diversity

Article

Plant Diversity along an Urbanization Gradient of a Tropical City

Balqis Aqila Alue [1], Noraine Salleh Hudin [1,2,*], Fatimah Mohamed [1,2], Zahid Mat Said [1,2] and Kamarul Ismail [3]

[1] Department of Biology, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, Tanjong Malim 35900, PRK, Malaysia
[2] Centre of Biodiversity and Conservation, Universiti Pendidikan Sultan Idris, Tanjong Malim 35900, PRK, Malaysia
[3] Department of Geography and Environment, Faculty of Human Science, Universiti Pendidikan Sultan Idris, Tanjong Malim 35900, PRK, Malaysia
* Correspondence: noraine@fsmt.upsi.edu.my; Tel.: +60-015-4879-7438

Abstract: This study aimed to investigate the plant diversity, plant traits, and environmental variables along the tropical urbanization gradient in Ipoh, Perak, Malaysia. The study areas comprised 12 sampling plots sized 1 km^2 that represented different urbanization intensities. Urbanization intensity was quantified as the percentage of the built-up area within a 1 km^2 area. A total of 96 woody plant species belonging to 71 genera and 42 families were found in the study areas. In general, species diversity, richness, and evenness declined significantly as urbanization intensity increased. The number of native species reduced by 67.6% when urbanization intensity increased from wildland to suburban while the non-native species remained stable along the urbanization gradient. Regarding the plant traits, tree height decreased with increasing urbanization intensity, while no significant result was found for specific leaf areas. All environmental factors were significantly associated with urbanization where air temperature and light intensity showed a positive relationship with increasing urbanization intensity while the opposite trend was found for air humidity. This study emphasizes the importance of built-up areas as the predictor of native species in the tropics. The findings of this study may help town planners and policymakers to create more sustainable urban development in the future.

Keywords: built-up area; geographical information systems (GIS); native species; plant diversity; urbanization gradient

Citation: Alue, B.A.; Salleh Hudin, N.; Mohamed, F.; Mat Said, Z.; Ismail, K. Plant Diversity along an Urbanization Gradient of a Tropical City. *Diversity* **2022**, *14*, 1024. https://doi.org/10.3390/d14121024

Academic Editors: Lucian Dinca and Mario A. Pagnotta

Received: 16 October 2022
Accepted: 21 November 2022
Published: 24 November 2022

1. Introduction

The rate of world urbanization is increasing, and by 2050 urbanization will account for 65% of the global population [1]. While urbanization frequently improves social life and living standards [2], it also has severe repercussions on humans and the natural environment [3]. Rapid urbanization can result in changes in environmental conditions [4] and degradation of the natural environment [5]. As a result of anthropogenic activities, there are drastic shifts in land use types [6,7] and this may put ecosystem services in jeopardy [8]. Ecosystem services and ecological processes depend primarily on plants, so plants must be adequately maintained and conserved [9]. Due to the importance of plants, it is also advocated that plant vegetation components should be used as a more effective metric of the ecological condition [10]. Such can be completed through vegetation monitoring which relies heavily on the analysis of plant species composition and structure [9].

Many biological processes depend on plants, and people would benefit greatly from them. For instance, plants may assist in lowering the temperature [11] controlling air pollution [12], improving the mental health of city dwellers (e.g., through horticulture and nature therapy) [13], encouraging social interactions (e.g., in community gardens) [14], and encouraging the preservation of biodiversity [15]. Given that people benefit from ecosystems, these advantages are known as ecosystem services. Therefore, it is important to maintain the plants, especially in metropolitan regions. Therefore, even though urbanization is continuously growing, we need to ensure that the ecological cycle is maintained.

Prior research on the impact of urbanization on plant diversity yielded inconsistent and contradictory results. Even though urbanization is expected to impact plant diversity [16] plant diversity patterns along an urbanization gradient vary greatly from study to study, rendering that plant diversity investigations and their relationship with urbanization gradient remained unclear [17]. For example, some studies discovered that plant diversity increases in tandem with urbanization, e.g., [17–19] which could be attributable to the unintended introduction of non-native plant species into urban areas [20]. Meanwhile, other research revealed that plants tend to peak, particularly around intermediate levels of urbanization, i.e., Godefroid and Koedam [21]; Ranta and Viljanen [22]; Zerbe [23]. This research validated the intermediate perturbation theory, suggesting that moderate perturbation would enable more species to survive than high or low perturbation [24]. On the contrary, other studies found that plant diversity increases with increasing distance from the metropolitan area [25], and this could be related to the decline of habitable spaces in urban areas, which generally leads to a decrease in plant diversity [26]. Because of the severe environmental changes brought about by urbanization, various plant diversity patterns emerge as urbanization increases.

Previous studies on plant diversity patterns along an urbanization gradient have mainly been conducted in temperate regions, e.g., Belgium [21], Finland [22], Zerbe [23], Kazakhstan [25], North America [26], Germany [27], Switzerland [28], subtropical region-e.g., from China by Wang et al. [17], Tian et al. [29], Yang et al. [30], and only a few were performed in the tropical region, e.g., Nigeria [10], India [19] and Malaysia [31]. Those in Malaysia investigated plant diversity only in wildlands, such as studies by Suratman [32], Onrizal et al. [33], and Ghollasimood et al. [34], while others were limited to green spaces in city centers only, such as studies by Nabilla et al. [35], Kanniah [36], Kanniah & Ho [37], and Rostam et al. [38]. Moreover, an earlier study in Malaysia by Rahmad & Akomolafe [31] that compared plant diversity between different urbanization intensity categorized the urbanization levels only based on visual observation and subjective perception, thus causing difficulty to compare the findings. This lack of knowledge becomes a concern because the tropical region does not only serve as habitats for a high number of plant species, but some tropical countries, especially those in the Southeast Asia, are experiencing urbanization at an accelerating rate [37]. Since previous studies showed mixed results on how urbanization affects plant diversity, there is a need to confirm how plant communities respond to urbanization in tropical cities.

Fundamentally, plant traits are correlated to plant strategies [38], which are responsible for the adaptations of plants to the environmental changes [3,17]. Palma et al. [39] have stated that plant traits determine whether the plant species will survive in the long run especially in a harsh condition. Such harsh conditions could be induced by changes in environmental conditions when natural landscapes undergo disturbance caused by urban development. Eventually, this scenario will affect the abundance and diversity of plants in the cities. In response to the ecosystem change, the functional traits of organisms that stimulate their development and growth are essential in determining which species thrive and cease to exist [40].

Hence, the aims of this study were (i) to explore plant diversity patterns along a tropical urbanization gradient; (ii) to examine the relationship between urbanization intensity with plant traits (tree height and specific leaf area (SLA)); and (iii) to investigate the variations in environmental conditions (air temperature, air humidity, and light intensity) along the urbanization gradient. To address these aims, data on plant diversity, plant traits, and environmental variables were obtained from 12 sampling plots that sized 1 km^2. These plots represented different urbanization intensities according to the percentage of the built-up area of the plots. Regression analyses were later performed, which involved the data on plant diversity, plant traits, and environmental variables against the percentage of the built-up area of each plot.

2. Materials and Methods

2.1. Study Area

We conducted fieldwork in the Ipoh city council in the Perak State of Peninsular Malaysia. Perak State was chosen because it is able to serve as a "regional state", with Ipoh serving as the core urban center [41]. Additionally, anthropogenic activities have resulted in massive landscape modifications and abrupt changes in land use in Perak [42]. For example, Perak state has lost about 16 percent (189,423 ha) of its forest cover in the last 29 years [42]. Moreover, Ipoh is known as a phytogeography ally unique area with three elements, including limestone flora [43], the Perak sub-province that influences the Sumatran flora [44], and the Seasonal Asiatic Intrusion that is enclave invasion by Burmese-Thai floristic elements [43]. Thus, Ipoh is an ideal place to study the impacts of urbanization on plant diversity.

This research was performed in four distinct urbanization settings, i.e., wildland, rural, suburban, and urban areas in Ipoh City Council in the Perak state of Peninsular Malaysia (101°3′57.118747″–101°3′57.118747″ E, 4°28′26.148383″–4°28′26.148383″ N, Figure 1). Ipoh is located between the two major cities in Malaysia, which are Kuala Lumpur and Penang, and thus serves as a significant hub for road transportation across west Malaysia. Most economic ventures concentrate in Ipoh due to the large population and high volume of road traffic [45]. The Ipoh city is bordered by limestone hills which can also be found throughout the northeast, east, and southeast suburban areas. Ipoh has the typical climate of a rainforest. The monthly relative humidity of the city shows slight differences while the temperature varies between 20.7 °C to 30.6 °C throughout the year. With an average of 200 mm (7.9 in) of rain per month and 2427.9 mm (95.59 in) of rain annually, Ipoh experiences high rainfall over the year. October is the most humid month for Ipoh city, with rain falling at an average of 297.2 mm (11.70 in). In addition to that, the driest month is January, with an average of 132.3 mm (5.21 in) of rainfall.

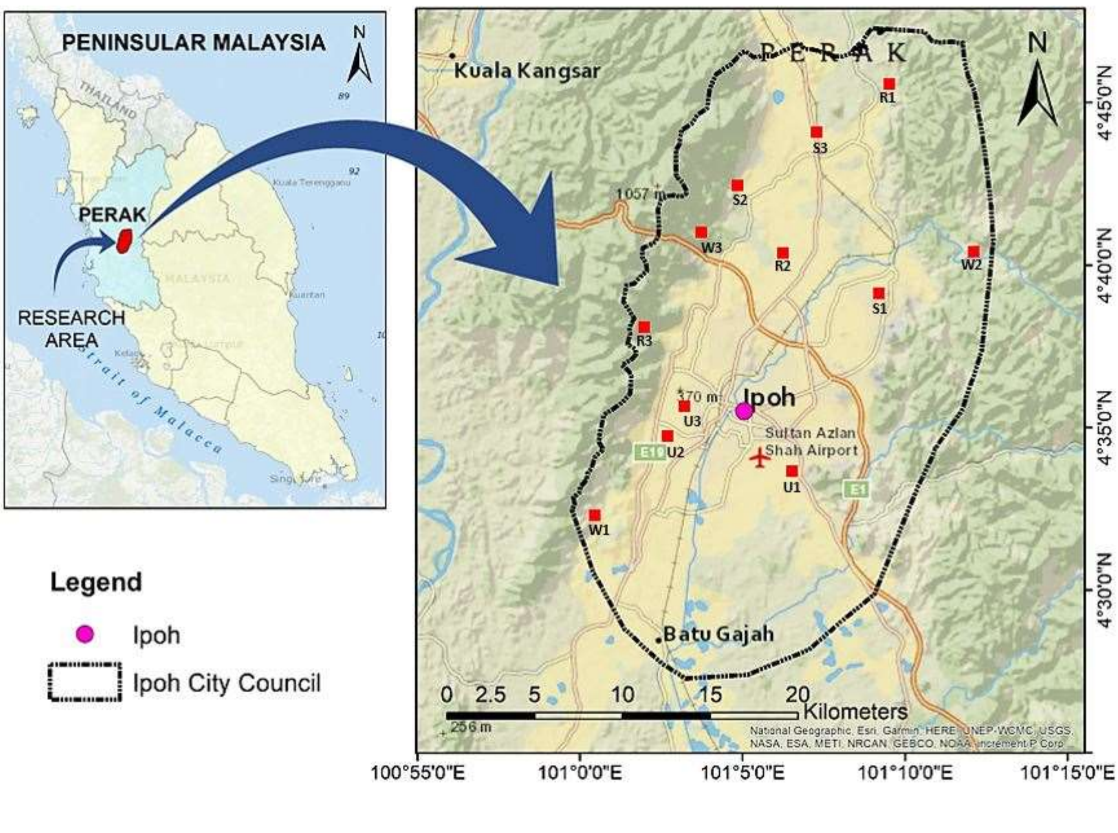

Figure 1. Study area in Ipoh, Perak in Peninsular Malaysia where 12 sampling plots represented an urbanization gradient. W: wildland, R: rural, S: suburban, U: urban.

2.2. Urbanization Intensity Quantification

The urbanization intensity of sampling sites was determined based on the percentage of the built-up area within a 1 km^2 area. As built-up percentage can be quantified in any urban environment, regardless of geographical, cultural, and historical variation, the built-up percentage is an adequate proxy of urbanization intensity. The urbanization intensity quantification was performed in ArcGIS version 10.8 software using the Ipoh land use map issued by Malaysia's Federal Department of Town and Country Planning. The map is composed of 12 distinct attributes of land use. These characteristics were classified into two categories, which were the green areas and built-up areas. The built-up areas consisted of seven features which were manufacturing, service and infrastructure, commercial, institutional, mixed construction, transport and mobility, and residential or housing areas. On the other hand, forests, parks, recreation centers, undeveloped land, and farming areas made up the green areas. The water body was exempted from all categories. To achieve unbiased sampling, tessellation of the map consisting of 1 km $\times$ 1 km grid squares was completed where these squares corresponded to the size of the study plot. Then, the percentage of built-up area of each square was calculated. Following the urbanization categorization using the built-up percentage of the 1 km^2 plots by [46], four categories of urbanization intensity were identified, which were the wildland (0–2% built-up percentage), rural (5–20%), suburban (30–50%) and urban areas (>50%). The study plots were selected randomly, and each category was replicated twice, which created a total of 12 sampling plots.

2.3. Field Sampling

Twelve sampling plots sized 1 km^2 were randomly established in Ipoh, Perak, to represent an urbanization gradient (Figure 1). Previous study suggested that an area that sized 500–1000 m^2 with a minimum aspect ratio of 1:20 of a rectangular plot is sufficient for studies on tropical plant diversity [47]. To increase coverage of area sampled within a plot, this study used 40 subplots sized 1 m $\times$ 25 m that were randomly positioned within the plot, which produced a total sampling area of 1000 m^2 per plot. Any plants with a diameter at breast height (DBH, 1.3 above the ground) of 5 cm and above in the subplot were included as samples. The number of individuals per species was recorded and each species was identified by a plant taxonomist from the Forest Research Institute Malaysia (FRIM). We determined the nativity status of plant species based on the Royal Botanic Garden database.

2.4. Plant Traits

Plant height and SLA (mm^2 mg^{-1}) represented the functional traits of the plant species. The maximum value of tree height and SLA were quantified using a standardized method [48]. To calculate SLA, one healthy leaf was collected from each of the five mature individuals [49]. The leaf samples should be relatively young (presumably more photosynthetically active) and carefully selected from fully expanded and hardened leaves of adult plants growing in light or directly proportional optimal conditions [48]. When feasible, leaves with visible signs of a disease or a thick cover of epiphyllous were avoided. Following that, carefully selected leaves were wrapped in moist paper, placed in sealed plastic bags to minimize water loss during transpiration, and kept in a cool box before being transferred to the laboratory to measure leaf area [48]. The selected leaves were digitally scanned, and the leaf area was estimated using the ImageJ software. The leaves were then oven-dried for 72 h at 60 °C before being weighed [49], and the SLA was calculated as area divided by dry mass.

2.5. Environmental Conditions

Air temperature, relative humidity, and light intensity were measured at the study sites to represent the environmental variables. At the height of 1.3 m above the ground [50], the readings were taken at noon [51] on the day with no clouds visible and clear skylight [52].

The 1 km^2 plot was divided into five equal sections, each with a measurement station spaced 200 m apart. The environmental variables were measured three times at each location.

2.6. Plant Species Richness, Diversity and Evenness along the Urbanization Gradient

Three indices were used to define the plant species diversity in each plot: the Shannon–Wiener species diversity index (H′), plant species richness, evenness index.

2.6.1. Species Richness

The species richness of plant was determined by Margalef's index of richness, Dmg [53]. Given as:

$$\mathrm{Dmg} = \frac{(\mathrm{S}-1)}{\ln \mathrm{N}} \tag{1}$$

where S = number of species in total, and N = total number of individual species in a sampling plot.

2.6.2. Species Diversity

Since species diversity is regularly used as an ecological indicator, various diversity indices can be used to examine various features of group structure; nonetheless, the Shannon–Weiner index is the most frequently used as a diversity indicator [54]. This study measured species diversity between urbanization intensity using the Shannon–Weiner index since it is widely used. This index takes both species abundance and species richness into account.

Shannon–Weiner diversity index (H′) was calculated using the following equation [54].

$$\mathrm{H}' = -\sum_{\mathrm{i}=1}^{\mathrm{S}} \mathrm{Pi} \ln \mathrm{Pi} \tag{2}$$

where H' = the species diversity, and Pi = the proportion of species i relative to the total number of species. The resulting product was summed across species and multiplied by -1.

2.6.3. Species Evenness

Species evenness index (J) was used to calculate how evenly the species were distributed within the study area [55]. Species evenness was calculated as:

$$\mathrm{J} = \frac{\mathrm{H}'}{\mathrm{H}'\,\mathrm{max}} \tag{3}$$

where J = Pielou's evenness, H' = Shannon diversity index, H' max = In S (number of species).

2.7. Statistical Analysis

Linear regression was used to analyze the influence of urbanization intensity on plant diversity, richness, and evenness using IBM SPSS Statistics version 24. To understand how urbanization affects the number of native and non-native plant species along the urbanization gradient, two separate analyses of linear regression were performed with the percentage of built-up area and number of native and non-native species as the variables. Since the regression analysis involving the native species obtained a significant result, a one-way ANOVA was performed to compare the number of native species between different urbanization settings (urban, suburban, rural, and wildland). Then, we performed Tukey HSD test to determine which urbanization level significantly reduce the number of native species. Regarding plant functional traits (tree height and SLA) and environmental factors (air temperature, relative humidity, and light intensity), these variables were correlated with the percentage of built-up area using Pearson's correlation.

3. Results

Overall, in all 12 sampling plots which covered an area of 0.1 hectares, a total of 96 woody plant species families with a DBH of 5.0 cm or greater belonging to 71 genera, and 42 were found from the urban area, suburban, rural, and wildland (Table 1). Based on the total number of families obtained from this study, it encompassed 16.94% of the entire families of flora recorded by Turner [56] in Peninsular Malaysia while the 71 genera represented 4.24% of the total of 1674 genera reported. The number of species found in this study comprised 1.16% of the total 8290 species documented in Peninsular Malaysia. However, it should be noted that Turner [56] had included all types of plant species in the checklist, whereas the present study only collected the species with a DBH of 5 cm or greater.

Table 1. Plant species and their abundance in urban, suburban, rural, and wildland areas in Ipoh, Perak, Malaysia.

No.	Family	Plant Species	Abundance				Nativity Status
			U	S	R	W	
1	Anacardiaceae	*Buchanania arborescens* (Blume) Blume				31	N
2	Anacardiaceae	*Mangifera indica* L.	55	62	71	102	A
3	Anacardiaceae	*Swintonia floribunda* Griff.				26	N
4	Annonaceae	*Monocarpia marginalis* (Scheff.) J. Sinclair				17	N
5	Annonaceae	*Polyalthia cauliflora* Hook.f. & Thomson				35	N
6	Apocynaceae	*Alstonia angustiloba* Miq.		7			N
7	Apocynaceae	*Alstonia spatulata* Blume				76	N
8	Apocynaceae	*Plumeria alba* L.	7				A
9	Araliaceae	*Arthrophyllum diversifolium* Blume				47	N
10	Asteraceae	*Chromolaena odorata* (L.) R. M. King & H. Rob.		17			A
11	Bignoniaceae	*Tabebuia rosea* (Bertol.) DC.	10			21	A
12	Calophyllaceae	*Mesua ferrea* L.				28	N
13	Cannabaceae	*Trema tomentosa* (Roxb.) Hara				28	N
14	Caricaceae	*Carica papaya* L.	11	12			A
15	Celastraceae	*Salacia maingayi* M. A. Lawson				41	N
16	Combretaceae	*Terminalia mantaly* H. Perrier	8	11			A
17	Dipterocarpaceae	*Dipterocarpus oblongifolius* Blume				28	N
18	Dipterocarpaceae	*Shorea bracteolata* Dyer				17	N
19	Dipterocarpaceae	*Shorea hopeifolia* (F.Heim) Symington				39	N
20	Dipterocarpaceae	*Shorea multiflora* (Burck) Symington			17		N
21	Euphorbiaceae	*Hura crepitans* L.	22		27		A
22	Euphorbiaceae	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.			58	98	A
23	Euphorbiaceae	*Macaranga denticulata* (Blume) Müll.Arg.		6			N
24	Euphorbiaceae	*Macaranga tanarius* (L.) Müll. Arg.		13	101	67	A
25	Euphorbiaceae	*Mallotus muticus* (Müll. Arg.) Airy Shaw		13	28		N
26	Euphorbiaceae	*Microdesmis caseariifolia* Planch. ex Hook.				29	N
27	Fabaceae	*Adenanthera pavonina* L.	33	14			N
28	Fabaceae	*Acacia auriculiformis* A. Cunn. ex Benth.		35	38	48	A
29	Fabaceae	*Acacia mangium* Willd.		41		35	A
30	Fabaceae	*Aganope thyrsiflora* (Benth.) Polhill				28	N
31	Fabaceae	*Bauhinia purpurea* L.			18		A
32	Fabaceae	*Caesalpinia sappan* L.	12				A
33	Fabaceae	*Millettia pinnata* (L.) Panigrahi				33	N
34	Fabaceae	*Parkia speciosa* Hassk.		10			N
35	Fabaceae	*Samanea saman* (Jacq.) Merr.	15				A
36	Guttiferae	*Garcinia mangostana* L.			24	33	N
37	Hypericaceae	*Cratoxylum formosum* (Jack) Benth. & Hook.f. ex Dyer				27	N
38	Hypericaceae	*Cratoxylum maingayi* Dyer				24	N
39	Ixonanthaceae	*Ixonanthes icosandra* Jack				30	N
40	Ixonanthaceae	*Ixonanthes reticulata* Jack			16		N
41	Lamiaceae	*Vitex pinnata* L.				26	N
42	Lauraceae	*Beilschmiedia perakensis* Gamble				47	N

Table 1. *Cont.*

No.	Family	Plant Species	Abundance				Nativity Status
			U	S	R	W	
43	Lauraceae	*Cinnamomum javanicum* Blume				20	N
44	Lauraceae	*Cinnamomum iners* Reinw. ex Blume			42	53	N
45	Lauraceae	*Cinnamomum verum* J.Presl			31		A
46	Lecythidaceae	*Barringtonia racemosa* (L.) Spreng.				29	N
47	Malvaceae	*Durio zibethinus* Murray		13	70	43	N
48	Malvaceae	*Hibiscus rosa-sinensis* L.		8			A
49	Malvaceae	*Microcos tomentosa* Sm.		15	22	39	A
50	Melastomataceae	*Pternandra coerulescens* Jack				37	N
51	Meliaceae	*Azadirachta indica* A.Juss.	8	11			A
52	Meliaceae	*Sandoricum koetjape* Merr.				23	N
53	Meliaceae	*Swietenia macrophylla* G.King				40	A
54	Moraceae	*Artocarpus elasticus* Reinw. ex Blume		12			N
55	Moraceae	*Artocarpus heterophyllus* Lam.		5	19	27	A
56	Moraceae	*Artocarpus integer* (Thunb.) Merr.			46	98	N
57	Moraceae	*Ficus aurata* (Miq.) Miq.		35		47	N
58	Moraceae	*Ficus benjamina* L.		6		22	N
59	Moraceae	*Ficus elastica* Roxb. ex Hornem.			16		N
60	Moraceae	*Ficus hispida* L.fil.			41	29	N
61	Moraceae	*Ficus magnoliifolia* Blume				21	N
62	Moraceae	*Ficus racemosa* L.				23	N
63	Moraceae	*Ficus religiosa* L.			16	22	N
64	Moraceae	*Ficus sinuata* Thunb.				28	N
65	Moraceae	*Streblus elongatus* (Miq.) Corner				92	N
66	Moringaceae	*Moringa oleifera* Lam.	9				A
67	Muntingiaceae	*Muntingia calabura* L.		33	39		A
68	Myrtaceae	*Syzygium aqueum* (Burm.fil.) Alston	7			32	N
69	Myrtaceae	*Syzygium grande* (Wight) Walp.			31	39	N
70	Myrtaceae	*Syzygium myrtifolium* Walp.				29	N
71	Myrtaceae	*Syzygium valdevenosum* (Duthie) Merr. & Perry				25	N
72	Myrtaceae	*Syzygium zeylanicum* (L.) DC.			25		N
73	Olacaceae	*Ochanostachys amentacea* Mast.				61	N
74	Opiliaceae	*Champereia manillana* (Blume) Merr.				24	N
75	Ochnaceae	*Ochna kirkii* Oliv.		8			A
76	Oxalidaceae	*Sarcotheca griffithii* (Planch. ex Hook.fil.) Hallier fil.				19	N
77	Passifloraceae	*Paropsia vareciformis* (Griff.) Mast.				25	N
78	Pentaphylacaceae	*Eurya acuminata* DC.				39	N
79	Phyllanthaceae	*Antidesma cuspidatum* Müll.Arg.				22	N
80	Phyllanthaceae	*Aporosa penangensis* (Ridl.) Airy Shaw				19	N
81	Phyllanthaceae	*Aporosa symplocoides* (Hook.f.) Gage				20	N
82	Phyllanthaceae	*Baccaurea parviflora* (Müll.Arg.) Müll.Arg.				34	N
83	Phyllanthaceae	*Commersonia bartramia* (L.) Merr.			13		A
84	Polygalaceae	*Xanthophyllum affine* Korth. ex Miq.				30	N
85	Rhamnaceae	*Ziziphus mauritiana* Lam.			21		N
86	Rhizophoraceae	*Pellacalyx saccardianus* Scort.				33	N
87	Rubiaceae	*Aidia densiflora* (Wall.) Masam.	7				N
88	Rubiaceae	*Morinda citrifolia* L.	15		22	25	N
89	Rubiaceae	*Morinda elliptica* (Hook.f.) Ridl.				28	N
90	Rubiaceae	*Pertusadina eurhyncha* (Miq.) Ridsdale				19	N
91	Sapindaceae	*Nephelium lappaceum* L.		25	50		N
92	Sapindaceae	*Pometia pinnata* J.R.Forst. & G.Forst.				29	A
93	Sapotaceae	*Mimusops elengi* L.				35	N
94	Sapotaceae	*Palaquium gutta* (Hook.) Baill.				60	N
95	Symplocaceae	*Symplocos cochinchinensis* (Lour.) Moore				33	N
96	Ulmaceae	*Gironniera nervosa* Planch.				38	N

Note: U = urban, S = suburban, R = rural and W = wildland; N = native species, A = non-native species.

3.1. Relationship between Urbanization and Plant Diversity, Richness, and Evenness

Wildland had the greatest number of species, and the highest species richness, evenness, and diversity (d = 8.58, J′= 0.97, H′ = 4.11). Rural was the second highest in species richness, evenness, and diversity (d = 3.68, J′ = 0.95, H′ = 3.10), followed by suburban (d = 3.49, J′ = 0.93, H′ = 2.95) and urban (d = 2.41, J′ = 0.90, H′ = 2.38) (Table 2). This study found that plant diversity ($r = -0.781$; $p = 0.003$), richness ($r = -0.0842$; $p = 0.001$), and evenness ($r = -0.901$; $p < 0.001$) significantly decreased when urbanization intensity increased (Figure 2).

Table 2. Diversity indices in urban, suburban, rural, and wildland areas in Ipoh, Perak, Malaysia. See Table S1 for details on the native and non-native species.

	Urban	Suburban	Rural	Wildland
Number of species	19	28	36	79
Number of native species	6	15	22	68
Number of non-native species	13	13	14	11
Number of individuals	219	412	902	2472
Number of families	11	13	16	35
Shannon, H′	2.38	2.95	3.10	4.11
Evenness, J	0.90	0.93	0.95	0.97
Margalef's, Dmg	2.41	3.49	3.68	8.58

In addition, native species was the highest in the wildland while the non-native species were dominant in the urban area. A regression analysis on the number of native plant species against the built-up percentage yielded a significant negative relationship ($r = -0.730$; $p = 0.007$) whereby the built-up percentage explained 53.3% of the variation in the number of native species. To find out at what urbanization level the number of native species significantly reduce, a one-way ANOVA analysis was performed. Overall comparison between the number of native species in urban, suburban, rural, and wildland found a significant difference ($F(3,8) = 38.146$, $p < 0.001$). Further analysis using the Tukey HSD test indicated that the number of native species significantly reduced in the rural area (M = 7.333, SD = 1.528) in comparison to the wildland (M = 22.667, SD = 4.509) (Table 3) by 67.6%. No further decline was found since the numbers of native species between rural, suburban (M = 5.000, SD = 1.732), and urban (M = 2.000, SD = 1.000) areas were statistically similar (Table 3).

Table 3. Multiple comparisons on the number of native species in urban, suburban, rural, and wildland areas in Ipoh, Perak, Malaysia.

Urbanization Setting		Mean Difference (I-J)	Std. Error	Sig.
I	J			
Wildland	Rural	15.33333	2.10819	0.000 *
	Suburban	17.66667	2.10819	0.000 *
	Urban	20.66667	2.10819	0.000 *
Rural	Suburban	2.33333	2.10819	0.696
	Urban	5.33333	2.10819	0.129
Suburban	Urban	3.00000	2.10819	0.521

* The mean difference is significant at the 0.05 level.

On the other hand, no significant relationship between the number of non-native species and the built-up percentage was found ($F(3,8) = 0.083$, $p = 0.967$). The non-native species which were found in great numbers in urban areas of Ipoh were *Terminalia mantaly*, *Mangifera indica*, *Caesalpinia sappan*, *Azadirachta indica*, *Moringa oleifera*, *Tabebuia rosea*, *Samanea saman*, *Hura crepitans*, *Carica papaya*, and *Plumeria alba.* Meanwhile, *Morinda citrifolia*, *Syzygium aqueum*, *Adenanthera pavonina*, *Aidia densiflora*, and *Morinda citrifolia* were the native species that successfully survived in the urban environment.

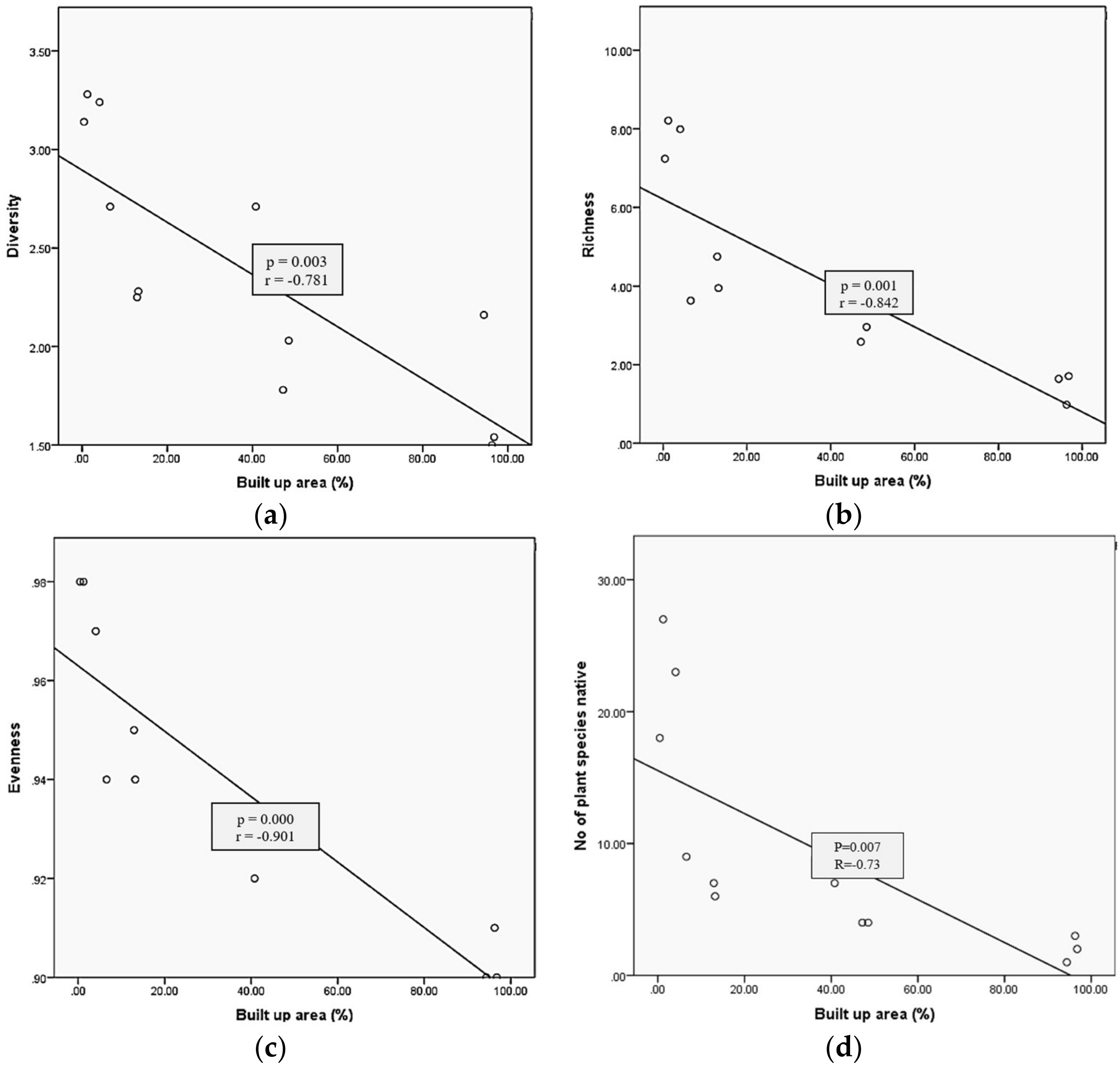

Figure 2. Relationships between the percentage of built-up area and (**a**) plant diversity; (**b**) plant richness; (**c**) plant evenness; and (**d**) plant native (species).

3.2. Relationship between Urbanization with Plant Traits and Environmental Conditions

Regarding plant trait, we found a significant relationship between the percentage of built-up area and plant height (r = −0.656, p = 0.021; Figure 3a) but not SLA (r = 0.354, p = 0.260; Figure 3b). All environmental conditions (temperature: r = 0.809, p = 0.001, Figure 3c; air humidity: r = −0.859, p < 0.01, Figure 3d; and light intensity: r = 0.769, p = 0.003, Figure 3e) were significantly correlated with the percentage of the built-up area.

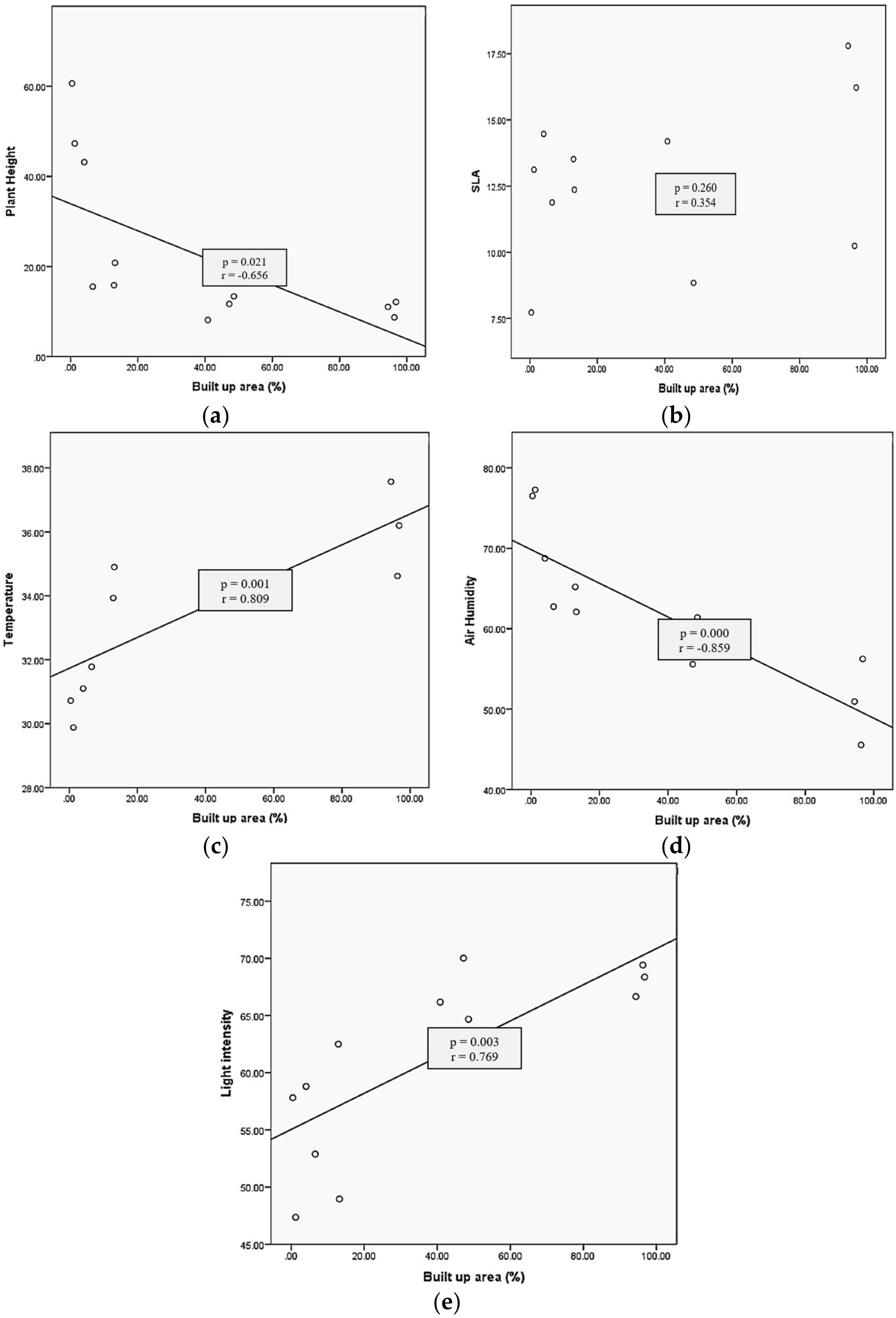

Figure 3. Relationship between percentage of built-up area and (**a**) plant height (m); (**b**) SLA; (**c**) temperature (°C); (**d**) air humidity (%); and (**e**) light intensity (Klux).

4. Discussion

4.1. Effect of Urbanization on Plant Diversity

The study revealed the pattern of plant diversity as a function of the urbanization gradient, and the findings showed that as urbanization increases, plant diversity decreases. Most notably, the findings of this study contradict the prior reports on diversity gradient in cities with rising plant species richness in urban areas and most of the studies are coming from temperate regions such as China and Germany as Wang [17], Čeplová [18], and McKinney [57]. The increase in plant diversity in urban areas could be attributed to various factors. For instance, the urban landscape is highly heterogeneous, providing diverse habitats for various plant species [58]. Urban areas typically include a variety of land use and land cover types. Hence, these land attributes and their spatial compositions are likely to promote plant diversity [59]. Following that, urban socioeconomic conditions, cultural diversity, and land use management are all essential elements determining the plant diversity pattern along the urbanization gradient [60]. Furthermore, the unintended introduction of many non-native species into urban regions has been identified as one of the most fundamental causes contributing to high plant variety in urban environments [61]. Hence, all these factors may work in tandem to establish plant diversity [62].

According to earlier research, cities appear to enhance plant diversity [19]. However, this is not the case in Ipoh, Perak. From 1850 to 1930, the tin industry expanded and resulted in the massive migration of Chinese workers to tin mining industrial towns in Perak. Thus, Ipoh, Perak was recognized as one of the greatest cities in the country from 1911 to 1931 and was primarily involved with tin mining. Tin production was favorably associated with urban population development; hence, as Malaysia develops, more people will relocate to and dwell in places like Ipoh city [63]. In accordance with the mission of becoming a developed country, these countries' industrial, transportation infrastructure, and major construction activities have resulted in massive land clearing. As a result of the high population, the percentage of built-up areas in urban areas increased; hence, Perak has experienced massive landscape changes and drastic changes in land use/cover due to anthropogenic activities [41]. Meanwhile, Hosni et al. [64] stated that during the last 20 years, a significant quantity of forested land had been lost by 183.12 hectares, while construction and development land has increased significantly by 157.12 hectares in Ipoh Perak. A common outcome of urbanization is the substantial loss of plants, leading to further negative impacts on the natural ecology [6].

Based on the regression analysis between plant diversity and the percentage of built-up area, it appears to be negatively related, like what was found by Vakhlamova et al. [25], Aronson et al. [61], and McKinney [65]. This demonstrates that as the percentage of built-up area increases, plant diversity decreases in Ipoh, Perak. Similarly, the number of native species was significantly lower in areas with higher urbanization intensity. This result is aligned with the earlier findings by Aronson et al. [16], Blouin [20], Ranta [22], and Vakhlamova [25] that also highlighted that native species were more prevalent in locations with less development, such as rural area or wildland. Previous studies have demonstrated that the intensively "constructed" landscape of urban cores has the poorest species diversity along the urbanization gradient [65]. This could be caused by a significant reduction inhabitable land for plants in highly populated places, high coverage of impermeable surfaces in urban areas, which diminish and fragment plant-able space, and the frequent stomping of vegetated areas [25]. Moreover, changes in landscape patterns due to population growth and urbanization significantly impact the dispersion of plant diversity [66]. Most crucially, urban fragments reduce the remaining space for plant species [24]; thus, plant species requiring much space have difficulty surviving [67]. Furthermore, habitat fragmentation results in smaller patches, lowering habitat quality and cutting down the number of plants in the patches, leading to loss of plant diversity [68].

Only 25 plant species are listed as non-native out of 96 plant species found in our study areas, but these species were distributed evenly along the urbanization gradient. Human introductions and plants' ability to utilize new resources in urban settings could probably be the reasons for the occurrence of non-native species. The non-native species that thrived in the rural, suburban, and urban areas of Ipoh were ornamental plants; hence, human introduction plays a vital role in the establishment of these plant species in urban areas. Those found in wildlands could also be the result of human activities because the three wildland areas were recreation forests. Thus, the unintentional introduction by humans such as through transportation may explain this finding.

Non-native species are considered an emerging risk of harm to biodiversity at spatial and temporal scales [69]. However, it is unlikely that the decline of native species with the increasing urbanization intensity was caused by the competition with the non-native species since the number of non-native species was similar along the urbanization gradient. Hence, this emphasizes the importance of built-up areas as the predictor of plant diversity along the urbanization gradient.

4.2. Changes in Plant Functional Traits along Urbanization Gradient

Urbanization could act as a filter for plant species by altering the physical environment since it may affect the plant structure and functional traits which will result in the alteration of ecosystem services [3]; thus, an analysis of plant traits would be beneficial to understand how plants respond towards urbanization. In different ecosystems, functional traits are increasingly considered good indicators of the effect of biodiversity on natural ecosystems and ecosystem services [70]. Furthermore, studying the relationship between plant traits at community levels is also pivotal for connecting the processes that determine composition and function [71].

Plant height was negatively correlated with urbanization intensity in this study, resulting in only shorter plants being discovered in urban areas, whereas taller plant species were more common in the wildland. Temperatures are expected to be higher in cities compared to non-urban areas as mentioned in past studies [72,73]. Referring to the previous studies by Lüttge & Buckeridge [74], in these low-altitude urban plains, top overgrowth is getting more apparent and height restrictions are in place. This is explained by water stress, which is more intense at the tops of trees due to the influence of gravity. Therefore, the solution to temperature-related water stress is a reduction in tree top heights from the ground. The tops of trees at different heights have similar leaf water relations. They are controlled by tree top height, under the stress of drought brought on by temperature.

Other than that, as temperature increases in urban areas, plant growth and development will be adversely affected, resulting in smaller and shorter plants, slower reproductive production, lower yield capability [75], and short-lived species [4]. However, several studies, such as those by Song et al. [3], Cochard et al. [49], and Williams et al. [76] are not parallel with this finding. According to earlier studies, urbanization favors taller species in response to urban pressure, which have a substantial competitive advantage, whereas short species are more prone to extinction in urban environments [76]. The variations in these results could be caused by other factors such as local landscape management. For instance, plants in urban areas are normally pruned for ecstatic and safety purposes, therefore tall trees as less common in this environment. In this study, we found that urbanization was significantly positively associated with air temperature. Gong and Gao [77] showed that temperature significantly influenced SLA, therefore we would predict that SLA would relate to urbanization intensity. However, this prediction was not supported by our result as SLA was not statistically associated with the percentage of built-up area. Even though this study found a rise in temperature with the increasing urbanization intensity, it is possible that the increase is rather moderate and not significant enough to have an impact on the SLA. Moreover, analysis of SLA from various climatic regions indicated a significant impact of temperature on SLA occurred in higher latitudes but less in the tropics [77]. Hence, the use of SLA in studies related to urbanization and plant traits in the topics should be carefully considered.

This study also found that SLA was not statistically associated with the percentage of built-up area. In opposition to our finding, a past study by Song et al. [3] from China stated that SLA was statistically significant with urbanization gradient and that they claimed urban areas had increased plant diversity, since the study area contain high nitrogen which could be attributable to an increase in nitrogen affinity as urbanization increases [78]. Furthermore, earlier research has found significant links between SLA and nutrient accessibility such as nitrogen and phosphorus [79]. However, a study by Cochard et al. [49] shows the same result as the present study and this was due to the uneven distribution of soil nutrients such as nitrogen and phosphorus along the urbanization gradient. In this study, Ipoh city appeared to be a limestone area [43]; thus, soils in Ipoh that originated from limestone parent material are primarily rich in calcium and high in pH [80]. Additionally, calcium and pH are two elements that significantly impact the vegetation pattern in the limestone region [81]. Our findings suggest that the concentration of calcium and pH are probably similar in all our study plots or that calcium and pH are not necessarily important factors that influence SLA.

However, the scarcity of apparent plant trait trends in Malaysia should also be emphasized, and more in-depth investigations are essential to grasp better the relevance of these traits in urbanization gradient contexts.

4.3. Environmental Impacts on Filtering Diversity Species

Environmental factors (air temperature, air humidity, and light intensity) were significantly associated with the percentage of built-up area in this study. In Ipoh, Perak, the most built-up area had the highest temperature, the least moisture, and the greatest light intensity. Conversely, the temperature in the wildland area was the lowest, with the highest air humidity and the lowest light intensity.

Findings from previous studies also showed that temperature increases with increasing urbanization intensity. For instance, Morris et al. [72] found that the temperature increased towards the urban center of Klang Valley, Malaysia, where the highest temperature was recorded in the commercial area. Similarly, a study by Saha et al. [73] which focused on one tropical and two subtropical urban agglomerations in India also discovered that areas with more built-up coverage had higher temperatures. Moreover, the projection of the urban climate in the tropical city of Ho Chi Minh City, Vietnam in the 2050s revealed that temperature will increase in both urban and rural areas, but the more urbanized areas will experience an additional 0.5 °C increment than the rural areas [82]. Such changes in environmental conditions can occur when vegetated areas are converted into impervious surfaces, particularly in urbanized areas [83,84].

Climate change has an impact on plants' growth [85]; hence, plants must deal with a variety of stressful situations during their lives. Due to urbanization, only a few plant species can survive in urban environments, which are known as alcalinophilous (light-loving plants) [86], thermophilous (warm-loving plants) [76], and drought-tolerant species [4]. Warm-loving, drought-tolerant, and light-loving plants are only found in big cities or otherwise; they will become extinct due to their inability to cope with harsh environmental conditions [75].

The results of this study showed that when urbanization intensity increased, air temperature also increased, while plant diversity reduced. Studies that investigated the direct effects of urbanization-related temperature on plant species diversity are scarce but a study by Lososová et al. [87] found a similar result that showed a reduction in the species diversity of native and non-native plant species due to the warmer climate of cities. The contradicting results of the non-native species between this study and Lososová et al. [87] are likely to be caused by the considerable influence of humans in introducing non-native species in Ipoh. Regarding the native species, a similar outcome to this study was obtained although Lososová et al. [87] focused on plant diversity in European cities. This suggests that climatic region is a less important factor in determining the effects of urban-related climate conditions on plant diversity. The increased temperature in either tropical or temperate cities induces stressful conditions for plants which eventually limits their survival.

On the contrary, a study by Zhang et al. [88] which involved 672 worldwide cities, including 99 from tropical countries found that urbanization in the tropical region barely affects plant growth due to temperature. The difference in this result compared to ours could be because the climatic data of the tropical region in Zhang et al. [88] were taken from three countries which were Malaysia, Brazil, and India while this study focused on local climate in the study plot. In addition to that, the vegetation data in this study were collected in the field but those in Zhang et al. [88] were the satellite-sensed data where there are possibilities that some of the satellite images may be of low confidence due to conditions such as snow and cloud. Therefore, the specificity of data (regional vs. local) should be taken into account when analyzing results from different studies. In this study, one of the plant species found in wildland, rural and urban areas is *Morinda citrofolia* which was discovered to be capable of surviving extreme environmental circumstances and prolonged periods of drought conditions [89]. Moreover, *Morinda citrofolia* can thrive in both acidic and alkaline soils, conditions with climates that range from extremely dry to excessively moist and shaded conditions (>80% shade) [90]. *Morinda citrofolia* also has a deep and robust taproot and extensive root system, making it exceedingly difficult to eliminate once established [91]. This could explain how *Morinda citrofolia* can adapt to urban, rural, and wildland areas.

Referring to Table 1, *Mangifera indica* is the only species discovered in all levels of urbanization in this study. A human has deliberately moved mango sp. for ages. At the same time, *Mango* sp. is a drought-tolerant species that can resist the seasonal dry season for up to 8 months. Its deep tap with sinker roots and long-lived and rigid leaves with a thick cuticle nutrient uptake are all drought-tolerant properties of *Mango* sp. [92]. *Mangifera indica* plants can withstand a wide range of climatic conditions as they may continue living in swampy areas as well as hot and humid climates [93]. Bally [92] also mentioned that mango trees are found well in regions with a well-defined, generally cold dry season with a high-temperature accumulation of full sunlight during the flowering and fruit development phase.

According to Table 1, *Caesalpinia sappan* was only be found in the urban areas of Ipoh; however, based on Hung et al. [94], *Caesalpinia sappan* is a species that requires high intensities of light and known as drought tolerant. Therefore, more drought tolerance species prefer with warmer and dry conditions [95] especially in urban areas. Many plant species that cannot survive or adapt to harsh environments face greater extinction risk since urbanization act as a filter of plant species. This could be mainly attributable to excessive light with warmer temperatures affecting plant productivity, growth, and development [75]. However, according to the Royal Botanic Garden, *Caesalpinia sappan* is a non-native species to peninsular Malaysia, and most non-native species are environmentally sustainable and resistant to drought [25].

Plant species that could not sustain in urban areas can be found in rural and wildland areas since rural and wildland have lower temperatures, with higher air humidity and lower light intensity compared to urban areas. For instance, in this study, referring to Table 1, *Shorea* sp. was found in rural and wildland areas. Since *Shorea* sp. grows at different rates; seedlings are sensitive to light intensity and must be grown in the shade for a while before being exposed to sunlight which makes it grow faster [96] and this would make sense why *Shorea* sp. could not survive in urban areas and this type of forest species is presumed to be adapted to shady conditions [4].

Based on the case of *Morinda citrofolia*, *Mangifera indica*, *Caesalpinia sappan*, and *Shorea* sp., we implied that urbanization favors plants with a wide range of environmental tolerance where it allows the plants to withstand the warmer, drier, and sunnier conditions of the urban environment. Such characteristic is common in non-native species [21] and it may explain their ability to survive in cities after being introduced by humans.

5. Conclusions

Plant diversity is essential to ecosystem consistency and functionality. Acknowledging the plant diversity pattern across urbanization gradient and the correlation between the built-up area with plant diversity, plant nativity, plant traits, and environmental factors are very important for urban planners towards new green infrastructure and how to preserve plant diversity in urban areas. Our study found that rapid urbanization and the high number of built-up areas in Ipoh, Perak reduced plant diversity and filters a few species of plants by adjusting physical surroundings, resulting in species decreasing along the urbanization gradient. The noticeable drastic changes in the environment caused by urbanization imply a tendency to produce different types of patterns for plant diversity as urbanization increases. In addition, non-native plants can be found at all levels of urbanization intensity, thus highlighting the role of human in dispersing species.

As the temperature rises, the intensity of the light and humidity in the environment decreases, creating stressful conditions for plant species. Only some plant species may survive in harsh conditions. If this persists, plant diversity may continue to decrease in a few years due to high urbanization without proper town planning or sustainable urban management. We chose only a few plants functional traits and environmental factors to investigate in the research, even though plant species may have other traits and environmental factors that can affect ecosystem functions. Soil factors, for example, play a significant role in plant distribution and diversity. More research on the mechanisms of how environment affects plant traits is required to understand the relationship between plant functional diversity and ecosystem processes while preserving urban development in Malaysia.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d14121024/s1, Table S1: Family, species name, nativity status, and native range of plants in Ipoh, Perak, Malaysia.

Author Contributions: Conceptualization, N.S.H., Z.M.S. and F.M.; methodology, N.S.H. and Z.M.S.; validation, F.M. and Z.M.S.; formal analysis, B.A.A., N.S.H. and K.I.; investigation, B.A.A.; resources, N.S.H. and K.I.; data curation, F.M. and Z.M.S.; writing—original draft preparation, B.A.A., N.S.H., F.M., Z.M.S. and K.I.; writing—review and editing, B.A.A. and N.S.H.; visualization, B.A.A.; supervision, N.S.H. and F.M.; project administration, N.S.H.; funding acquisition, N.S.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Higher Education Malaysia, grant number FRGS/1/2018/WAB13/UPSI/03/1.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.21609456.v1.

Acknowledgments: We would like to acknowledge PLANMalaysia for providing the land use map of Ipoh City Council. We also thank the Department of Biology, Faculty of Science and Mathematics, and Geography and Environment Department, Faculty of Human Science, Universiti Pendidikan Sultan Idris for providing adequate research facilities.

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

References

1. Ali, R.; Bakhsh, K.; Yasin, M.A. Impact of urbanization on CO2 emissions in emerging economy: Evidence from Pakistan. *Sustain. Cities Soc.* **2019**, *48*, 101553. [CrossRef]
2. Zhao, S.; Shi, X.M.; Niu, Y.F. Evaluation of the overall level of new urbanization in Hebei province based on factor analysis and GIS. *Asian Agric. Res.* **2014**, *6*, 44–49.
3. Song, G.; Wang, J.; Han, T.; Wang, Q.; Ren, H.; Zhu, H.; Hui, D. Changes in plant functional traits and their relationships with environmental factors along an urban-rural gradient in Guangzhou, China. *Ecol. Indic.* **2019**, *106*, 105558. [CrossRef]
4. Petersen, T.K.; Speed, J.D.M.; Grøtan, V.; Austrheim, G. Competitors and ruderals go to town: Plant community composition and function along an urbanisation gradient. *Nord. J. Bot.* **2021**, *39*, njb.03026. [CrossRef]

5. Trisos, C.H.; Merow, C.; Pigot, A.L. The projected timing of abrupt ecological disruption from climate change. *Nature* **2020**, *580*, 496–501. [CrossRef] [PubMed]
6. Yang, J.; Li, S.; Lu, H. Quantitative Influence of Land-Use Changes and Urban Expansion Intensity on Landscape Pattern in Qingdao, China: Implications for Urban Sustainability. *Sustainability* **2019**, *11*, 6174. [CrossRef]
7. Kadeba, A.; Nacoulma, B.M.I.; Ouedraogo, A.; Bachmann, Y.; Thiombiano, A.; Schmidt, M.; Boussim, J.I. Land cover change and plants diversity in the Sahel: A case study from northern Burkina Faso. *Ann. For. Res.* **2015**, *58*, 109. [CrossRef]
8. Cheng, F.; Liu, S.; Hou, X.; Wu, X.; Dong, S.; Coxixo, A. The effects of urbanization on ecosystem services for biodiversity conservation in southernmost Yunnan Province, Southwest China. *J. Geogr. Sci.* **2019**, *29*, 1159–1178. [CrossRef]
9. Zisadza-Gandiwa, P.; Mango, L.; Gandiwa, E.; Goza, D.; Parakasingwa, C.; Chinoitezvi, E.; Muvengwi, J. Variation in woody vegetation structure and composition in a semi-arid savanna of Southern Zimbabwe. *Int. J. Biodivers. Conserv.* **2013**, *5*, 71–77.
10. Ikyaagba, T.E.; Tee, T.N.; Dagba, B.I.; Ancha, U.P.; Ngibo, K.D.; Tume, C. Tree composition and distribution in Federal University of Agriculturema Kurdi, Nigeria. *J. Res. For. Wildl. Environ.* **2015**, *7*, 147–157.
11. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landsc. Urban Plan.* **2010**, *97*, 147–155. [CrossRef]
12. Abhijith, K.V.; Kumar, P.; Gallagher, J.; McNabola, A.; Baldauf, R.; Pilla, F. Air pollution abatement performances of green infrastructure in open road and built-Up street canyon environments—A review. *Atmos. Environ.* **2017**, *162*, 71–86. [CrossRef]
13. Wolf, K.L.; Robbins, A.S.T. Metro nature, environmental health, and economic value. *Environ. Health Perspect.* **2015**, *123*, 390. [CrossRef] [PubMed]
14. Guitart, D.; Pickering, C.; Bryne, J. Past results and future directions in urban community gardens research. *Urban For. Urban Green.* **2012**, *11*, 364–373. [CrossRef]
15. Botzat, A.; Fisher, L.K.; Kowarik, I. Unexploited opportunities in understanding live able and biodiverse cities. A review on urban biodiversity perception and valuation. *Glob. Environ. Chang.* **2016**, *39*, 220–233. [CrossRef]
16. Aronson, M.F.J.; Handel, S.N.; La Puma, I.P.; Clemants, S.E. Urbanization promotes non-native woody species and diverse plant assemblages in the New York metropolitan region. *Urban Ecosyst.* **2015**, *18*, 31–45. [CrossRef]
17. Wang, M.; Li, J.; Kuang, S.; He, Y.; Chen, G.; Huang, Y.; Łowicki, D. Plant Diversity along the Urban–Rural Gradient and Its Relationship with Urbanization Degree in Shanghai, China. *Forests* **2020**, *11*, 171. [CrossRef]
18. Čeplová, N.; Kalusová, V.; Lososová, Z. Effects of settlement size, urban heat island and habitat type on urban plant biodiversity. *Landsc. Urban Plan.* **2017**, *159*, 15–22. [CrossRef]
19. Jha, R.K.; Nölke, N.; Diwakara, B.N.; Tewari, V.P.; Kleinn, C. Differences in tree species diversity along the rural-urban gradient in Bengaluru, India. *Urban For. Urban Green.* **2019**, *46*, 126464. [CrossRef]
20. Blouin, D.; Pellerin, S.; Poulin, M. Increase in non-native species richness leads to biotic homogenization in vacant lots of a highly urbanized landscape. *Urban Ecosyst.* **2019**, *22*, 879–892. [CrossRef]
21. Godefroid, S.; Koedam, N. Distribution pattern of the flora in a peri-urban forest: An effect of the city–forest ecotone. *Landsc. Urban Plan.* **2003**, *65*, 169–185. [CrossRef]
22. Ranta, P.; Viljanen, V. Vascular plants along an urban-rural gradient in the city of Tampere, Finland. *Urban Ecosyst.* **2011**, *14*, 361–376. [CrossRef]
23. Zerbe, S. Biodiversity in Berlin and its potential for nature conservation. *Landsc. Urban Plan.* **2003**, *62*, 139–148. [CrossRef]
24. Yan, Z.; Teng, M.; He, W.; Liu, A.; Li, Y.; Wang, P. Impervious surface area is a key predictor for urban plant diversity in a city undergone rapid urbanization. *Sci. Total Environ.* **2019**, *650*, 335–342. [CrossRef] [PubMed]
25. Vakhlamova, T.; Rusterholz, H.-P.; Kanibolotskaya, Y.; Baur, B. Changes in plant diversity along an urban–rural gradient in an expanding city in Kazakhstan, Western Siberia. *Landsc. Urban Plan.* **2014**, *132*, 111–120. [CrossRef]
26. Cameron, G.N.; Culley, T.M.; Kolbe, S.E.; Miller, A.I.; Matter, S.F. Effects of urbanization on herbaceous forest vegetation: The relative impacts of soil, geography, forest composition, human access, and an invasive shrub. *Urban Ecosyst.* **2015**, *18*, 1051–1069. [CrossRef]
27. Albrecht, H.; Haider, S. Species diversity and life history traits in calcareous grasslands vary along an urbanization gradient. *Biodivers. Conserv.* **2013**, *22*, 2243–2267. [CrossRef]
28. Melliger, R.L.; Braschler, B.; Rusterholz, H.-P.; Baur, B. Diverse effects of degree of urbanisation and forest size on species richness and functional diversity of plants, and ground surface-active ants and spiders. *PLoS ONE* **2018**, *13*, e0199245. [CrossRef] [PubMed]
29. Tian, Z.; Song, K.; Da, L. Distribution patterns and traits of weed communities along an urban-rural gradient under rapid urbanization in Shanghai, China: Weed communities on urban-rural gradient. *Weed Biol. Manag.* **2015**, *15*, 27–41. [CrossRef]
30. Yang, J.; Li, X.; Li, S.; Liang, H.; Lu, H. The woody plant diversity and landscape pattern of fine-resolution urban forest along a distance gradient from points of interest in Qingdao. *Ecol. Indic.* **2021**, *122*, 107326. [CrossRef]
31. Rahmad, Z.B.; Akomolafe, G.F. Distribution, Diversity and Abundance of Ferns in a Tropical University Campus. *Pertanika J. Trop. Agric. Sci.* **2018**, *41*, 1875–1887.
32. Suratman, M.N. Tree Species Diversity and Forest Stand Structure of Pahang National Park, Malaysia. *Biodivers. Enrich. A Divers. World* **2012**, *19*, 45–56.
33. Onrizal, O.; Ismail, S.N.; Mansor, M. Diversity of plant community at Gunung Ledang, Malaysia. In Proceedings of the International Conference on Agriculture, Environment, and Food Security 2018, Medan, Indonesia, 24–25 October 2018. IOP Conference Series: Earth and Environmental Science, 2019.

34. Ghollasimood, S.; Hanum, I.F.; Nazre, M.; Kamziah, A.K.; Awang Noor, A.G. Vascular Plant Composition and Diversity of a Coastal Hill Forest in Perak, Malaysia. *J. Agric. Sci.* **2011**, *3*, 111. [CrossRef]
35. Nabilla, F.; Devi, K.K.; Siong, H.C. Analysis of fragmented green spaces in kuala lumpur, Malaysia. *Chem. Eng. Trans.* **2019**, *72*, 457–462.
36. Kanniah, K.D. Quantifying green cover change for sustainable urban planning: A case of Kuala Lumpur, Malaysia. *Urban For. Urban Green.* **2017**, *27*, 287–304. [CrossRef]
37. Kanniah, K.D.; Ho, C.S. Urban Forest cover change and sustainability of malaysian cities. *Chem. Eng. Trans.* **2017**, *56*, 673–678.
38. Kleyer, M. Enhancing landscape planning: Vegetation-mediated ecosystem services predicted by plant traits. *Landsc. Urban Plan.* **2021**, *215*, 104220. [CrossRef]
39. Palma, E.; Catford, J.A.; Corlett, R.T.; Duncan, R.P.; Hahs, A.K.; McCarthy, M.A.; McDonnell, M.J.; Thompson, K.; Williams, N.S.G.; Vesk, P.A. Functional trait changes in the floras of 11 cities across the globe in response to urbanization. *Ecography* **2017**, *40*, 875–886. [CrossRef]
40. Funk, J.L.; Larson, J.E.; Ames, G.M.; Butterfield, B.J.; Cavender-Bares, J.; Firn, J.; Wright, J. Revisiting the Holy Grail: Using plant functional traits to understand ecological processes: Plant functional traits. *Biol. Rev.* **2017**, *92*, 1156–1173. [CrossRef]
41. van Grunsven, L.; Benson, M. Urban Development in Malaysia: Towards A New Systems Paradigm. *Urban Policy Ser.* **2020**. Available online: www.thinkcity.com.my/wuf10 (accessed on 20 November 2022).
42. Wan Mohd Jaafar, W.S.; Abdul Maulud, K.N.; Muhmad Kamarulzaman, A.M.; Raihan, A.; Md Sah, S.; Ahmad, A.; Razzaq Khan, W. The Influence of Deforestation on Land Surface Temperature—A Case Study of Perak and Kedah, Malaysia. *Forests* **2020**, *11*, 670. [CrossRef]
43. Wong, K.M. Plant endemism patterns in Borneo and Malay Peninsula and Patterns of Plant Endemism and Rarity in Borneo and the Malay Peninsula. *For. Res. Cent.* **1998**, 139–169.
44. Ashton, P.S. Plant conservation in the Malaysian region. *Malay. Nat. Soc.* **1992**, 86–93.
45. Razak, H.A.; Wahid, N.B.A.; Latif, M.T. Anionic Surfactants and Traffic Related Emission from an Urban Area of Perak, Malaysia. *Arch. Environ. Contam. Toxicol.* **2019**, *77*, 587–593. [CrossRef]
46. Marzluff, J.M.; Bowman, R. *Avian Ecology and Conservation in an Urbanizing World*; Donnelly, R., Ed.; Kluwer Academic: Boston, MA, USA; Springer: Berlin/Heidelberg, Germany, 2001; p. 581.
47. Yang, T.-R.; Lam, T.Y.; Su, S.-H. A simulation study on the effects of plot size and shape on sampling plant species composition for biodiversity management. *J. Sustain. For.* **2019**, *38*, 116–129. [CrossRef]
48. Pérez-Harguindeguy, N.; Díaz, S.; Garnier, E.; Lavorel, S.; Poorter, H.; Jaureguiberry, P.; Cornelissen, J.H.C. Corrigendum to: New handbook for standardised measurement of plant functional traits worldwide. *Aust. J. Bot.* **2016**, *64*, 715. [CrossRef]
49. Cochard, A.; Pithon, J.; Braud, F.; Beaujouan, V.; Bulot, A.; Daniel, H. Intraspecific trait variation in grassland plant communities along urban-rural gradients. *Urban Ecosyst.* **2019**, *22*, 583–591. [CrossRef]
50. Li, H.; Meng, H.; He, R.; Lei, Y.; Guo, Y.; Ernest, A.; Tian, G. Analysis of Cooling and Humidification Effects of Different Coverage Types in Small Green Spaces (SGS) in the Context of Urban Homogenization: A Case of HAU Campus Green Spaces in Summer in Zhengzhou, China. *Atmosphere* **2020**, *11*, 862. [CrossRef]
51. Gatto, E.; Buccolieri, R.; Aarrevaara, E.; Ippolito, F.; Emmanuel, R.; Perronace, L.; Santiago, J.L. Impact of Urban Vegetation on Outdoor Thermal Comfort: Comparison between a Mediterranean City (Lecce, Italy) and a Northern European City (Lahti, Finland). *Forests* **2020**, *11*, 228. [CrossRef]
52. Huang, L.; Chen, H.; Ren, H.; Wang, J.; Guo, Q. Effect of urbanization on the structure and functional traits of remnant subtropical evergreen broad-leaved forests in South China. *Environ. Monit. Assess.* **2013**, *185*, 5003–5018. [CrossRef]
53. Magurran, A.E. *Ecological Diversity and Its Measurement*; Princeton University Press: Princeton, NJ, USA, 1988.
54. Shannon, C.E.; Weiner, V. A Mathematical Theory of Communication University Press. *Ill. Urban* **1949**, *5*, 101–107.
55. Atsbeha, G.; Demissew, S.; Woldu, Z.; Edwards, S. Floristic composition of herbaceous flowering plant species in Lalay and Tahtay Michew districts, central zone of Tigray, Ethiopia. *Afr. J. Ecol. Ecosyst.* **2015**, *2*, 159–169.
56. Turner, I.M. A catalogue of the vascular plants of Malaya. *Gard. Bull. (Singap.)* **1995**, *47*, 346.
57. McKinney, M.L. Urbanization as a major cause of biotic homogenization. *Biol. Conserv.* **2006**, *127*, 247–260. [CrossRef]
58. Fahrig, L.; Baudry, J.; Brotons, L.; Burel, F.G.; Crist, T.O.; Fuller, R.J.; Martin, J.-L. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes: Heterogeneity and biodiversity. *Ecol. Lett.* **2011**, *14*, 101–112. [CrossRef] [PubMed]
59. Jentsch, A.; Steinbauer, M.J.; Alt, M.; Retzer, V.; Buhk, C.; Beierkuhnlein, C. A systematic approach to relate plant-species diversity to land use diversity across landscapes. *Landsc. Urban Plan.* **2012**, *107*, 236–244. [CrossRef]
60. Huang, Y.; Chen, Y.; He, Y.-J.; Wang, M.; Kuang, S.-J.; Chen, G.-J.; Li, J.-X. Effects of socioeconomic factors on urban plant diversity of residential areas in Shanghai, China. *J. Appl. Ecol.* **2019**, *30*, 3403–3410.
61. Aronson, M.F.J.; La Sorte, F.A.; Nilon, C.H.; Katti, M.; Goddard, M.A.; Lepczyk, C.A.; Winter, M. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proc. R. Soc. B Biol. Sci.* **2014**, *281*, 20133330. [CrossRef] [PubMed]
62. Uchiyama, Y.; Kohsaka, R. Spatio-temporal Analysis of Biodiversity, Land-use Mix and Human Population in a Socio-ecological Production Landscape: A Case Study in the Hokuriku Region, Japan. *Procedia Eng.* **2017**, *198*, 219–226. [CrossRef]
63. Lee, C.; Jitaree, W. Structural Change and Urbanization: The Case of Peninsular Malaysia. *Thail. World Econ.* **2019**, *37*, 26–38.

64. Hosni, A.T.; Teriman, S.; Adnan, N.A.; Kamar, M.A.A. Time Series Analysis of Land Cover Using Remote Sensing Technology. *J. Comput. Theor. Nanosci.* **2020**, *17*, 902–910. [CrossRef]
65. McKinney, M.L. Urbanization, Biodiversity, and Conservation. *BioScience* **2002**, *52*, 883. [CrossRef]
66. Peng, Y.; Liu, X. Research progress in effects of urbanization on plant biodiversity. *Biodivers. Sci.* **2007**, *15*, 558.
67. Yuan, Z.; Xu, J.; Wang, Y.; Yan, B. Analyzing the influence of land use/land cover change on landscape pattern and ecosystem services in the Poyang Lake Region, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 27193–27206. [CrossRef] [PubMed]
68. Li, X.; Jia, B.; Zhang, W.; Ma, J.; Liu, X. Woody plant diversity spatial patterns and the effects of urbanization in Beijing, China. *Urban For. Urban Green.* **2020**, *56*, 126873. [CrossRef]
69. Butchart, S.H.M.; Walpole, M.; Collen, B.; van Strien, A.; Scharlemann, J.P.W.; Almond, R.E.A.; Watson, R. Global Biodiversity: Indicators of Recent Declines. *Science* **2010**, *328*, 1164–1168. [CrossRef] [PubMed]
70. Rosenfield, M.F.; Müller, S.C. Plant Traits Rather than Species Richness Explain Ecological Processes in Subtropical Forests. *Ecosystems* **2020**, *23*, 52–66. [CrossRef]
71. Zirbel, C.R.; Bassett, T.; Grman, E.; Brudvig, L.A. Plant functional traits and environmental conditions shape community assembly and ecosystem functioning during restoration. *J. Appl. Ecol.* **2017**, *54*, 1070–1079. [CrossRef]
72. Morris, K.I.; Chan, A.; Morris, K.J.K.; Ooi, M.C.; Oozeer, M.Y.; Abakr, Y.A.; Nadzir, M.S.M. and Mohammed, I.Y. Urbanisation and urban climate of a tropical conurbation, Klang Valley, Malaysia. *Urban Clim.* **2017**, *19*, 54–71. [CrossRef]
73. Saha, S.; Saha, A.; Das, M.; Saha, A.; Sarkar, R.; Das, A. Analyzing spatial relationship between land use/land cover (LULC) and land surface temperature (LST) of three urban agglomerations (UAs) of Eastern India. *Remote Sens. Appl. Soc. Environ.* **2021**, *22*, 100507. [CrossRef]
74. Lüttge, U.; Buckeridge, M. Trees: Structure and function and the challenges of urbanization. *Trees* **2020**, 1–8. [CrossRef]
75. Hatfield, J.L.; Prueger, J.H. Temperature extremes: Effect on plant growth and development. *Weather Clim. Extrem.* **2015**, *10*, 4–10. [CrossRef]
76. Williams, N.S.G.; Hahs, A.K.; Vesk, P.A. Urbanisation, plant traits and the composition of urban floras. *Perspect. Plant Ecol. Evol. Syst.* **2015**, *17*, 78–86. [CrossRef]
77. Gong, H.; Gao, J. Soil and climatic drivers of plant SLA (specific leaf area). *Glob. Ecol. Conserv.* **2019**, *20*, e00696. [CrossRef]
78. Vallet, J.; Daniel, H.; Beaujouan, V.; Rozé, F.; Pavoine, S. Using biological traits to assess how urbanization filters plant species of small woodlands: Biological traits to assess how urbanization filters plant species. *Appl. Veg. Sci.* **2010**, *13*, 412–424. [CrossRef]
79. Dwyer, J.M.; Hobbs, R.J.; Mayfield, M.M. Specific leaf area responses to environmental gradients through space and time. *Ecology* **2014**, *95*, 399–410. [CrossRef]
80. Gauld, J.H.; Robertson, J.S. Soils and Their Related Plant Communities on the Dalradian Limestone of Some Sites in Central Perthshire, Scotland. *J. Ecol.* **1985**, *73*, 91. [CrossRef]
81. Zakaria, R.; Nizam, M.S.; Faridah, H. Association of Tree Communities with Soil Properties in a Semi Deciduous Forest of Perlis, Peninsular Malaysia. *BIOTROPIA-Southeast Asian J. Trop. Biol.* **2020**, *27*, 69–79.
82. Doan, V.Q.; Kusaka, H. Projections of urban climate in the 2050s in a fast-growing city in Southeast Asia: The greater Ho Chi Minh City metropolitan area, Vietnam. *Int. J. Climatol.* **2018**, *38*, 4155–4171. [CrossRef]
83. Kubota, T.; Lee, H.S.; Trihamdani, A.R.; Phuong, T.T.T.; Tanaka, T.; Matsuo, K. Impacts of land use changes from the Hanoi Master Plan 2030 on urban heat islands: Part 1. Cooling effects of proposed green strategies. *Sustain. Cities Soc.* **2017**, *32*, 295–317. [CrossRef]
84. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global change and the ecology of cities. *Science* **2008**, *319*, 756–760. [CrossRef]
85. Ciceu, A.; Popa, I.; Leca, S.; Pitar, D.; Chivulescu, S.; Badea, O. Climate change effects on tree growth from Romanian forest monitoring Level II plots. *Sci. Total Environ.* **2020**, *698*, 134129. [CrossRef] [PubMed]
86. Schwoertzig, E.; Poulin, N.; Hardion, L.; Trémolières, M. Plant ecological traits highlight the effects of landscape on riparian plant communities along an urban–rural gradient. *Ecol. Indic.* **2016**, *61*, 568–576. [CrossRef]
87. Lososová, Z.; Tichý, L.; Divíšek, J.; Čeplová, N.; Danihelka, J.; Dřevojan, P.; Fajmon, K.; Kalníková, V.; Kalusová, V.; Novák, P.; et al. Projecting potential future shifts in species composition of European urban plant communities. *Divers. Distrib.* **2018**, *24*, 765–775. [CrossRef]
88. Zhang, L.; Yang, L.; Zohner, C.M.; Crowther, T.W.; Li, M.; Shen, F.; Guo, M.; Qin, J.; Yao, L.; Zhou, C. Direct and indirect impacts of urbanization on vegetation growth across the world's cities. *Sci. Adv.* **2022**, *8*, eabo0095. [CrossRef]
89. Nelson, S.C. Morinda citrifolia *(noni), Ver 4, Species Profiles for Pacifc Island Agroforestry*; Permanent Agricultural Resources: Holualoa, HI, USA, 2006; pp. 1–13.
90. Francis, J.K. *Wildland Shrubs of the United States and Its Territories: Thamnic Descriptions, Volume 1*; General Technical Report IITF-GTR-26; US Department of Agriculture, Forest Service, International Institute of Tropical Forestry, US Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO, USA, 2004; 830p.
91. Rojas-Sandoval, J. *Morinda citrifolia (Indian mulberry)*; Invasive Species Compendium: Wallingford, UK, 2020.
92. Bally, I.S.E. *Mangifera indica (mango)*; Species Profiles for Pacific Psland Agroforestry: Mareeba, Australia, 2006; pp. 1–25.
93. Derese, S.; Guantai, E.M.; Souaibou, Y.; Kuete, V. Mangifera indica L. (Anacardiaceae). In *Medicinal Spices and Vegetables from Africa*; Academic Press: Cambridge, MA, USA, 2017; pp. 451–483.

94. Hung, T.; Dang, N.; Dat, N. Methanol extract from Vietnamese *Caesalpinia sappan* induces apoptosis in HeLa cells. *Biol. Res.* **2014**, *47*, 20. [CrossRef] [PubMed]
95. Walentowski, H.; Falk, W.; Mette, T.; Kunz, J.; Bräuning, A.; Meinardus, C.; Zang, C.; Sutcliffe, L.M.E.; Leuschner, C. Assessing future suitability of tree species under climate change by multiple methods: A case study in southern Germany. *Ann. For. Res.* **2017**, *60*, 101–126. [CrossRef]
96. Purwaningsih; Kintamani, E. The Diversity of Shorea spp. (Meranti) at Some Habitats in Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *197*, 012034. [CrossRef]