BIO Web of Conferences **190**, 01024 (2025) https://doi.org/10.1051/bioconf/202519001024
INCOBEST 2025

Assessing the Threat of *Ageratina riparia* to Biodiversity: A Comprehensive Study in Mount Merbabu National Park

Alanindra Saputra [1, 2*], *Ruth Carisa* Putri [2], *Kristina* Dewi [3], *Andhika Puspito* Nugroho [1], Purnomo [1], and *Suwarno* Hadisusanto [1]

[1] Universitas Gadjah Mada, Department of Biology Doctoral Program Faculty of Biology, 91944 Teknika Selatan Street, Sekip, Utara, Yogyakarta 55281, Indonesia
[2] Universitas Sebelas Maret, Department of Biology Education, Faculty of Teacher Training and Education, Ir. Sutami Street No.36A Surakarta 57126, Indonesia
[3] Mount Merbabu National Park, Winong, Boyolali 57315, Central Java, Indonesia

Abstract. Invasive alien species pose a significant threat to biodiversity conservation in protected areas. *Ageratina riparia* has been identified as a problematic invasive species in Merbabu National Park in Central Java. This study analyzed the population structure, distribution patterns, and habitat suitability of *A. riparia* to assess its ecological impacts on native ecosystems. Vegetation surveys were conducted using systematic sampling across different elevation zones of the park. The population density, frequency, and coverage were measured. Distribution patterns were analyzed using the Morisita Index, and habitat suitability modeling was performed using MaxEnt. riparia showed a high population density (7.85 individuals/m²) with 10.79% ground coverage and 78.67% occurrence frequency across sampling points. The species exhibited clustered distribution patterns (Morisita Index > 1) concentrated on mid-to-upper mountain slopes. MaxEnt modeling demonstrated excellent predictive performance (AUC = 0.907) and identified optimal habitat conditions in vulnerable, endemic-rich forest ecosystems. *A. riparia* represents a significant ecological threat to Merbabu National Park's biodiversity through its high dominance, wide distribution, and habitat adaptability. Spatial distribution maps are essential tools for prioritizing conservation interventions and monitoring strategies.

1. Introduction

Mount Merbabu, located in the Central Java region, is a protected area on the island of Java. Mountains are the center of biodiversity and contribute to human health. One of the mountains in Indonesia that is interesting to study is Mount Merbabu because it is a habitat for living things and is beneficial for the water system, namely, as a water source for the community. The Mount Merbabu environment presents an intriguing subject for study because of its potential advantages for conservation initiatives.

[*] Corresponding author: alanindrasaputra@mail.ugm.ac.id

This area has been degraded and provides opportunities for the entry of invasive species into low-lying plant communities [3]. This will cause problems because of the characteristics of invasive plants, namely, fast growth, fast and abundant reproduction, no natural enemies, and ecosystem domination. The overexploitation of natural resources, land conversion, and climate change threaten Indonesia's biodiversity. Invasive alien species are also a threat to biodiversity in Indonesia [1]. Invasive alien species originate from outside the habitat and are introduced into the environment in non-native habitats [2]. Invasive alien species grow rapidly and have an ecological impact on endemic plants in an area.

Invasive alien species appear to be influenced by environmental disturbances, and their growth of invasive alien species occurs naturally [1]. The succession process is closely related to the growth and development of invasive species. In a succession process, invasive alien plant species act as pioneer species that cover the land and alter the environment. Invasive alien species that can adapt well will obtain better resources from native species in those habitats. Thus, alien species can multiply rapidly and invade.

Invasive species are a real threat to biodiversity because they can damage forest biodiversity [4]. Invasive species threaten the integrity of nature and semi-nature and substantially negatively impact flora and fauna. The existence of invasive alien species can suppress native species in ecosystems, leading to the extinction of native species. Invasive species are also an international issue for biodiversity conservation, and their control and management require huge costs [3]. Invasive species are a threat because they can damage native ecosystems and alter nutrient and hydrological cycles. Mastery of their cover indicates the spread of invasive species. The wider the spread, the wider the cover in which it grows, and this type of plant becomes a competitor for endemic plants [2].

Ageratina riparia is an invasive species. This plant is a lower-level plant that can grow at altitudes of 975 meters above sea level to 1,706 meters above sea level. This plant is often found in mountainous areas, secondary forests, and open or semi-open spaces. This plant is an invasive weed that can grow rapidly, particularly in tropical regions. The presence of this plant can be influenced by all measurable environmental factors, such as light intensity, air humidity, soil moisture, soil pH, air temperature, soil temperature, altitude, and land slope. Additionally, *A. riparia* has a high reproductive and adaptive capacity in its environment.

A. riparia can grow and develop in shady or open habitats with sufficient light intensity [5]. Light intensity is one of the factors that can influence other environmental parameters such as humidity and air temperature. Therefore, a high tolerance range for light intensity is accompanied by tolerance for variations in temperature and humidity. This allows plants to adapt to various environmental conditions. Additionally, *A. riparia* can grow and thrive on land with low to steep slopes. This plant can tolerate shade [6].

A. riparia is also often found in low soil pH ranges of 5-6, where soil pH is the tolerance range for the plant to survive. Soil with a pH of 5-6 indicates that the soil is acidic (<7) but close to neutral. Good soil is soil that tends to be acidic to neutral. Soil acidity can be caused by the content and quality of soil organic matter [5]. This plant has spreading roots, allowing it to absorb more nutrients, including pollutants [4].

A. riparia has a high tolerance for environmental factors, resulting in very high reproductive capacity, both generatively and vegetatively. This plant produces 10,000–100,000 seeds per year. This plant has a wide distribution [6] because its seeds are easily dispersed by wind and water, allowing it to dominate and potentially eliminate native species [6]. On eroded or sloping land, surface water carries these seeds during rain, causing them to accumulate in one place, where they then grow and develop [5]. This can lead to a decrease in plant diversity in low-plant communities. The damage caused by *A. riparia*, which is this plant species, has a significant impact on plant communities, allowing exotic species to compete with and potentially displace native species, leading to damage to natural ecosystems [7]. This can lead to a decrease in species richness and biodiversity, which are important factors in the ecosystem balance. *A. riparia* can replace native species in an area and contribute to the decline of native species by outcompeting them for resources, altering habitat structure, and changing ecosystem structure [8]. The invasion of *A. riparia* can negatively impact ecosystem services, such as soil fertility, water regulation, and pollination, which adversely affect conservation efforts [8].

Research on *A. riparia* at Mount Merbabu has not been conducted extensively yet. Published studies only comprehensively cover IAS, with *A. riparia* being a part of IAS, and the research location does not encompass the entire area. The research conducted has not yet detailed the vegetation structure and distribution across different habitat types or elevation zones on Mount Merbabu, Indonesia. Additionally, the suitability of the *A. riparia* habitat on Mount Merbabu has not yet been analyzed. Based on this, research on *A. riparia* as a threat to biodiversity on Mount Merbabu is required. This study examines *A. riparia* in Mount Merbabu National Park using a modern ecological approach that not only looks at a single species but also investigates how the plant alters trophic relationships within the ecosystem. In habitat suitability analysis, this study used a Geographic Information System (GIS) approach and predictive modeling to map the distribution of invasive species and predict areas most vulnerable to invasion. This study aimed to determine the importance of the value index, density, dominance, frequency, and distribution of *A. riparia* and to generate a spatial model for analyzing the habitat suitability of this plant.

2. Materials and Methods

2.1. Study area

The research location is in the Mount Merbabu National Park area, with an altitude of ± 600 – 3,142 meters above sea level. The Mount Merbabu area mostly has a hilly, cliffy, and gorge topography, with slopes ranging from 8% to >60%, including climate type B, with rainfall ranging from 2,000-3,000 mm and a temperature range of 17 °C-30 °C. The Mount Merbabu National Park area consists of four types of ecosystems based on altitude and seven area management zones. This area has four types of ecosystems: low-mountain tropical rainforest, high-mountain tropical rainforest, and sub-alpine forest ecosystems [5]. The research was conducted in Mount Merbabu National Park because the area is a center of biodiversity and contributes to human life. Mount Merbabu is a habitat for living creatures and is beneficial for water management, serving as a water source for the community. This area has been degraded and fragmented due to forest fires or other activities [3], providing an opportunity for invasive species to enter the lowland plant communities.

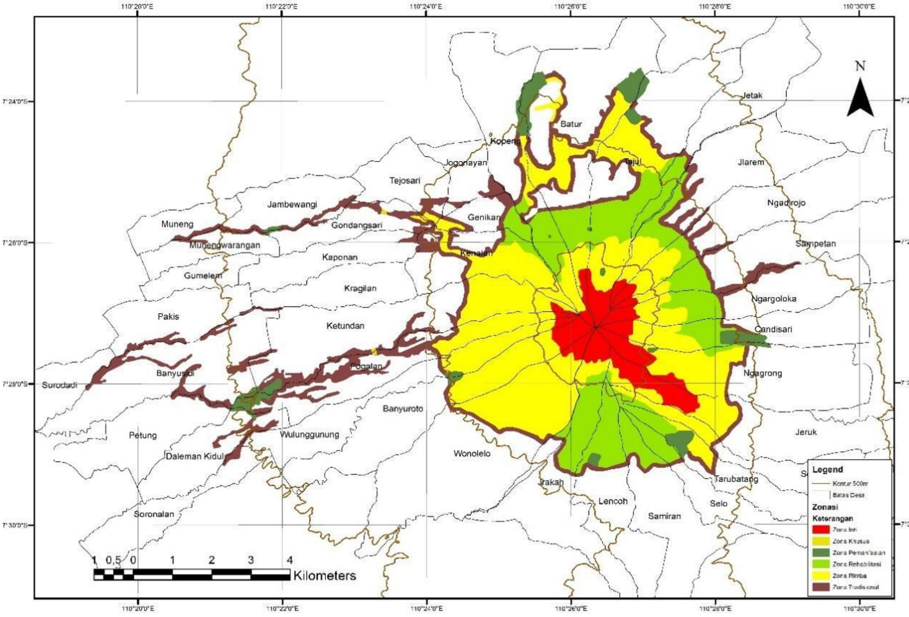

Fig. 1. Map of the Research Location.

2.2.Procedure

The study will be conducted from June 2024 to May 2025. The sampling technique used was random sampling based on ecosystem type (elevation) and zoning. The total number of sampling points was 75 plots. The field sampling method used a quadrant plot with a plot size of 2x 2 meters.

2.2.1 *Analysis of plant structure*

2.2.1.1 *Density (D)*

Density indicates the relative proportion of a species in an area compared with other species. Densities are essential for evaluating species dominance and interactions between plants within a given community, thus providing an overview of vegetation structure [3]. In general, the density is calculated using Formula 1.

$$\text{Density (Dx)} = \frac{\Sigma\ individual\ spesies\ x}{\Sigma\ sample\ area} \quad (1)$$

2.2.1.2 *Frequency (F)*

Frequency was used to assess how often a particular species *of A. riparia* was found in a given area compared to other species of *A. riparia*. Frequency helps analyze plant communities, especially in examining patterns of species dispersal and in understanding the relative dominance of species within an ecosystem. In general, frequency is calculated using Formula 2 [3].

$$\text{Frequency (Fx)} = \frac{\Sigma\ units\ of\ plots\ occupied\ by\ species\ x}{\Sigma\ total\ sampling\ plots} \quad (2)$$

2.2.1.3 *Dominance (Dm)*

Dominance refers to the proportion or influence of *A. riparia* species in an ecosystem compared to other species. Dominance is observed from the total biomass of species in an ecosystem. Species dominance was calculated as the percentage of *A. riparia* cover obtained from the value of the basal area using Formula 3 [3].

$$\text{Dominance (Dmx)} = \frac{\Sigma\ cover\ spesies\ x}{\Sigma\ sample\ area} \quad (3)$$

2.2.2 *Types of analysis distributions*

The type of distribution was analyzed based on the ecosystem type and zoning, and the Morisita Index calculation was used to determine whether the pattern distribution was random, grouped, or ordinary. Formula 4 is used to calculate the Morisita Index.

$$I\delta = N\ \frac{\Sigma\, x2 - \Sigma\, x}{(\Sigma\, x)2 - \Sigma\, x} \quad (4)$$

Information:
$I\delta$ = Morisita index
Σx = Number of individuals per plot
$\Sigma x2$ = Square of the number of individuals per plot
N = Number of sampling plots

If $I\delta$ = 0, the community similarity is low, whereas $I\delta$ A value of 1 indicates that the community similarity is high or equal [9]. After calculating the Morisita index, a chi-square test was performed to determine the uniformity index (Mu) and the grouping index (Mc). The indices are used to improve the Morisita index by placing an absolute scale from -1 to +1 [2]. The distribution pattern is shown through the calculation of Mu and Mc, in Formulas 5 and 6.

$$Mu = \frac{X^2 0.975 - n + \Sigma xi}{(\Sigma xi) - 1} \quad (5)$$
$$Mc = \frac{X^2 0.025 - n + \Sigma xi}{(\Sigma xi) - 1} \quad (6)$$

Information:
Mu = Morisita Index for uniform distribution patterns
$X^2_{0.975}$ = Chi-square value of a table with n-1 degrees of freedom and 97.5% confidence interval
Mc = Morisita Index for grouping distribution patterns
$X^2_{0.025}$ = Chi-square value of the table with n-1 degrees of freedom and a confidence interval of 2.5%
Σxi = Number of individuals of one species in the ith plot
n = Number of plots

Based on the results of Mu and Mc, the Standard Morisita Degree Index (Ip) was calculated, which shows the dominant distribution pattern of plant species [2, 9]. Formulas 7, 8, 9, and 10 are equations for calculating Ip.

$$Ip = 0.5 + 0.5\left(\frac{I\delta - Mc}{N - Mc}\right), \text{ when } I\delta \geq Mc > 1 \quad (7)$$
$$Ip = 0.5\left(\frac{I\delta - 1}{Mc - 1}\right), \text{ when } Mc > I\delta \geq 1 \quad (8)$$
$$Ip = -0.5\left(\frac{I\delta - 1}{Mu - 1}\right), \text{ when } 1 > I\delta > Mu \quad (9)$$
$$Ip = -0.5 + 0.5\left(\frac{I\delta - Mu}{Mu}\right), \text{ when } 1 > Mu > I\delta \quad (10)$$

The determination of plant distribution patterns based on Ip values [2, 9] is as follows: 1) If Ip = 0, then the plant species is randomly distributed; 2) If Ip < 0, then the plant species are uniformly distributed; 3) If Ip > 0, then the plant species are distributed in groups.

2.2.3 *Spatial modeling of species distribution*

To model and predict the spatial distribution of *A. riparia, we used* the maximum entropy algorithm (MaxEnt). MaxEnt modeling was chosen because of its effectiveness in utilizing presence-only data, which is often the only data available for invasive species. This method identifies areas with high habitat suitability that are potential invasion targets, providing a scientific basis for management and mitigation strategies.

Relevant environmental variables or predictors will be used to characterize the ecological niche of *A. riparia*. The selection of variables was based on the ecological understanding of the species and data availability. The predictors included climatic variables (https://www.worldclim.org/), topography, land cover, and distance to anthropogenic features. All environmental variables will be processed to have a uniform spatial resolution and coordinate projection systems.

Spatial distribution modeling will be conducted using MaxEnt software (version 3.4.4). The process includes 1) data partitioning, 2) MaxEnt Parameter Configuration, 3) Model Training, and 4) Model Evaluation. The performance of the model was evaluated using separate test data. The main evaluation metrics included: 1) Area Under the Receiver Operating Characteristic Curve (AUC-ROC); 2) True Skill Statistic (TSS); 3) Partial AUC; 4) Response Curves; and 5) Jackknife Test.

3. Result and discussion

3.1. Result

The research results obtained are the vegetation structure and distribution of *A. riparia* in Mount Merbabu National Park, as well as the spatial modeling of *A. riparia* distribution to analyze the habitat suitability of the species. Vegetation structure analysis included the number of individuals, density, dominance/coverage, and frequency. Species distribution encompasses the presence of species in each ecosystem type based on altitude. The distribution was also analyzed based on its pattern using the Morista Index Analysis (Iδ) method. Spatial modeling of *A. riparia* distribution using MaxEnt produced a distribution model map and habitat suitability analysis for the species.

3.1.1 *Structure of A. riparia in Mount Merbabu National Park*

Table 1. Results of *A. riparia* analysis in Mount Merbabu National Park.

Parameter	Result
Number of Species	2356
Density	7.85 individuals /meter^2
Dominance / Coverage	10.79%/meter^2
Frequency	78.67%

Based on Table 1, the number of *A. riparia* identified in the research area in the Merbabu National Park area, based on 75 plot points occupied, was found to be as many as 2356 individuals. Invasive plant species are defined as non-native species that occupy a new ecosystem and can spread and develop populations rapidly. The existence of invasive species can alter the community structure of ecosystems, decrease biodiversity, and cause environmental damage [10].

Density is the number of individuals found at the observation plot. The higher the density value of a species, the more species are found at the observation plot point. Based on Table 1, the results of density analysis were obtained for *A. riparia,* which is 7.85 individuals /m^2, showing that *A. riparia* has a significant density. Factors affecting species density include resources such as water, nutrients, and sufficient space. Habitats with abundant resources tend to have higher densities. The invasive nature of *A. riparia* growing in the plot area will affect other species and native species. High density reduces the space and resources available for native species for their development.

The dominance or coverage of *A. riparia* is shown in Table 1, with a value of 10.79%/m2. These results indicate that *A. riparia* dominates part of the area studied. The dominance of a species in a certain area can explain the dominance of space and resources of certain species, which can hinder the growth and survival of native species [10]. The dominance of a species is related to the invasion of a species; high performance in growth, reproduction, and tolerance to varying environmental conditions causes a species to be dominant in an area, thus affecting the resources and other plant species and communities. The dominance of invasive species can lead to competition with native species, for example, in competition for light and nutrients because of their deeper roots, resulting in higher levels of water and nutrient uptake. Invasive species can alter the interactions between herbivores and plants, thereby impacting the entire food web. The dominance of invasive species can lead to community homogenization, resulting in a decline in native species populations to extinction.

Frequency is the number of species found at all plot points created, while relative frequency is the comparison between the frequency of the type and the total number of frequencies of all species [3]. Based on Table 1, the relative frequency obtained was 78.67%. Overall, *A. riparia* was found at almost every observation plot. *A. riparia* was found at 59 points out of a total of 75 observation plots in the Mount Merbabu National Park Area. According to Whitmore [10], high relative frequency values indicate that a species has a wide distribution because it has successfully adapted to and dominated the habitat.

3.1.2 *Distribution of A. riparia*

A. riparia exists in all types of ecosystems, namely tropical ecosystems, sub-mountains, mountains, subalpine, and in all zones. Its presence decreases in the subalpine ecosystem type at elevations above 2400 m above sea level. The presence of *A. riparia* based on ecosystem type and zoning is shown in Table 2.

Table 2. The presence of *A. riparia* based on ecosystem type and zoning.

Categor y	Altitude (masl)	Ecosystem Type	Zoning	Existence
I	<1.000	Tropical	Tradisional	✓
II	1.000-1.500	Sub Mountains	Traditional, Utilization, & Jungle	✓
III	1.500-2.000	Mountains	Core, Rehabilitation, & Utilization	✓
IV	2.000-2.400			
V	>2.400	Subalpine	Core and Jungle	✓

A. riparia can grow at an altitude of 975 – 1,706 meters above sea level and is often found in mountainous areas, secondary forests, and open or semi-open areas. The existence of *A. riparia* in category I with an altitude of <1,000 m above sea level was found, but the population density of *A. riparia* in category I was lower than its optimal habitat based on its ecological preference. This occurs because the height of the location affects soil conditions, climate, and competition with other species. At high altitudes, *A. riparia* is found more abundantly, especially at altitudes between 975 and 1706 m above sea level, which is the optimal distribution area of this species. The higher the altitude of the distribution area, the better the environmental conditions, such as lower temperatures and higher humidity, thereby increasing the growth potential and well-being of the species. In lowlands (<1,000 m above sea level), climatic conditions that do not favor its ecological preferences, such as high temperatures and low humidity, usually reduce the abundance *of A. riparia* and may limit its growth and distribution.

The distribution pattern of *A. riparia* was analyzed using poison analysis, which showed a non-random distribution pattern. This analysis was supported by the Morista Index Analysis (Iδ), which indicated a clustered/grouping distribution pattern. The results of the distribution pattern analysis are presented in Table 3.

Table 3. Results of distribution pattern analysis *of A. riparia.*

Parameter	Result
ID	1.61
MU	78.21
MC	76.69
Morisita Degree	0,004
Criterion	Clustered/Grouping

The distribution pattern of *A. riparia* is clustered, which shows that it is caused by differences in environmental conditions that cause individuals to group according to their response to weather changes, reproductive processes, common habitat needs, and the availability of food or shelter [2, 9]. The grouping distribution pattern shows a low individual mortality rate if the environmental conditions are extreme or unfavorable compared to randomly or evenly distributed individuals [2, 9]. The grouping distribution pattern is the result of habitat similarities and resource needs that support the growth of invasive species. This grouping distribution pattern is advantageous for invasive species, as it increases the likelihood of interactions and reproduction with other individuals, resulting in more offspring and strengthening the population in the invaded area. The increasing population of invasive species in the invaded area expands its distribution because it has a high adaptability to various environmental conditions.

3.1.3 Spatial modeling of A. riparia distribution

3.1.3.1 Receiver Operating Characteristic (ROC) Curve

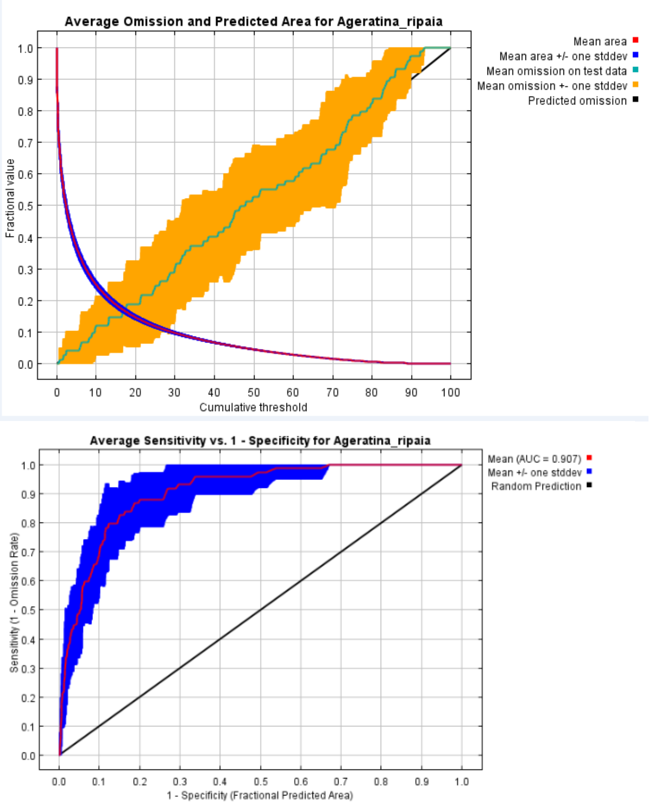

Fig 2. Receiver Operating Characteristic (ROC) Curve.

The receiver operating characteristic (ROC) curve in Figure 2 illustrates the relationship between sensitivity and specificity in the context of species identification. Sensitivity describes how accurately the model predicts the presence of a species, whereas specificity measures the model's accuracy in predicting the absence of a species. The ROC curve was used to evaluate the performance of the species distribution models by calculating the area under the curve (AUC). The higher the AUC value, the better the model performance, with an excellent AUC value above 0.90 [11]. This ROC curve illustrates the relationship between sensitivity (1 - omission rate) and 1 specificity (fractional predicted area) of the model, which serves as the basis for evaluating the model's classification performance against suitable habitats for the species in the study area. The red line represents the average ROC curve obtained from all model replications, the blue area shows the standard deviation (±1 SD) of the replication results, and the black diagonal line indicates the random prediction, which serves as the baseline for evaluation. The area under the curve (AUC) value of 0.907 indicates a very good predictive performance. In the context of MaxEnt modeling, AUC values range from 0 to 1, with values >0.9 categorized as very good models [11]. This indicates that the model has a high ability to distinguish between suitable and unsuitable locations for the presence of *A. riparia* in the study area. High sensitivity and low 1-specificity values in most areas of the curve indicate that the model can accurately predict the presence of species with a low error rate. This is important for the conservation and management of invasive species, such as *A. riparia*, which negatively affects local biodiversity. This model helps identify potential habitats that need to be monitored or controlled to prevent further spread.

3.1.3.2 Map of A. riparia distribution model

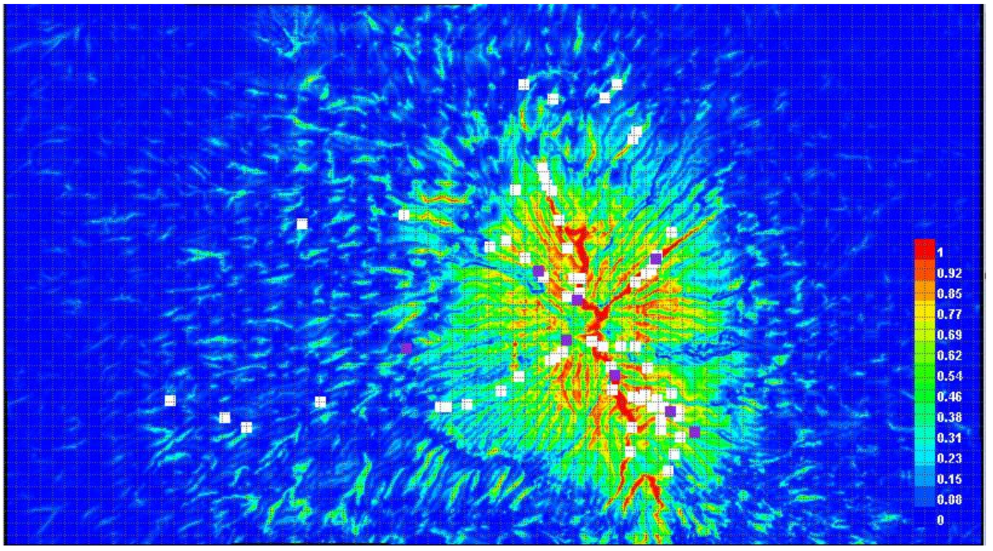

Fig 3. Map of *the A. riparia* distribution model.

Based on Figure 3, the spatial distribution of *A. riparia* in Mount Merbabu National Park appears to be highly concentrated in the middle-to-upper slope zones of the mountain, with a transparent suitability gradient (logistic output) from blue (0 = very unsuitable) to red (> 0.9 = very suitable). The red-yellow radial pattern follows the valleys and disturbance pathways (e.g., hiking trails or water flows) that cut through the forest, a characteristic often reported for invasive species that utilize open gaps and disturbed land as dispersal corridors [11].

3.1.3.3 Jackknife test results

The jackknife test is a statistical method for measuring the impact of environmental variables on the accuracy of species distribution models. The gain test measures how well the model can distinguish between suitable and unsuitable locations for the species [11].

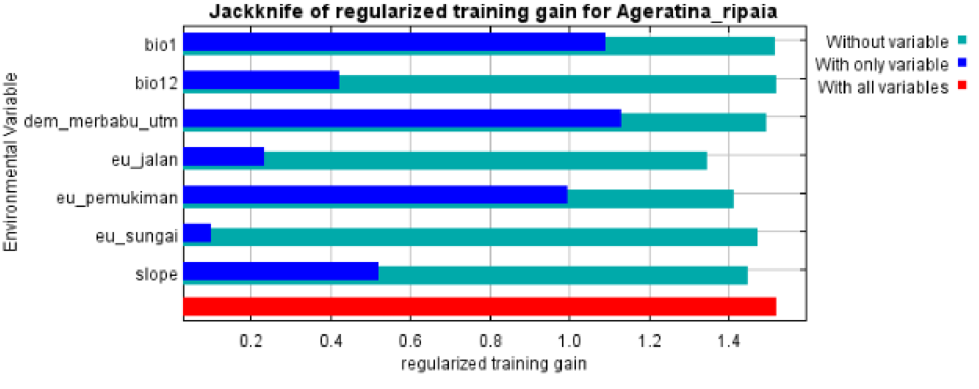

Fig 4. Jackknife test results to see the impact of environmental variables on the *A. riparia* distribution model.

Figure 4 shows the results of the jackknife test on the importance of the environmental variables. The environmental variable that produced the highest gain when used separately was dem_merbabu_utm, which means that this variable contains the most useful information independently. Meanwhile, the environmental variable that showed the greatest decrease in gain when removed from the model was eu_jalan, indicating that this variable provided information not possessed by other variables. The displayed values are the averages of several repetitions (replicate runs).

3.2. Discussion

Invasive species pose a significant threat to biodiversity because they can cause damage and disrupt the balance of forest ecosystems [4]. Invasive species also have a significant negative impact on flora and fauna communities, as they can suppress the presence of native species in the ecosystem. Invasive species have become a global issue in biodiversity conservation. *A. riparia* is an invasive species. *A. riparia* contributes to the decline of native species by outcompeting them for resources, altering habitat structure, and changing ecosystem structure. This can lead to a decrease in species richness and biodiversity, which are important factors in ecosystems. On Mount Merbabu, *A. riparia* poses a serious threat to the ecosystem, potentially dominating and eliminating native species.

This research confirms and strengthens the evidence of the serious threat posed by the invasion of *A. riparia* to biodiversity and ecosystem balance in Mount Merbabu National Park. This study examined the importance of the value index, density, dominance, frequency, and distribution of *A. riparia* and generated a spatial model for analyzing the habitat suitability of this plant. The results also show that *A. riparia* constitutes a significant and widespread population across all types of ecosystems and zoning in Mount Merbabu National Park. This indicates a concerning level of invasion.

The results of the structural analysis show that the density of *A. riparia*, which reaches 7.85 individuals/m² and a land cover of 10.79%/m², indicates a significant dominance in the plant community. These results are consistent with the research on *A. riparia* in a study at the Eka Karya Bali Botanical Garden, which showed a high INP value [7]. This spatial dominance is concerning because of the characteristics of *A. riparia* as an aggressive pioneer weed [7]. The frequency of species presence reached 78.67% of the total sampling points, further affirming *A. riparia*'s ability to form colonies in various locations and ecosystem types, which indicates a widespread ecological threat.

Invasion by dominant species, such as *A. riparia*, often leads to a decrease in the diversity of native species through resource competition (light, water, and nutrients), the release of allelochemicals, and changes in habitat structure [2]. *A. riparia* has abundant seeds, spreads easily, is tolerant of shade, dominates, and has the potential to eliminate native species; therefore, its reproductive power is high [6]. In the context of TNGM, which is rich in endemic biodiversity and rare species, the dominance of *A. riparia* has the potential to displace less-competitive native plant species, alter the structure and composition of vegetation, and reduce the availability of habitat and resources for local fauna. This can trigger a domino effect that threatens the stability of food webs and the overall ecosystem functioning. *A. riparia* is a very dangerous threat because it can damage native ecosystems and alter nutrient and hydrological cycles[2]. *A. riparia* has a high tolerance for environmental factors, resulting in a high reproductive capacity, both generatively and vegetatively, and its seeds are easily dispersed [6]. The research findings at Mount Merbabu

National Park are consistent with studies conducted at Knuckles Forest Reserve in Sri Lanka, which state that the invasive species *A. riparia* forms dense ground cover in significant submontane forest areas, potentially reducing the density and diversity of native forest species by affecting sunlight penetration and the dispersal of other plant seeds [36].

The distribution of *A. riparia* spreads across all ecosystem types and zones in the TNGM. Ecosystem types on Mount Merbabu are classified based on altitude; thus, the altitude gradient affects the physical, chemical, and microbiological properties of the soil, which in turn influences species distribution [14]. Additionally, the altitude gradient affects climatic factors such as temperature and rainfall, and non-climatic factors such as human intervention, soil pH, and humidity, which can significantly influence the distribution of *A. riparia* [15]. The distribution pattern of *A. riparia* based on the Morisita Index was clustered. The clustered distribution pattern indicates the presence of areas where *A. riparia* has successfully formed dense aggregates, most likely in locations with optimal resource availability or minimal competition pressure from native species. Additionally, plants reproduce by producing seeds that fall near their parents [2]. The availability of nutrients and climatic conditions are environmental factors that play the most significant role in the spread of a species in nature [2]. Adult *A. riparia* plants can produce 10,000–100,000 seeds per year. It is usually dispersed through wind and water sources. This plant has a wide distribution [6]. The invasive plant *A. riparia* has characteristics of rapid growth, rapid reproduction, rapid spread, and a wide tolerance range. Moreover, the invasive plant *A. riparia* lacks natural enemies or parasites that can inhibit its growth, allowing it to dominate ecosystems [2]. This dominance can reduce biodiversity, damage the environment, and affect the variety of food choices.

Spatial distribution modeling using MaxEnt can significantly help in understanding habitat suitability and analyzing ways to prevent the spread of *A. riparia*. The modeling results, with an AUC value of 0.907, indicate excellent predictive performance and provide important insights into the potential habitats of *A. riparia*. These results show that the model has a high ability to distinguish between suitable and unsuitable locations for the presence of *A. riparia*, making it useful for monitoring and management efforts [11]. The high accuracy of this model supports the use of species distribution modeling as an effective tool in invasion ecology to predict the spread of invasive alien species and identify vulnerable areas [12]. A distribution model map showing habitat suitability concentrations on the mid-to-upper slopes of the mountain (suitability gradient from blue to red) is essential. These zones may have a combination of environmental factors (e.g., humidity, temperature, soil type, and disturbance levels) that are optimal for the growth and spread of *A. riparia*.

The practical implications of the research results obtained are to provide an ecological picture of *A.* Based on the analysis of its structure and vegetation distribution, this plant is highly dominant and widespread in various ecosystem types. This poses a threat to the biodiversity of Mount Merbabu National Park. Based on this, planning is needed to mitigate and control the spread and population explosion of *A. riparia* in the future. This was identified using spatial modeling, which can identify vulnerable points so that invasion risk maps and areas with the highest threat levels can be viewed. These data can be used as a basis for prioritizing the management and control of development and spread. Data on vegetation structure, distribution, and spatial data can serve as a reference for preventing the spread and prioritizing conservation, especially in critical habitats. Overall, these findings indicate that *A. riparia* poses a significant ecological threat to biodiversity and ecosystem balance in the Mount Merbabu National Park. Management efforts must include controlling the *A. riparia* population in invaded areas, preventing its spread to uninvaded areas, and restoring the native habitats. Further research on the specific impacts of *A. riparia* on native species, community dynamics, and long-term ecosystem functions is urgently needed to formulate the most effective management strategies. Collaboration between sectors, policymakers, and the public is needed to conserve biodiversity from the threat of invasive species dominance.

4. Conclusion

A. riparia demonstrated a notably high population density of 7.85 individuals per square meter, with a ground coverage of 10.79% and an occurrence frequency of 78.67%. The species exhibited clustered distribution patterns concentrated on mid-to-upper mountain slopes. MaxEnt modeling demonstrated excellent predictive performance (AUC = 0.907) and identified optimal habitat conditions in vulnerable, endemic-rich forest ecosystems. A. riparia represents a significant ecological threat to the park's biodiversity through its high dominance, wide distribution, and habitat adaptability. Spatial distribution maps are essential for prioritizing conservation interventions and monitoring strategies to control the spread of this invasive species and protect native biodiversity.

5. Acknowledgments

We thank The Institute for LPPM UNS, the Research and Community Service Institute in Universitas Sebelas Maret, which provides research grant funding in 2024 based on Contract Decree Number 194.2/UN27.22/PT.01.03/2024. We thank Gunung Merbabu National Park for the research permit and many of the facilitations that allowed this research to achieve its goals.

References

1. A. Rasyid, S. M. Suleman, L. Tangge and M. A. Achmad, Types and Densities of Invasive Plant Alien Species (IAS) in the Great Forest Park (TAHURA) of Palu City Implemented as Learning Media. J. of Biology Science and Education, **8**, 630-638 (2020).
2. H. Sulistiyowati, E. Rahmawati, and R. Wimbaningrum, Spatial Distribution Pattern of *Lantana camara* L. Invasive Alien Plant Population in the Savanna Pringtali Resort Bandealit Area, Meru Betiri National Park. J. of Basic Sciences, **22**, 19-24 (2021).
3. Nurmiyati, A. Saputra, P. Karyanto, R. A. I. Dewi, E. Murwaningsih, Y. A. Mala, S. M. Ati. Lower Crop Community Structure and its Implication on the Availability of Food Substrate for the Javan Fuscous Langur. AIP Conference Proceedings 2540, 030002, Surakarta, Indonesia, July 27–28 (2023). https://doi.org/10.1063/5.0105992.
4. J. Master, Types of Invasive Alien Plants in the Road Corridor that Passes Through Bukit Barisan Selatan National Park, in Proceedings of the National Seminar on Science and Technology VI, Institute for Research and Service, University of Lampung, October 1 (2015).
5. D. A. I. T. Sari, I. M. S. Wijaya, Sutomo, Abundance of invasive alien species of teklan (*A. riparia* (Regel) R. M. King and H. Rob.: Asteraceae) on floor vegetation in “Eka Karya” Botanical Garden, Bali. J. Biologi Udayana, **26,** 186-197 (2022).
6. P. S. Ajiningrum, N. A.Hanubah, F. M. H. Gultom, and R. A. Wardani, The diversity of understory plants has medicinal potential on the climbing path of Mount Pundak. STIGMA: J. of Mathematics and Natural Sciences Unipa, **16**, 35-41 (2023).
7. N. Nurlia, and W. Abd Karim, Analysis of angiosperm plant vegetation in Ranga-ranga village, Masama District, Banggai Regency. Edubiotics, **5**, 71-80 (2020).
8. S. P. S. Yadav, D. K. Mehata, N. P. Ghimire, S. Katel, S. Pokhrel, P. Gyawali, P., and U. Timilsina, Invasive alien plant species (Banmara): Investigating its invasive potential, ecological consequences on biodiversity, and management strategies. J. of Agriculture and Food Research, **15** (2024). https://doi.org/10.1016/j.jafr.2024.101031.

9. L. Siahaan, I. Hilwan, Y. Setiawan, Spatial Distribution of Andaliman Potential Habitat acanthopodium DC .) in Samosir Island , North Sumatera (Zanthoxylum), J. of Natural Resources and Environmental Management, **9**, 861-871(2019).
10. S. Solfiyeni, C. Chairul and Marpaung, Analysis of invasive plant vegetation in the Anai Valley nature reserve, West Sumatra. In Proceedings Biology Education Conference: Biology, Science, Enviromental, and Learning, **13,** 743-747, August 6 (2016).
11. Y. Zhao, M. Zhao, L. Zhang, C. Wang, and Y. Xu, Predicting the Possible Distribution of Tea (Camellia sinensis L.) under Climate Change Scenarios Using the MaxEnt Model in China. Agriculture, **11**, 1122 (2021). https://doi.org/10.3390/agriculture11111122.
12. A. Jiménez-Valverde, P. Acevedo, A.M. Barbosa, J. M., Lobo, and R. Real, Predictive modelling of the potential distribution of the alien invasive plant *Carpobrotus edulis* (L.) N.E.Br. in the Iberian Peninsula. Biological Invasions, **13**, 2199-2211 (2011). https://10.1007/s10530-011-0004-7.
13. P. A., Rupasinghe, & A. M. T. A. Gunaratne. Impacts of Ageratina riparia (Regel) R. M. King & H. Rob. on natural regeneration of sub-montane forests at Knuckles Forest Reserve, Sri Lanka. Ceylon Journal of Science, **46**, 85-96. (2017) https://doi.org/10.4038/CJS.V46I4.7471.
14. M. O. Hosli. Shifts in chemical and microbiological properties belowground of invader *Ageratina adenophora* along an altitudinal gradient. Journal of Plant Ecology-Uk, **15**, 561-570 (2022). https://doi.org/10.1093/jpe/rtac003.
15. B. Li, X. Ni, & C. Zhao. Altitudinal Patterns of Native and Invasive Alien Herbs along Roadsides in the Dayao Mountain National Nature Reserve, Guangxi, China. Diversity, **15**, 105 (2023). https://doi.org/10.3390/d15010105.