

Species Diversity and Microhabitat Adaptation of *Selaginella* in the Urban Landscape of Malang City

Tsabitah Ratnaningtyas*

Universitas Negeri Malang, Indonesia

Email: tsabitah.ratnaningtyas.2203426@students.um*

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ABSTRACT

Background: *Selaginella* is an ancient heterosporous lycophyte with a center of diversity in tropical regions and high sensitivity to microhabitat conditions, while urbanization pressure has the potential to trigger habitat fragmentation and environmental filtration that affect the structure of the understory plant community. **Objective:** This study aims to analyze the species diversity and microhabitat response of *Selaginella* in the urban landscape of Malang City. **Methods:** The study was conducted descriptively and exploratively in five subdistricts using stratified purposive sampling based on microhabitat type. Species data, morphological characteristics, and microenvironmental parameters (light intensity, temperature, humidity, and soil pH) were analyzed using Simpson's index, the Kruskal-Wallis test, and Spearman's correlation. **Results:** The results showed that *Selaginella* was found at 19 points out of 72 observation points with four species identified and a strong dominance of *Selaginella eurynota* ($D = 0.499$; $H' = 0.971$), while the environmental parameters between microhabitats did not differ significantly ($p > 0.05$), indicating microclimate homogeneity. **Conclusion:** These findings confirm that community structure is more influenced by microclimate stability and species ecological tolerance than by contrasting abiotic variations, so urban green space management needs to consider habitat heterogeneity to support the sustainability of tropical ferns.

INTRODUCTION

Selaginella is a genus of ancient heterosporous lycophyte with a wide global distribution and a very high level of diversity, especially in the tropics. Globally, the genus *Selaginella* encompasses 700–750 species and is the largest and most taxonomically complex genus among heterosporous ferns, with the highest diversity in the tropical and subtropical regions of the world (Zhou & Zhang, 2023). Recent phylogenetic studies of *Selaginellaceae* show that many of the morphological characters in the genus *Selaginella* are homoplasy, so the apparent morphological variations do not necessarily reflect true evolutionary kinship relationships. This condition shows that the morphological differences in (Zhou & Zhang, 2023) *Selaginella* cannot be explained by its external appearance alone, but need to be understood by considering the environmental factors in which it grows as well as its evolutionary history.

In the study of the diversity of fern flora in Indonesia, it was reported that there are around 39 species of *Selaginella* spread from lowlands to mountains on various Indonesian islands

(Sumatra, Java, Bali, Kalimantan, Sulawesi, Maluku, Lombok, and Irian Jaya) with distribution patterns that vary based on elevation. In addition, studies on altitudinal gradients in the southern part of Java show that (Andik Wijayanto, 2014) *Selaginella* has a habitat preference in humid and watery environments, which are commonly found in highlands and mountains with high rainfall, reflecting adaptation to shady and humid conditions over open dry habitats. The distribution of (Setyawan et al., 2016) *Selaginella* shows clear variation along the gradient of the environment, both in composition and type richness. Although the island of Java is one of the important regions for *Selaginella* diversity, most studies have focused on natural or semi-natural habitats, while information on the existence and distribution patterns of *Selaginella* in urban landscapes is limited.

The limitation of this information is becoming increasingly relevant along with the increasing urbanization process. Urbanization is a process of landscape transformation that simultaneously changes habitat structure, microclimate conditions, and biotic community composition. These changes are generally characterized by habitat fragmentation, increased surface temperature, fluctuations in humidity, as well as the dominance of artificial substrates, which ecologically select plant groups with specific tolerances and adaptation strategies. In this context, ferns are a relevant group to study due to their dependence on microhabitat conditions, particularly light and moisture (Anderson, 2021; Landeros-López et al., 2025; Schwerbrock & Leuschner, 2016).

The findings have prompted increased attention to the potential of ferns as an ecological indicator. In the past decade, attention to the role of ferns as an ecological indicator has begun to increase, including in urban environments (Salinitro et al., 2019; Silva et al., 2018; Yang et al., 2021). Research in the urban forests of Jakarta shows that *Selaginella* can still be found in locations that maintain soil moisture and canopy shade, although its species composition is influenced by the level of disturbance and habitat quality. Internationally, studies in the urban forests of Veracruz, Mexico, show that microclimatic variations, particularly temperature, relative humidity, and light intensity have a significant effect on the morphological character of the associated lower fern plants direct to its ecological function. However, studies that specifically integrate (Landeros-López et al., 2025). *Selaginella* species diversity with morphological variation as a response to urban microhabitats are still very limited, especially in Indonesia.

The urgency of this research is underscored by several critical factors. First, accelerating urbanization in Indonesian cities continues to transform natural and semi-natural habitats, potentially threatening *Selaginella* populations before their diversity and ecological requirements are adequately documented (Vuerich et al., 2021). Second, understanding how sensitive plant groups respond to urbanization provides insights into broader patterns of biodiversity loss and community restructuring in human-dominated landscapes. Third, *Selaginella*'s dependence on specific microhabitat conditions makes it a potential bioindicator for monitoring urban habitat quality and the effectiveness of green space management. Fourth, the presence of *Selaginella* in urban areas may contribute to ecosystem services including soil stabilization, moisture retention, and aesthetic value, warranting conservation attention. Fifth, as climate change interacts with urbanization effects, understanding baseline diversity and habitat requirements becomes essential for predicting future community changes (Parvar &

Salmanmahiny, 2025; Tobias et al., 2021; Urban et al., 2016, 2024; Williams & Newbold, 2020).

Based on this knowledge gap, this research is relevant to be conducted. Therefore, the study of Species Diversity and Adaptation of *Selaginella* Microhabitats in the Urban Landscape of Malang City was conducted to explore the diversity of *Selaginella* species and analyze the variation in its morphological character in response to differences in microhabitats in the urban landscape of Malang City, by attributing plant morphological characters to microenvironmental factors such as light intensity, humidity, temperature, and substrate type. This approach is expected to bridge the gap between the study of *Selaginella* in natural habitats and the understanding of its adaptation in fragmented urban environments, as well as provide a scientific basis for the use of *Selaginella* as an ecological indicator in the management of urban green spaces.

METHOD

This study was an exploratory descriptive research with a quantitative and qualitative approach to examine the diversity of species and variations in morphological adaptation of *Selaginella* in urban landscapes. The research was carried out in November-December 2025 in Malang City, East Java, covering five sub-districts, namely Klojen, Blimbing, Lowokwaru, Sukun, and Kedungkandang with various types of urban landscapes. The research subjects were individuals or groups of terrestrial *Selaginella* that grew naturally, with locations determined using stratified purposive sampling based on four microhabitat categories of humid-shade, humid-open, dry-shade, and dry-open.

Data were collected through exploration including species recording, observation of key morphological characteristics (plant height, leaf size and shape, leaf color, and branching pattern), and measurement of micro-environmental factors (light intensity, soil moisture, air and soil temperature, soil pH, and substrate type) using standard field instruments. Species diversity was analyzed using the Simpson Index, morphological differences between microhabitats were analyzed with ANOVA or Kruskal-Wallis according to the data character, and the relationship between morphological characters and environmental factors was analyzed using the Spearman correlation.

RESULT AND DISCUSSION

The Distribution of *Selaginella* in the Urban Landscape of Malang City

The mapping results showed that *Selaginella* was found at 19 of 72 observation points spread across five sub-districts in Malang City. These findings suggest that the distribution of *Selaginella* is limited and spatially uneven, reflecting the dependence of this genus on specific microhabitat conditions. The urban landscape of Malang City, which is composed of a combination of built-up areas and green spaces, causes the availability of suitable habitats for *Selaginella* to be found only in certain locations.

Some heterosporous ferns are sensitive to environmental conditions, *Selaginella* requires a moist, shady environment, and has a soil substrate with adequate organic matter content. Light intensity and soil moisture play a role as the main limiting factors in determining the existence of this genus. *Selaginella* tends to be found in habitats with low light intensity,

while open locations with high light exposure do not support its existence so this species is not found at most observation points (Suryani et al., 2023).

At the landscape scale, habitat fragmentation due to urbanization forms a distribution pattern of *Selaginella* that is localized in a habitat patch that still maintains appropriate microclimatic conditions. *Selaginella* spores are only able to thrive in a humidity and light stable environment, so changes in the structure of the urban landscape limit the connectivity between habitats that favor the existence of this genus. The study shows that urbanization tends to lead to a decline in the number of species with special habitat needs, as the modification of the urban environment reduces the chances for highly specialized species to survive (English et al., 2022).

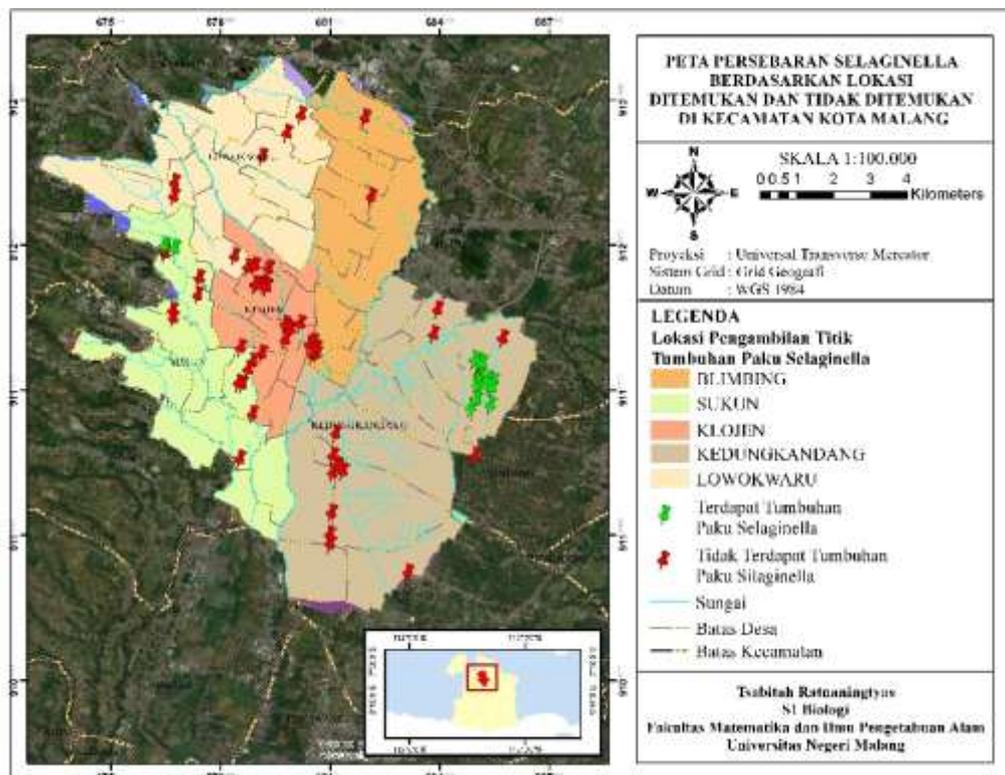
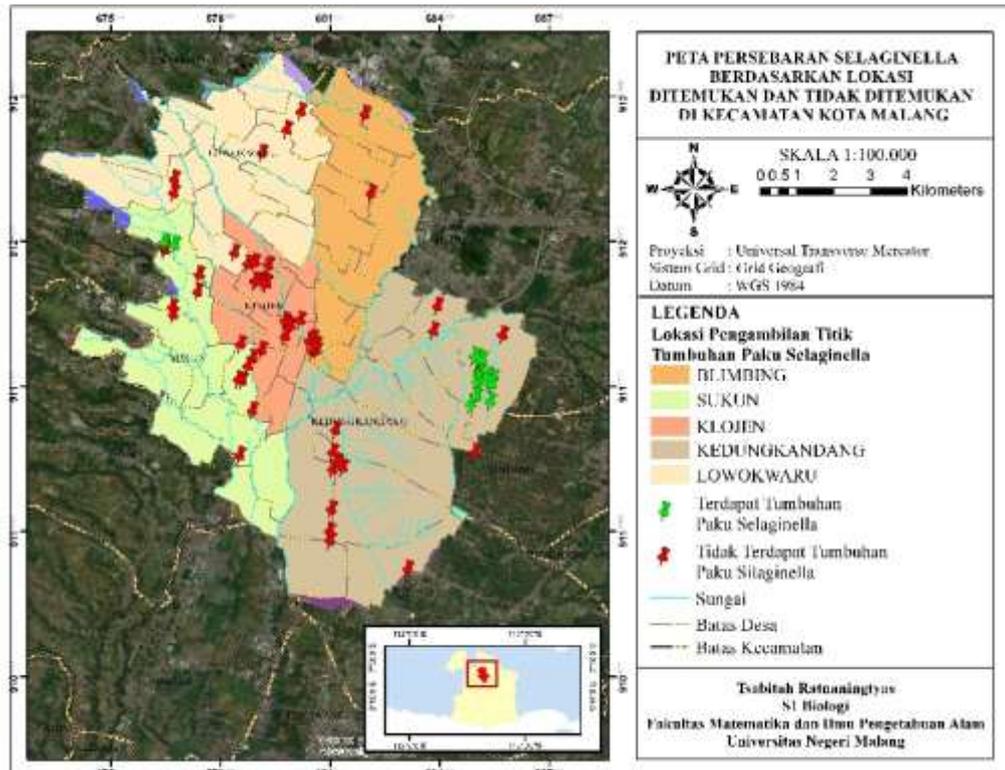


Figure 1. Map of the Distribution of *Selaginella*

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in Malang City

Thus, the distribution of *Selaginella* in Malang City is the result of the interaction between the ecological needs of species and the heterogeneity of the urban environment. Therefore, further analysis is focused on the locations that indicate the existence of *Selaginella* in order to obtain a more accurate picture of the community structure and habitat characteristics that underpin its existence.

***Selaginella* Species Diversity at the Microhabitat Level**

The distribution of four species of *Selaginella* in 19 microhabitats in the urban landscape of Malang City showed a clear dominance by *Selaginella eurynota*, which was recorded at 13 locations out of a total of 19 observation points ($\pi = 0.684$). The dominance index (D) for this community reached 0.499 which reflects the dominance of one species over the entire *Selaginella* community in the study area. This proportion of dominance is followed by three other species (*Selaginella kraussiana*, *Selaginella martensii*, and *Selaginella tamariscina*) which are each found in only two microhabitats ($\pi = 0.105$). Such community structures reflect a pattern of low evenness, where one strong species dominates, while the other species is sporadically dispersed in low numbers. This is indicated by the Shannon diversity index value (H') of 0.971 which indicates that despite the presence of four species, the community composition is unbalanced due to the high dominance of *Selaginella eurynota*. In the context of lycophytes and ferns, structural patterns are also influenced by environmental variables of an abiotic nature such as light intensity, humidity, and substrate type, which determine the dominance of a particular species in a modified habitat (Li et al., 2025).

Table 1. *Selaginella* Species Diversity Based on the Simpson Index at the Microhabitat Level

Species	Count of Microhabitats (N)	bee	(pi)^2	D	LNpi	(-) piLNpi	H'	
<i>Selaginella eurynota</i>	13	0.684	0.468	0.499	-	-0.260	0.971	
<i>Selaginella kraussiana</i>	2	0.105	0.011		2.251	-0.237		0.237
<i>Selaginella martensii</i>	2	0.105	0.011		2.251	-0.237		0.237
<i>Selaginella tamariscina</i>	2	0.105	0.011		2.251	-0.237		0.237
TOTAL	19		0.501					

The dominance of *Selaginella eurynota* ecologically indicates that the microhabitats found in Malang City provide more suitable environmental conditions for the growth and reproduction of this species than the other three species. Microhabitat variation, especially light intensity and humidity, play a role in determining the pattern of *Selaginella*'s presence in tropical habitats, although field studies generally show correlational relationships and not direct selection (Suryani et al., 2023) mechanisms. The dominance of a single species in a fragmented community, such as in an urban landscape, can be a sign of environmental filtering. This process occurs when the available microhabitat conditions are only able to support the growth of some types of organisms that are tolerant of these conditions, while other types are not competitive enough or are not able to adapt well to the existing environment.

Furthermore, the distribution patterns exhibited by three low-frequency species (*Selaginella kraussiana*, *Selaginella martensii*, and *Selaginella tamariscina*) reflect the effects of habitat disturbance and microhabitat heterogeneity in urban environments. Urbanization creates a mosaic of microhabitats that are heterogeneous in terms of light intensity, humidity, and substrate, allowing for the predominance of pioneer or disturbance-tolerant species as well as the sporadic presence of other species in more specific patches of habitats. Studies of the distribution of lycophyta and ferns in Northeast China show that species richness has significant spatial heterogeneity and correlates with environmental gradients, especially temperature and precipitation. The variation of climatic factors contributes to the distribution pattern of regional distribution and differences in the level of diversity between regions (Li et al., 2025).

Further analysis of the community dominance and diversity index supports the understanding that the *Selaginella* community in Malang City is influenced not only by the availability of growing places, but also by spatially varied microhabitat variables in this urban landscape. A relatively high dominance index value along with an H' value of almost 1 indicates a community with an asymmetrical structure, where the dominance of one species reflects its competitiveness towards local resources. In a study of urban forests in Veracruz, Mexico, microclimatic variations related to light intensity, humidity, and vegetation conditions were described as contributing to morphological variations in fern plants, including leaf size and leaf properties, in response to microenvironmental changes that occur due to forest

structure modifications. Understanding community structure is relevant in the study of urban ecology because it shows how the influence of abiotic factors mediates distribution of low-level vegetation quantitatively. (Landeros-López et al., 2025)

Overall, the distribution pattern of *Selaginella* species in Malang City illustrates strong environmental filtration in urban fern communities, where one dominant species defines the composition of the community and the other species remains minor or sparse, due to the heterogeneity of microhabitats influenced by urban structures. Findings from studies in Northeast China suggest that the composition of lycophytes and spike mosses is influenced by gradual geographic environments, where the majority of species have low frequency while some of the more common species tend to appear in larger elevation ranges (Li et al., 2025).

Statistical Assumption Test of Environmental Parameters Between Microhabitats

Based on the Shapiro-Wilk normality test, some variables had a p-value of 0.05 which indicates data was not normally distributed. In addition, the results of the Levene homogeneity test showed that most of the variables had $p < 0.05$ so that the variance between groups was not homogeneous. Therefore, comparative analysis between microhabitats was carried out using the non-parametric Kruskal-Wallis test, followed by the post hoc Dunn test if there were significant differences.

Statistical assumption testing was carried out to ensure the accuracy of the analysis method in comparing morphometric characters and environmental factors between seven microhabitats. The selection of the Shapiro-Wilk test was based on the consideration of a relatively small sample size because this test is more sensitive in detecting distribution deviations than the Kolmogorov-Smirnov (Ghasemi & Zahediasl, 2012) results show that several variables have a p< value of 0.05, including plant height in certain microhabitats ($p = 0.007$), soil moisture ($p = 0.000$), temperature ($p = 0.012$), air humidity ($p = 0.049$), and pH ($p = 0.000-0.001$). This indicates that some of the data is not normally distributed, so the use of parametric analysis risks producing biased estimates, especially in small samples. (Kim, 2013)

The variance homogeneity test using Levene showed that plant height ($p = 0.004$), soil moisture ($p = 0.000$), air humidity ($p = 0.000$), temperature ($p = 0.000$), and pH ($p = 0.011$) had inhomogeneous variance between microhabitats, while light intensity (lux) was relatively homogeneous ($p = 0.082$). This inhomogeneity reflects the heterogeneity of ecological conditions, such as differences in litter thickness, canopy intensity, and proximity to water sources. Statistically, violations of variance homogeneity are known to increase the risk of type I error distortion in F-based parametric procedures, including conventional ANOVA, especially when the sample sizes between groups are unbalanced. (Delacre et al., 2017)

Based on the results of the assumption test showing violations of normality and homogeneity of variance, the analysis of differences between groups was carried out using the Kruskal-Wallis test as a non-parametric alternative that does not require normal distribution and is based on data rating. This approach is relevant in the study of forest microhabitats, as microclimate variation naturally tends to result in an asymmetrical distribution of data. Ecologically, the variation in temperature and microclimatic conditions under the forest canopy reflects a pronounced microclimate gradient, where vegetation cover plays a role in mitigating

temperature fluctuations and influencing the dynamics of undergrowth communities (Tomczak & Tomczak, 2014). (De Frenne et al., 2019).

After the Kruskal-Wallis test showed significant differences ($p < 0.05$), the analysis continued with the Dunn follow-up test to identify different groups with multiple comparison correction. Thus, the results of the analysis are not only statistically valid, but also coherent with ecological dynamics at the micro scale. (Dinno, 2015).

Differences in Environmental Parameters Between Microhabitats

The Kruskal–Wallis test was conducted to determine the difference in environmental conditions in seven types of microhabitats that were the observation locations. The results of the analysis showed that all the parameters tested had an Asymp. Sig. > 0.05 , namely: plant height (0.230), soil moisture (0.333), light intensity (0.422), air humidity (0.636), temperature (0.385), and soil pH (0.512). Significance values greater than 0.05 indicate that there is no significant difference between microhabitats for each environmental parameter measured.

Thus, it can be interpreted that the environmental characteristics of the seven microhabitats are relatively homogeneous or do not show noticeable variations. These conditions indicate that the observed microhabitats are still in ecological zones that have a level of microclimate similarity, which may be influenced by vegetation cover factors such as canopy, litter, and the distribution of dominant plants that cause the microenvironment to be relatively uniform. This homogeneity also has the potential to cause the growth of vegetation or organisms living in the area to not differ significantly between locations.

Based on the test results, further analysis in the form of post hoc is not required. This is because post hoc is only carried out if the results of the Kruskal–Wallis test show a significant difference ($p < 0.05$), so an explanation is needed about which groups are different. However, in this study, all parameters had a $p > 0.05$, so there was no need for further comparative analysis.

Table 2. Results of Kruskal-Wallis Test of Environmental Parameters in Seven Types of Microhabitats

	Plant height	Soil moisture	LUX	Air humidity	temperature	pH
Kruskal-Wallis H	8.107	6.874	6.008	4.304	6.352	5.250
df	6	6	6	6	6	6
Asymp. Sig.	.230	.333	.422	.636	.385	.512
a. Kruskal Wallis Test						
b. Grouping Variable: Microhabitats						

The absence of significant differences indicates that the microclimatic conditions between locations are relatively homogeneous descriptively with different physical characteristics, such as shady slopes, moist valley bottoms, and rock crevices. In tropical forest ecosystems, canopy cover acts as a buffer for temperature and humidity fluctuations so that

variations between observation points are muted (De Frenne et al., 2019). This stability causes abiotic variation to not be sufficiently contrasting to form a real statistical difference.

Ecologically, the homogeneity of the microclimate favors the predominance of species with wide environmental tolerances and high colonization capabilities, as the genus *Selaginella* has high diversity in tropical and subtropical regions, which indicates the adaptation of this group to tropical humid environments. In relatively uniform environmental conditions, the mechanisms of competition and the efficiency of vegetative reproduction potentially determine community structure more than differentiation abiotic factors, so the diversity of (Weststrand & Korall, 2016). *Selaginella* species becomes low. Thus, the results of the analysis confirm that community structure is more influenced by microclimate stability than by sharp environmental variations between microhabitats.

CONCLUSION

Overall, the distribution of *Selaginella* in the urban landscape of Malang City is limited and fragmented, found in only 19 of the 72 observation points, which shows a strong dependence on moist, shaded, and organic matter-rich microhabitats. The community structure showed a pronounced dominance of *Selaginella eurynota* ($D = 0.499$; $H' = 0.971$) with low evenness, reflecting the process of environmental filtration in the mosaic of urban habitats where only species with wider ecological tolerance and high colonization power are able to survive. Although descriptively the microhabitats appear to be different, statistical tests show no significant differences in environmental parameters between sites ($p > 0.05$), which indicates the homogeneity of the microclimate due to the buffering effect of the canopy and vegetation structure. This condition confirms that microclimate stability plays a greater role in shaping species dominance than sharp abiotic variation, so that low diversity is not solely due to the limited number of species, but also a consequence of ecological selection in urbanized landscapes. Therefore, the management of urban green spaces needs to be directed at increasing the heterogeneity of vegetation structure, soil moisture, and habitat connectivity to support the sustainability of *Selaginella* communities and other understory plant species in tropical urban ecosystems.

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