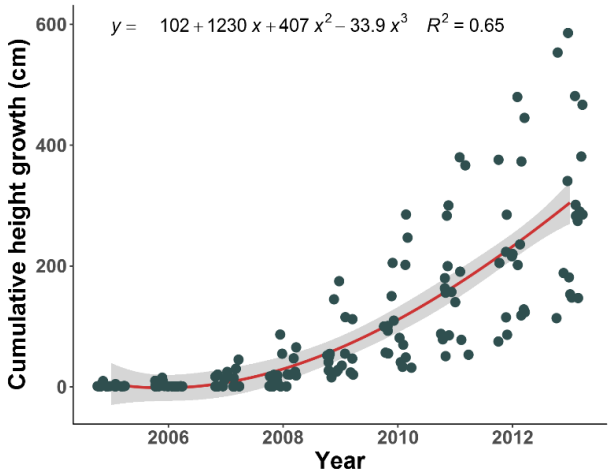


Figure 5. Cumulative height growth of *P. densiflora* established at the ecological restoration site.

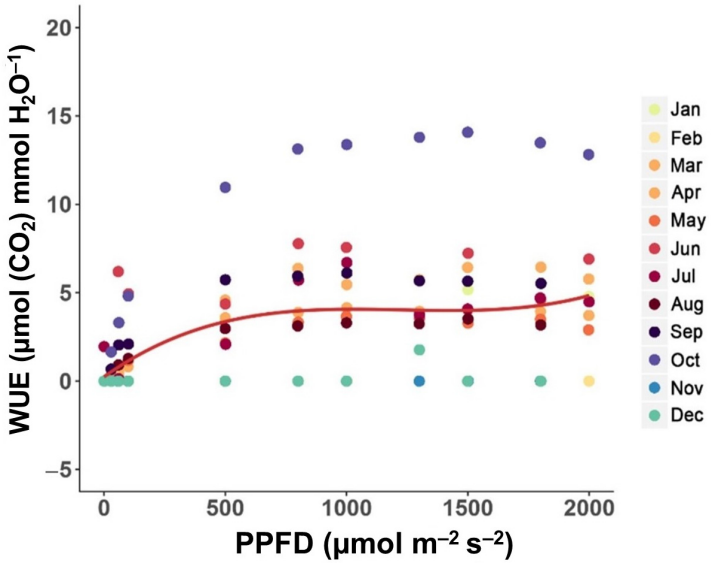


Figure 6. Water-use efficiency (WUE) of *P. densiflora* established at the ecological restoration site. PPFD: Photosynthetic photon flux density.

Table 3. Seasonal variation in monthly mean water-use efficiency of *P. densiflora* (μmol CO_2 mmol H_2O^{-1}).

WUE	January	February	March	April	May	June	July	August	September	October	November	December
Mean	0.90	0.00	2.58	3.85	2.17	4.83	3.05	2.25	4.03	9.22	0.08	0.16
S.E.	0.61	0.00	0.55	0.84	0.46	0.83	0.71	0.42	0.70	1.67	0.08	0.16

3.2. Climate Mitigating Function

The mean temperatures of the green roof areas were measured during the summer season (June to August 2015) and divided into daytime and nighttime. The daytime mean temperature of 26.9 °C (±3.8 °C) at the ecological restoration site was similar to that of 26.7 °C (±3.2 °C) at the reference site. However, the temperatures at the landscape architecture sites 1 and 2 averaged 30.8 °C (±5.6 °C) C and 32.3 °C (±5.4 °C), respectively, higher than the reference site. On the other hand, the mean air temperature at nighttime ranged from 22.3 to 22.7 °C across all of the sites. Nighttime temperatures at the ecological restoration site and landscape architecture 2 site showed significant differences from that at the reference site, whereas temperature at the landscape architecture 1 site did not differ significantly from that at the reference site (Table 4 and Figure 7).

Table 4. Mean air temperature during the summer season (June–August) on green roofs and at the reference site. The means with the same alphabetical character (*in superscript*), for each parameter, were not different from each other.

Study Site	Mean Air Temperature (°C) (±SD) in the Daytime	Mean Air Temperature (°C) (±SD) at Nighttime
Ecological restoration	26.9 ^{b} (±3.8)	22.3 ^{a} (±2.8)
Landscape architecture 1	30.8 ^{c} (±5.6)	22.7 ^{b} (±2.9)
Landscape architecture 2	32.3 ^{d} (±5.4)	22.3 ^{a} (±3.2)
Reference	26.7 ^{a} (±3.2)	22.6 ^{b} (±2.6)
F-value (p)	919.917 *** (0.000)	12.736 *** (0.000)

*** $p < 0.001$.

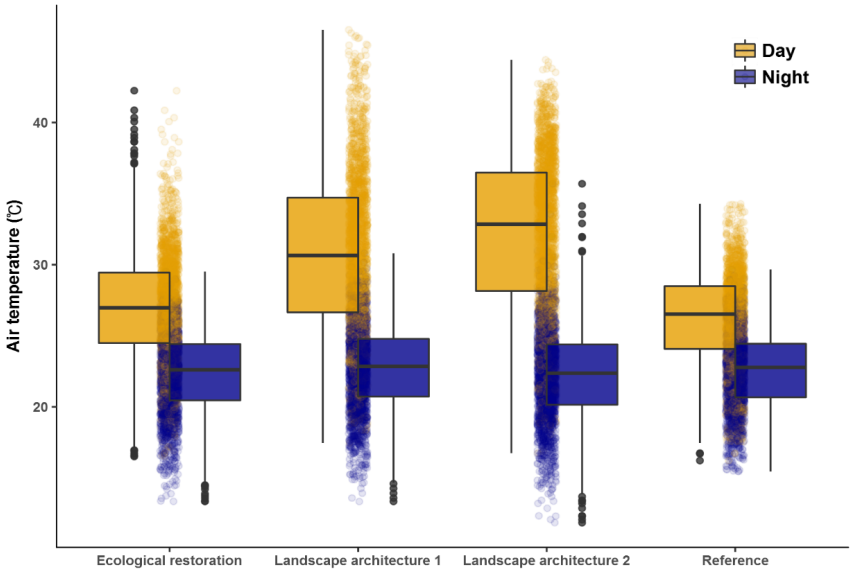


Figure 7. Air temperature (°C) during the summer season (June–August) during the day and at night on green roofs and at the reference site. The solid middle line represents the median, the box represents the interquartile range of temperatures, the error bars represent the minimal and maximal temperatures, and the dots represent outliers.

3.3. Soil Stabilization Function

The changes in the annual soil respiration of the green roof areas and the reference site are shown in Figure 8. According to the results of the survey, which started in October 2014, the monthly average soil respiration rate at the ecological restoration site was the lowest in February, at 25.0 mg CO_2 m^{-2} h^{-1}, and the highest in July, at 1127.5 mg CO_2 m^{-2} h^{-1}. The annual soil respiration rate at the reference site was the lowest in March, at 32.5 mg CO_2 m^{-2} h^{-1}, and the highest in July, at 909.6 mg CO_2 m^{-2} h^{-1}. The annual soil respiration rates of landscape architectures 1 and 2 were the lowest in March and November, at 8.3 mg CO_2 m^{-2} h^{-1} (landscape architecture 1) and 0.83 mg CO_2 m^{-2} h^{-1} (landscape architecture 2), respectively, and the highest in August, at 243.8 mg CO_2 m^{-2} h^{-1} and 187.9 mg CO_2 m^{-2} h^{-1}, respectively.

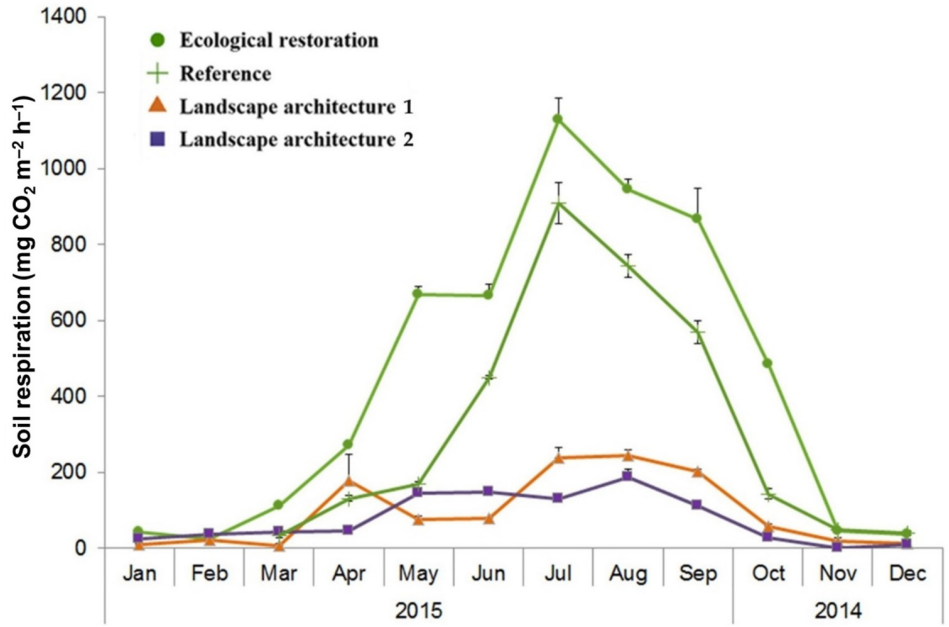


Figure 8. Seasonal variation in monthly mean soil respiration at the study sites.

The seasonal change pattern of the ecological restoration site was similar to that of the natural forest, but the existing green roof area did not show a clear seasonal change. The amounts of soil respiration calculated from the monthly mean soil respiration rates were 10.74 tons C ha^{-1} yr^{-1} for the ecological restoration site, and 2.33 tons C ha^{-1} yr^{-1}, and 1.85 tons C ha^{-1} yr^{-1} for the landscape architecture 1 and 2 sites, respectively. The annual soil respiration rate of the pine forest, the reference site, was 5.54 tons C ha^{-1} yr^{-1} (Table 5).

Table 5. Annual soil respiration at the study sites.

Study Site	Total Soil Respiration (tons C ha^{-1} yr^{-1})
Ecological restoration	10.74
Landscape architecture 1	2.33
Landscape architecture 2	1.85
Reference	5.54

3.4. Carbon Fixation Function

The biomass of the ecological restoration site was 1700.1 kg in 2014 and 2122.9 kg in 2015, and the net primary productivity of the ecological restoration site was calculated as 6.4 tons C ha^{-1} yr^{-1}. *S. dilatata* at the landscape architecture 1 site recorded a net primary productivity of 0.1 ton C ha^{-1} yr^{-1}, with little annual growth of the shrubs; at the same

site, net primary productivity was calculated as 0.2 ton C ha^{-1} yr^{-1} when considering both herb and shrub area. The biomass at the landscape architecture 2 site was 80.0 kg, and its net primary productivity was 0.1 ton C ha^{-1} yr^{-1}. The biomasses of the Korean red pine stand (reference site) were 4112.6 kg in 2014 and 4258.1 kg in 2015. As a result, the net primary productivity of the natural pine forest was estimated to be 1.8 tons C ha^{-1} yr^{-1} (Tables 6 and 7).

Table 6. Biomass and net primary productivity (NPP) of vegetation established on green roofs and in a *P. densiflora* stand on Mt. Bulam, the reference site.

Study Site	Species	2014			2015			NPP (tons C ha^{-1} yr^{-1})
		Above Ground (kg)	Below Ground (kg)	Total (kg)	Above Ground (kg)	Below Ground (kg)	Total (kg)	
Ecological restoration	*Pinus densiflora*	1450.6	249.5	700.1	1805.6	317.2	2122.9	6.435
	Total	1450.6	249.5	1700.1	1805.6	317.2	2122.9	6.435
Landscape architecture 1	*Syringa dilatata*	84.1	21.0	105.1	84.5	21.1	105.6	0.088
	Total	84.1	21.0	105.1	84.5	21.1	105.6	0.088
Reference	*Quercus variabilis*	299.9	97.6	397.4	325.6	106.1	431.6	0.428
	Juniperus rigida	33.9	6.3	40.2	35.3	6.6	41.9	0.021
	Quercus acutissima	135.8	47.0	182.8	135.8	47.0	182.8	0.000
	Pinus densiflora	2850.1	563.5	3413.6	2937.0	582.5	3519.5	1.323
	Quercus mongolica	45.1	33.4	78.6	47.5	34.8	82.3	0.047
	Total	3364.8	747.8	4112.6	3481.2	777.0	4258.1	1.819

Table 7. Biomass and net primary productivity (NPP) of herbaceous layers at two study sites.

Study Site	Stem (kg)	Leaf (kg)	Root (kg)	Total Biomass (kg)	NPP (tons C ha^{-1} yr^{-1})
Landscape architecture 1	6.6	30.0	15.0	42.6	0.164
Landscape architecture 2	15.7	41.3	23.0	80.0	0.071

3.5. Biological Habitat Functions

Totals of 26, 33, 20, and 24 plant species were recorded at the ecological restoration site, landscape architectures 1 and 2, and the reference site, respectively. Insects at the ecological restoration site, landscape architectures 1 and 2, and the reference site consisted of 367 individuals of 45 species, 374 individuals of 41 species, 159 individuals of 37 species, and 111 individuals of 41 species, respectively. For plant species, the reference site and ecological restoration site showed similar trends in species evenness and richness according to the slopes of the rank–dominance curves, whereas in the case of insects, the slope of the ecological restoration site was shallower than that of the reference site (Figure 9, Appendix A).

The density of the woody plants surveyed at the ecological restoration site was 2491 ha^{-1}. This density was composed of only Korean red pine (*P. densiflora*). The relative importance of the plants at the ecological restoration site was higher in the order of *P. densiflora* (79.5%), *Q. acutissima* (6.4%), *Festuca arundinacea* (3.1%), and *Kalimeris yomena* (2.6%) (Appendix A).

The woody plants of landscape architecture 1 consisted of a single species, *Syringa dilatata*, and herbaceous plants dominated the site. The relative importance of the plants in landscape architecture 1 was in the order of *Zoysia japonica* (65.1%), *S. dilatata* (13.5%), *Abeliophyllum distichum* (6.0%), and *Thymus quinquecostatus* (5.5%) (Appendix A).

Landscape architecture 2 was covered with only herbaceous plants, with relative importance in the order of *Setaria viridis* (30.7%), *Hemerocallis fulva* (13.0%), *Oenothera biennis* (11.6%), and *Caryopteris incana* (10.1%).

The density of the woody plants that appeared at the reference site, the pine forest (20 × 20 m), was 2050 ha^{-1}. The relative importance of the woody plants in the pine forest

was *P. densiflora* (72.4%), *Q. variabilis* (17.1%), *Q. mongolica* (3.3%), *Lindera obtusiloba* (0.8%), *Prunus serrulata* var. *pubescens* (0.8%), and *Lespedeza cyrtobotrya* (0.7%) (Appendix A).

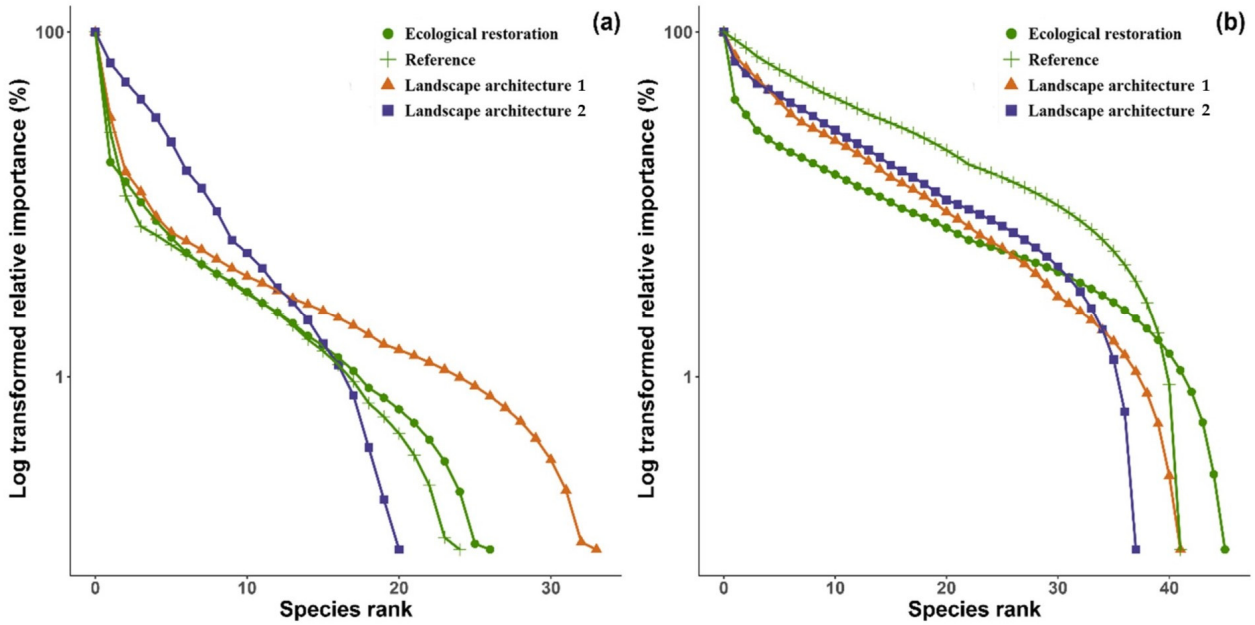


Figure 9. Species rank–dominance curves among the study sites for (**a**) plants and (**b**) insects.

Comparing the insect fauna at the species level at the ecological restoration site, the importance of *Aphidoidea* spp. was the highest at 67.3%, followed by *Microdrosophila cristata* (6.3%) and *Camponotus kiusuensis* (3.0%). At the reference site, *Aphidoidea* spp. had the highest importance value at 17.1%, followed by *Agromyzidae* spp. (14.4%) and *Camponotus kiusuensis* (9.0%). At landscape architecture 1, *Aphidoidea* spp. had the highest importance level at 36.4%, followed by *Drabescus femoratiformis* (11.2%) and *Tephritidae* spp. (8.6%). At landscape architecture 2, *Yemma exilis* showed the highest importance value at 32.1%, followed by *Drabescus femoratiformis* (10.1%) and *Psocidae* spp. (8.2%) (Appendix A, Table A2).

As a result of the stand ordination based on the vegetation data obtained from the green roof areas, the reference site and the ecological restoration site were distributed together on the left side of Axis I, and landscape architectures 1 and 2 were distributed on the right side of Axis I. They were distributed separately on the lower and upper parts, respectively, of Axis II. According to the results of stand ordination, *P. densiflora*, *Q. mongolica,* and *Lindera obtusiloba* strongly influenced the spatial arrangement of the ecological restoration site and the reference site, and *Setaria viridis* and *Zoysia japonica* affected the spatial distributions of landscape architectures 1 and 2, respectively (Figure 10a).

According to the results of the stand ordination based on the plant functional traits, the spatial distributions of the stands showed similar patterns to the results based on the species composition due to the influence of trees, mesophanerophytes (MM), and life forms in which seeds are dispersed by wind or water (D_1) (Figure 10b).

As a result of stand ordination based on insect species composition, both the ecological restoration site and the reference site were distributed on the left side of Axis I, and landscape architectures 1 and 2 were on the right side of Axis I. This was due to the influence of *Camponotus kiusuensis* (Figure 10c).

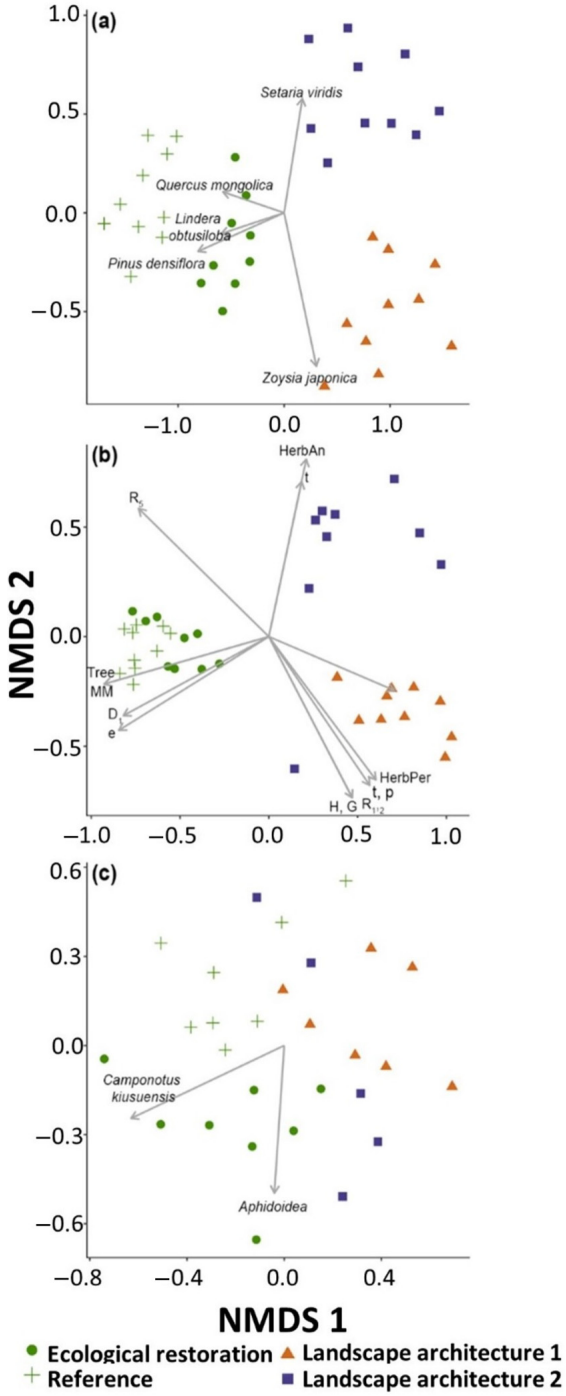


Figure 10. NMDS biplot of sites and variables. (**a**) Vegetation, (**b**) plant functional traits, and (**c**) insects. All variables had significant impacts on community differences ($p = 0.001$).

4. Discussion

4.1. Ecological Restoration and the Creation of Green Areas on Rooftops

Because rooftops of buildings are artificial spaces and the substrate used for rooftop greening is also artificial, rooftop greening was carried out based on reference information derived from a rocky mountain, which has an environment most similar to the poor conditions of roofs. This restoration method is equivalent to active restoration based on the restoration method proposed by Bradshaw [62]. In order to restore an urban ecosystem, it is necessary to imitate the structure of a natural forest established in a reference ecosystem of a similar environment [36,63,64]. Among the restoration methods for urban ecosystems,

rooftop greening should take into consideration the connectivity between the urban habitat and the nearby natural forests in order to acquire reference information most suitable for the environmental characteristics of the rooftop [65]. A process to select species from among the reference species, which can survive in human-created habitats, is also required [66,67].

For the ecological restoration of rooftops, an edaphic climax area consisting of a Korean red pine (*P. densiflora*) stand established on a rocky outcrop was selected as the reference site. Evaluating the effects of restoration after 10 years, the growth patterns of the Korean red pine were similar to those of 11-year-old pines (height: 4.0 m, D_{10}: 6.7 cm), consistent with the results of Kim et al. [68]. This result suggests that the growth conditions of the pine trees remained normal even in the harsh environments of the rooftops.

In particular, the water-use efficiency, which enables growth in dry environments over the long term and serves as a factor for determining the survival rate and productivity of plants, was lower than that of 1-year-old *Pinus contorta* (3–8 μmol CO_2 mmol H_2O^{-1}) but higher than that of 4-year-old *Pinus radiata* (about 2 μmol CO_2 mmol H_2O^{-1}) [69]. Because Korean red pines, which are known to be a drought-tolerant species, can grow by effectively controlling their stomata in harsh soil moisture conditions [70], they can play a role as a pioneer species in the development of vegetation in poor water conditions [71].

The results of this study show that the high growth rate and water-use efficiency of the planted Korean red pines stabilized the settlement on the rooftops. Furthermore, it is expected that the habitat stability of green roofs will be enhanced over time, due to the settlement of pine trees as a pioneer species.

4.2. Climate Mitigation Function of Green Roofs

Due to climate change, there has recently been a growing interest in green roofs, which are unique to the newly created carbon sink, unlike existing forest ecosystems [72]. Rooftop greening could be applied as a means of climate change adaptation for the sustainability of nature and social systems. The ecological restoration of green roofs has demonstrated an ecological function for improving the urban climate through the mitigation of the urban heat island effect [12], showing different functions depending on the greening method.

The air temperature of the ecological restoration site, measured during the summer season in the daytime, was 4 °C lower than that of the landscape architecture site and similar to the air temperature of the reference site. These results are consistent with previous studies that resulted in a lowered surface temperature with increasing biomass [35]. Compared to the low net production of the green roofs created using the existing landscape architecture methods, the ecological restoration site showed a remarkably high net production. It is judged that this was due to the influence of large ground plants, namely woody plants, at the ecological restoration site. Woody plants can lower the atmospheric temperature at the pedestrian-level better than geophytes—which are frequently planted in landscape architectures—because they provide shadows, most effectively reducing the surface radiation [73].

With a high net primary production, the ecological restoration site showed the highest soil respiration. The soil respiration rate of the ecological restoration site was more than double that of the reference site; this difference is attributed to the difference between the restored site (based on artificial substrate) and the reference site (rock outcrop area based on oligotrophic soil). These results are also related to the difference between the growth of the Korean red pine trees at the ecological restoration site and the edaphic climax stand, with dry and infertile soil, showing annual diameter growth rates of 0.6 cm per year and 0.2 cm per year, respectively.

4.3. Ecological Habitat Function of Green Roofs

The expansion of a city through land-use conversion completely changes the composition of natural and wild animal species around the city. Because the ecosystem components and structures in urban areas undergo the greatest changes due to human activities [74], green roofs restored based on reference information can function as a major element of

the urban landscape beyond the space provided just for aesthetic value and recreation. To arrive at this goal, it is necessary to acquire ecosystem information before development and to consider the connectivity with nearby natural forests [15,75]. A green roof restored to similar conditions to the natural ecosystem near the city, according to such reference information, can act as a stepping stone to provide a habitat for wild animals and plants through seed dispersal [14].

In order to evaluate the habitat function of the green roofs, stand ordination based on vegetation data was applied. The result showed that the species composition of the ecological restoration site imitating the pine stand was similar to that of the reference site. However, landscape architectures 1 and 2 differed greatly from that of the reference site in their species composition. Landscape architecture 2 was an extensive green roof and had some similar species to the reference site because of invasive species nearby. Landscape architecture 1, on the other hand, showed a great difference in its species composition, as it prevented invasive plants from entering.

Plant functional traits and environmental conditions play important roles in the formation of ecosystem functions in the restoration process, and trait-based approaches to restoration provide diverse interpretations by providing insights into community assembly and ecosystem functioning [48]. The results of stand ordination based on the functional trait composition of the plants showed more clear differences among greening methods than the results of ordination based on the composition of plant species (Figure 10). From this result, it was concluded that the similarity of the functional traits was very high. Applying ecological restoration to a green roof, which was developed using the existing landscape architecture system, showed a community assembly similar to that of the reference site. Therefore, the ecological restoration site is sufficient for ecosystem functioning.

Based on the results of the insect survey, *Aphidoidea* spp. and *Berytidae* spp., sap-sucking insects, dominated both the rooftop green areas and the reference site. All of the green roof areas had higher dominant rates of the first dominant species compared to the reference site. This is because most of the species emerge at certain times (June to July). The number of insect species was higher at the ecological restoration site than at the landscape architecture sites, since insect diversity depends on the quality and diversity of the substrate and the structure of the vegetation [24].

Carpenter ants (*Camponotus kiusuensis*), which reside both outdoors and indoors in moist, decaying, or hollow wood and are most commonly found in forest environments, were only collected from the restoration site and the reference site and were shown to be a significant indicator species. In the past, researchers believed that only the most mobile insect species could utilize green roof habitats [24]. However, recent studies have found that a wide variety of insects spontaneously colonize intensive green roofs, including medium, large, and even flightless insects that are found predominantly at the soil surface of ground-level or urban habitats [76]; a similar finding emerged in this study.

The composition and diversity of the vegetation and insects at the ecological restoration site were similar to those at the reference site, whereas the landscape architecture 1 and 2 sites, which utilized the landscape architecture method, were different from the reference site (Figures 9 and 10). These results confirm that applying the ecological restoration method for rooftop greening results in better biological habitat function than applying existing landscaping methods.

At the ecological restoration site, the soil respiration rate showed distinct seasonal changes similar to natural forests, while at sites where the existing landscape method was applied, the seasonal change in the soil respiration rate was not clear and the amount of soil respiration was significantly low (Figure 8 and Table 5). These results can be interpreted as showing a difference between the ecological restoration sites and the sites applying the existing landscaping method in the formation of the soil ecosystem and the support of biodiversity [77–80]

4.4. Selection of Plant Species Suitable for Rooftop Greening

Since the 1980s, researchers have tested many herbaceous and woody plant species in different rooftop conditions [81–85]. The composition and characteristics of green roof vegetation depend on many factors. To a large extent, the substrate depth dictates the vegetation diversity and the range of possible species. The genus *Sedum* is suitable in a shallow soil depth of 2 to 5 cm due to its fast drying speed and resistance to severe temperature changes. Grasses such as *Festuca*, *Elymus*, and *Poa* spp., geophytes such as *Iris* spp. with underground storage organs, in which the plants hold energy and water, and drought-tolerant herbaceous perennials such as *Achillea*, *Allium*, and *Andropogon* spp. can be introduced as the soil depth deepens, but undesirable weeds often also enter [86]. Further research is needed to identify suitable plant species for living roofs in many other climatic regions. Most plants for green roofs are usually selected from plant species that originate in permanently open (non-forested) habitats, such as rock outcrops, cliffs, dunes, and heathland [31].

One way to improve green roof performance is to select plant species from natural habitats with similar environmental conditions to green roofs [31,87]. Seasonal and diurnal extremes of water availability are common on granite outcrops [88], making them ideal habitats for identifying potential green roof plants [86].

In this study, reflecting the recent trend of imitating reference sites, rooftop greening was carried out by imitating a pine forest established on an outcrop of a rocky mountain as a reference site with similar conditions to the roof of a building (Figure 10). As a result, unlike the sites where the existing landscape architecture method was applied, the species composition of plants and insects resembled the reference site. Furthermore, the carbon absorption capacity and the stability of the soil were higher than those of the landscape architecture sites (Figure 8 and Table 5).

4.5. Ecosystem Services of Green Roofs

Green or vegetated roofs have great potential to restore ecosystem services to cities [18–20]. In fact, urban development, due to population concentration, has resulted in great damage to wildlife, such as the loss of habitat. Rooftop greening has reversed this trend, contributing to supporting biodiversity by providing shelter or habitats for wildlife in urban areas [13,89–91].

In addition, urbanization has caused various environmental problems due to excessive land use and energy consumption. In particular, it causes local climate change, and the effect is evaluated to be greater than the climate change effect that occurs when the carbon dioxide concentration doubles [92]. Various buildings and pavement areas have a particularly significant impact. These problems can be partially mitigated by altering the buildings' surficial properties. Roofs can represent up to 32% of the horizontal surface of built-up areas [17] and are important determinants of the energy flux and of buildings' water relations. The addition of vegetation and soil to roof surfaces can lessen several negative effects of buildings on local ecosystems and reduce the buildings' energy consumption. Green roofs are an attractive option for energy savings in the building sector. They reduce buildings' energy demand through the improvement of their thermal performance [87,93–95]. Green roofs can also be viewed as a practical tool to mitigate the urban heat island (UHI) effect, i.e., to decrease the ambient air temperature in urban areas. Several densely populated and intensely urbanized areas in the world suffer from UHI problems and the worst urban eco-environments [96,97]. Green roofs are tools that combat the UHI effect and increase the albedo of urban areas [93].

Initially, reduced stormwater runoff was usually discussed as the main effect of rooftop greening [98–101], but various effects have been revealed over time. Those benefits include air and water quality improvement [22,102,103], sound insulation [22,24,104], fire resistance [83], and longevity of the roof membrane [105]. Plants introduced for rooftop greening contribute greatly to triggering such ecosystem service functions [90,106]. In

addition, as shown in the results of this study, the effects were different depending on the vegetation introduced (Figure 8 and Table 5).

5. Conclusions and Future Plans

This study was conducted to evaluate the restoration effects of green roofs created by applying the ecological restoration method in terms of their climate mitigation function and ecological habitat function. Ecological restoration applied for rooftop greening was carried out by imitating the Korean red pine forest established on a rocky mountain similar to the rooftop. Rooftop greening using the existing landscaping method differs from our study by mainly introducing plants of the genus *Sedum* or adding some landscaping and horticultural plants. Therefore, the restoration effect was evaluated by comparing the results of this study with the results collected in natural pine forests and places created by these landscaping methods. Through monitoring, it was confirmed that the ecological restoration method could guarantee the growth of the planted species and meet the habitat function. In addition, when ecological restoration was carried out on the rooftop considering the functional characteristics of the plants, it was confirmed that it could mitigate the urban heat island phenomenon, maximize productivity, and stabilize the soil ecosystem compared to when the existing landscaping method was applied. The vegetation and insect fauna established at the ecological restoration site were more similar to those of the natural pine forest compared to those of the sites where the existing landscaping method was applied, and the diversity of insects was also higher. Considering those results, it is expected that the green roof created by applying the ecological restoration method could act as a wildlife refuge, enhancing the connectivity of the urban ecosystem as a stepping stone in the urban landscape. However, despite these positive effects, the result of evaluating the carbon budget appears as the carbon source when the heterotrophic respiration is added and the causes of the differences in soil respiration among sites have not yet been confirmed. In the future, more detailed studies of soil biota and carbon budget evaluation with a longer-term perspective are required.

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Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Species Composition of Plants at the Study Sites.

Scientific Name	Importance Value (%)			
	Restoration	Landscaping 1	Landscaping 2	Reference
Huperzia miyoshiana Ching	-	0.7	-	-
Equisetum arvense L.	-	0.4	-	-
Pteridium aquilinum var. *latiusculum* Und. ex Heller.	-	-	-	0.3
Pinus densiflora Siebold & Zucc.	79.5	-	-	72.4
Salix chaenomeloides Kimura	0.1	-	-	-
Alnus sibirica Fisch. ex Turcz.	-	-	-	0.2

Table A1. *Cont.*

Scientific Name	Importance Value (%)			
	Restoration	Landscaping 1	Landscaping 2	Reference
Castanea crenata Siebold & Zucc.	-	-	-	0.3
Quercus variabilis Blume	-	-	-	17.1
Quercus dentata Thunb.	-	-	-	0.2
Quercus acutissima Carruth.	6.4	-	-	-
Quercus mongolica Fisch. ex Ledeb.	-	-	-	3.3
Fatoua villosa Nakai	-	0.1	-	-
Persicaria japonica H. Gross ex Nakai	-	0.1	-	-
Persicaria lapathifolia Gray	-	0.1	-	-
Dianthus chinensis L.	-	0.2	-	-
Lindera obtusiloba Blume	-	-	-	0.8
Lepidium apetalum Willd.	0.4	-	-	-
Sedum kamtschaticum Fisch. & Mey.	0.2	0.3	1.0	-
Sedum latiovalifolium Y. N. Lee	-	-	3.2	-
Sedum sarmentosum Bunge	0.2	-	0.6	-
Prunus yedoensis Matsum.	0.4	-	-	-
Sorbus alnifolia K. Koch	-	-	-	0.4
Stephanandra incisa Zabel	-	-	-	0.3
Prunus serrulata var. *pubescens* (Makino) Nakai	-	-	-	0.8
Chamaecrista nomame H. Ohashi	0.4	-	-	-
Glycine soja Siebold & Zucc.	0.4	0.3	-	-
Indigofera kirilowii Maxim. ex Palib.	-	-	-	0.1
Kummerowia striata Schindl.	0.3	-	-	-
Lespedeza cuneata G. Don	0.1	-	-	-
Lespedeza cyrtobotrya Miq.	-	-	-	0.7
Trifolium repens L.	-	0.2	-	-
Oxalis corniculata L.	-	1.0	0.6	-
Acalypha australis L.	-	0.2	-	-
Euphorbia supina Raf.	-	0.8	0.8	-
Phyllanthus ussuriensis Rupr. & Maxim.	-	0.3	0.6	-
Zanthoxylum schinifolium Siebold & Zucc.	-	-	-	0.6
Rhus tricocarpa Miq.	-	-	-	0.1
Rhus javanica L.	-	-	1.3	0.2
Acer palmatum Thunb.	-	0.1	-	-
Acer buergerianum Miq.	0.1	-	-	-
Buxus koreana Nakaiex T. H. Chung & al.	1.1	-	-	-
Pachysandra terminalis Siebold & Zucc.	-	0.1	-	-
Parthenocissus tricuspidata Planch.	0.7	-	-	0.6
Viola mandshurica W. Becker	-	0.1	-	-
Viola patrinii DC. ex Ging.	-	0.3	-	-
Oenothera biennis L.	-	-	11.6	-
Styrax japonicus Siebold & Zucc.	-	-	-	0.1
Abeliophyllum distichum Nakai	-	6.0	-	-
Syringa oblata var. *dilatata* Rehder	-	13.5	-	-
Metaplexis japonica Makino	-	0.2	0.9	-
Callicarpa japonica Thunb.	-	-	-	0.1
Caryopteris incana Miq.	0.1	-	10.1	-
Mosla punctulata Nakai	-	0.1	0.2	-
Thymus quinquecostatus Celak.	-	5.5	-	-
Paulownia coreana Uyeki	-	-	-	0.1
Weigela subsessilis L. H. Bailey	-	-	-	0.2
Patrinia scabiosaefolia Fisch. ex Trevir.	0.4	-	-	-
Ambrosia artemisiifolia L.	0.1	-	-	-
Artemisia princeps Pamp.	0.6	0.8	-	-
Aster yomena Honda	2.6	-	-	-
Conyza canadensis Cronquist	-	0.2	-	-
Erigeron annuus Pers.	0.3	0.1	-	-

Table A1. *Cont.*

Scientific Name	Importance Value (%)			
	Restoration	Landscaping 1	Landscaping 2	Reference
Ixeridium dentatum Tzvelev	-	0.2	-	-
Allium senescens L.	-	-	0.4	-
Disporum smilacinum A. Gray	2.0	-	0.1	-
Hemerocallis fulva L.	-	-	13.0	-
Hosta longipes Matsum.	0.1	2.4	-	-
Lilium lancifolium Thunb.	0.2	-	2.7	-
Commelina communis L.	0.1	-	6.6	0.5
Digitaria ciliaris Koel.	-	0.1	8.7	-
Eragrostis multicaulis Steud.	-	0.1	-	-
Festuca arundinacea Schreb.	3.1	-	-	-
Miscanthus sinensis var. *purpurascens* Rendle	0.1	-	-	0.2
Phragmites japonica Steud.	-	-	6.5	-
Setaria viridis P. Beauv.	-	0.3	30.7	-
Spodiopogon sibiricus Trin.	-	-	-	0.4
Zoysia japonica Steud.	-	65.1	-	-
Cyperus amuricus Maxim.	-	0.1	0.4	-
Total (%)	100.0	100.0	100.0	100.0

Table A2. Species Composition of Insects at the Study Sites.

Scientific Name	Importance Value (%)			
	Ecological Restoration	Landscaping 1	Landscaping 2	Reference
Acrididae				
Anapodisma miramae Dovnar-Zapolskyi	-	1.9	-	-
Mongolotettix japonicas Bolivar	0.3	-	-	-
Tetrix japonica Bolivar	-	2.1	-	-
Agermyzidae				
Agermyzidae spp.	0.8	1.1	4.4	14.4
Anobiidae				
Ptilineurus marmoratus Reitter	0.3	0.3	-	-
Aphidoidea				
Aphidoidea spp.	67.3	36.4	6.9	17.1
Aphrophoridae				
Aphrophoridae spp.	-	6.7	-	-
Apidae				
Coelioxys yanonis Matsumura	-	-	0.6	0.9
Berytidae				
Yemma exilis Horváth	1.1	-	32.1	1.8
Braconidae				
Braconidae spp.	-	0.5	1.9	-
Callimomidae				
Callimomidae spp.	-	0.3	-	2.7
Chironomidae				
Chironomus plumosus prasinus	0.8	1.9	-	2.7
Chironomidae spp.	1.1	0.5	0.6	0.9
Chrysomelidae				
Phyllotreta striolata Fabricius	-	-	-	1.8
Chrysomelidae spp.	-	-	0.6	6.3
Cicadellidae				
Drabescus femoratiformis Kwon	2.2	11.2	10.1	2.7
Cicadellidae spp.	0.8	1.9	3.8	0.9
Cicadidae				
Cicadidae spp.	0.8	-	-	-

Table A2. *Cont.*

Scientific Name	Importance Value (%)			
	Ecological Restoration	**Landscaping 1**	**Landscaping 2**	**Reference**
Cixiidae				
Xestocephalus koreanus Kwon	-	-	-	0.9
Cixiidae spp.	-	2.1	-	-
Coccinellidae				
Harmonia axyridis	1.6	-	1.3	0.9
Propylea japonica Thunberg	0.3	-	-	0.9
Coreidae				
Hygia opaca	-	-	-	1.8
Delphacidae				
Sogatella furcifera Horvath	-	-	1.3	0.0
Dictyopharidae				
Dictyophara patruelis Stål	0.3	-	-	-
Drosophilidae				
Microdrosophila cristata Okada	6.3	1.1	1.3	-
Drosophilidae spp.	1.1	4.3	6.3	4.5
Eucharitidae				
Eucharitidae spp.	0.5	-	0.6	-
Eulophidae				
Brachymeria obscurata	-	-	0.6	1.8
Eulophidae spp.	1.4	0.8	-	0.9
Formicidae				
Temnothorax congruus	-	0.3	-	6.3
Temunothorax spinosior Forel	0.3	-	0.6	1.8
Camponotus kiusuensis	3.0	-	-	9.0
Formica japonica Motschulsky	1.1	1.9	1.9	-
Crematogaster teranishii Santschi	0.5	-	3.1	3.6
Gryllidae				
Teleogryllus emma Ohmachi	-	5.9	-	-
Gryllidae spp.	0.3	3.7	-	-
Inocelliidae				
Inocelliidae spp.	0.5	-	-	-
Lygaeidae				
Ninomimus flavipes Matsumura	0.3	0.5	1.3	2.7
Membracidae				
Butragulus flavipes Uhler	-	-	-	1.8
Miridae				
Harpocera koreana Josifov	0.5	-	-	-
Lygocoris hilaris Horváth	-	-	-	0.9
Muscidae				
Fannia Prisca	-	-	1.3	-
Phryganeidae				
Phryganeidae spp.	0.3	-	-	-
Pipunculidae				
Pipunculus kumamotoensis	-	-	-	0.9
Psocidae				
Psocidae spp.	-	2.7	8.2	1.8
Psychodidae				
Psychoda alternata	-	-	-	0.9
Pyrgomorphidae				
Atractomorpha lata Motschulsky	1.4	0.3	-	-
Rhopalidae				
Alloeotomus chinensis Reuter	1.4	0.5	0.6	-
Deraeocoris ulmi Josifov	0.3	-	-	0.9
Rhopalus sapporensis Matsumura	0.3	-	-	-
Stictopleurus punctatonervosus minutus	0.3	-	3.1	1.8
Trigonotylus ruficornis	-	-	0.6	-
Scarabaeidae				

Table A2. *Cont.*

Scientific Name	Importance Value (%)			
	Ecological Restoration	Landscaping 1	Landscaping 2	Reference
Blitopertha orientalis Waterhouse	0.3	-	-	-
Tenebrionidae				
Tenebrionidae spp.	0.3	-	-	-
Tenthredinidae				
Tenthredinidae spp.	-	0.3	-	-
Tephritidae				
Tephritidae spp.	0.3	8.6	3.8	-
Tettigonidae				
Gampsocleis sedakovii obscura Walker	0.3	-	-	-
Paratlanticus ussuriensis Uvarov	-	0.8	-	0.9
Hexacentrus japonicus Karny	0.3	-	-	-
Tingidae				
Stephanitis nashi Esaki	0.8	0.5	0.6	-
Tingidae spp.	-	-	-	0.9
Tiphiidae				
Tiphia ordinaria Smith	0.5	0.8	1.9	1.8
Tiphiidae spp.	-	0.3	0.6	-
Total (%)	100	100	100	100

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