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Impacts of edge effects on the invasion of alien plant species in Bantimurung Bulusaraung National Park, Indonesia

WARDIMAN MAS'UD[1], RISMA ILLA MAULANY[2], PUTU SUPADMA PUTRA[3], PUTU OKA NGAKAN[2,♥]

[1]Graduate Program of Forestry Science, Faculty of Forestry, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia

[2]Forest Conservation Study Program, Faculty of Forestry, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia. Tel./fax.: +62-411-589592, ♥email: ngakan.po@unhas.ac.id

[3]Department of Agricultural Sciences, Postgraduate School, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia

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Abstract. *Mas'ud W, Maulany RI, Putra PS, Ngakan PO. 2023. Impacts of edge effects on the invasion of alien plant species in Bantimurung Bulusaraung National Park, Indonesia. Biodiversitas 24: 6160-6168.* Invasive Alien Plant Species (IAPS) are a threat to biodiversity and natural ecosystems. Factors influencing the IAPS distribution are well-known, but the impact of edge effects on the distribution is rarely discussed. This study aims to reveal the effect of differences in physical environmental factors along the edge effect gradient on the distribution of IAPS in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia. Twenty-five line transects were established where 125 plots (20m x 20m) were systematically located to analyze the density, dominance, and distribution of IAPS on the edge bordering natural forest ecosystems and anthropogenically disturbed areas. Of the 21 IAPS found, 95.2% were distributed in clumps and 4.8% at random. As the light intensity decreases significantly ($r = 0.042$; $p = 0.029$) with the increasing distance from the edge to the forest interior, the IAPS density decreases significantly ($r = -0.512$; $p = 0.0001$). Species of IAPS that experienced a decrease in individuals were those with a habitus of herbs and shrubs. Considering that the seedlings were found to spread outside their mother tree stands, *Swietenia macrophylla* King. and *Maesopsis eminii* Engl. are suspected to be long-lived IAPS that have the potential to spread to natural karst forest ecosystems, so they need to be monitored continuously.

Keywords: Anthropogenic disturbances, distribution, karst forest ecosystem, physical environmental, pioneer species

INTRODUCTION

Invasive Alien Plant Species (IAPS) are among the greatest threats to biodiversity and ecosystem functions (Brundu and Richardson 2016; Lapin et al. 2019). In addition, IAPS also have a negative impact on nature's contribution to people, and good quality of life (IPBES 2023). Their ability to adapt to anthropogenically disturbed habitats outside their natural habitat allows these plant species to spread across various vegetation types (Braun et al. 2016; Jamil et al. 2022). Invasive alien plant species threaten biodiversity by competing native species for nutrient uptake and sunlight availability (Wahyuni et al. 2016; Hejda et al. 2017; Solfiyeni et al. 2022). These species also have the potential to halt the process of regeneration of native species (Dyderski and Jagodzinski 2020). Six percent of all invasive alien plants are reported to have a negative impact on nature, nature's contribution to people, and good quality of life. As many as 218 invasive alien species have caused the extinction of 1,215 local native species, 15.4% of which are IAPS (IPBES 2023). In Indonesia, IAPS are reported to have invaded natural ecosystems in several conservation areas (Kudo et al. 2014; Padmanaba et al. 2017; Mukaromah and Imron 2019).

There are several environmental factors that have the potential to influence the distribution of IAPS, which can be mainly distinguished into biotic and abiotic factors. Biotic factors are environmental elements composed by living organisms such as the species composition and structure of the original ecosystem. While the abiotic factors are environmental elements composed by physical attributes including soils and microclimate such as soil moisture, temperature and light intensity. Both factors might contribute simultaneously on the spread and establishment of IAPS (Radosevich et al. 2007; Witt et al. 2018).

Edge effects are changes in species composition and community structure that occur at the boundary of two ecosystems (Potts et al. 2016). The occurrence of edge effects in a forest landscape can be caused by various factors, such as differences in topography, soil type, landform, and anthropogenic disturbances (Harper et al. 2005). Edge effects can also occur when part of a natural ecosystem is affected by a nearby disturbed ecosystem. In the edge effects resulted from the disturbance of adjacent ecosystems, biotic and abiotic environmental factors change along a gradient from the outer edge to the interior of the natural ecosystem (Alignier and Deconchat 2013; Astiani et al. 2018). Changes in abiotic (physical environment) factors along with edge effects can make it easier for IAPS to invade natural ecosystems (Otto et al. 2014; Ruwanza 2019; Brown el al. 2020).

Bantimurung Bulusaraung National Park (Babul National Park) with an area of ±43,750 ha is a conservation area situated in South Sulawesi Province, Indonesia with the main objective is for the preservation of the limestone (karst) ecosystem. The area encompasses three districts in the province: Maros, Pangkep and Bone. Karst ecosystem has unique characteristics in which the limestone geological formation has poor soil quality, limiting the growth of tree vegetation and making tree crown density in karst forests generally low. While not suitable for many plant species, such conditions can be an excellent habitat for IAPS to grow. In addition, massive anthropogenic activities, such as farming, mining and illegal grazing, in areas bordering Babul National Park might create edge effects which facilitate the invasion and establishment of IAPS into the national park area. These have the potential to threaten the growth of native plant species in the karst forest ecosystem of Babul National Park, many of which are endemic.

The karst forest ecosystem is very fragile; therefore, the potential invasion of IAPS into the forest interior ecosystem of Babul National Park needs to be considered early on. This is very important because many plant species in the karst ecosystem of Babul National Park, such as *Hopea celebica* Burck, *Diospyros celebica* Bakh., more than 30 species of *Ficus*, at least 3 species of *Garcinia*, *Artocarpus heterophyllus* Lam., *Parartocarpus* sp., *Dracontomelon dao* (Blanco) Merr. & Rolfe, and *Pangium edule* Reinw. are either native or endemic (Putra et al. 2023; Yelastri et al. 2023) and hosts for various species of wildlife that are unique to the karst forest ecosystem. This national park is also the habitat of many groups of endemic and endangered primate to South Sulawesi, including *Macaca maura* (Schinz 1825) (Albani et al. 2020; Riley et al. 2023). Allowing invasion by IAPS into karst ecosystems will place native and endemic plant and wildlife species under threat of extinction. Information regarding the threat of IAPS in Babul National Park is still limited to the presence of invasive *Spathodea campanulata* Beauv. as reported by Nasri and Ngakan (2022), while the presence of other invasive species and their level of threat to native biodiversity are still unknown. This study aimed to reveal the species composition and distribution patterns of IAPS and analyze the influence of physical environmental factors on the distribution of these species along the gradients of edge effect in Babul National Park. The results of this study will greatly assist in preventing and eradicating the invasion of IAPS into karst forest ecosystems in Babul National Park and elsewhere.

MATERIALS AND METHODS

Study area and period

The research was carried out in the management area of the Tondong Tallasa Resort of Babul National Park (hereinafter Tondong Tallasa Resort), located in South Sulawesi Province, Indonesia (119º34'17"-119º55'13" E, 04º42'49"-05º06'42" S). There are 5 villages bordered with the Tondong Tallasa Resort management area, namely Malaka, Bantimurung, Bonto Birao, Lanne and Bonto Masunggu (Figure 1). The research was conducted in five months, from August to December 2022.

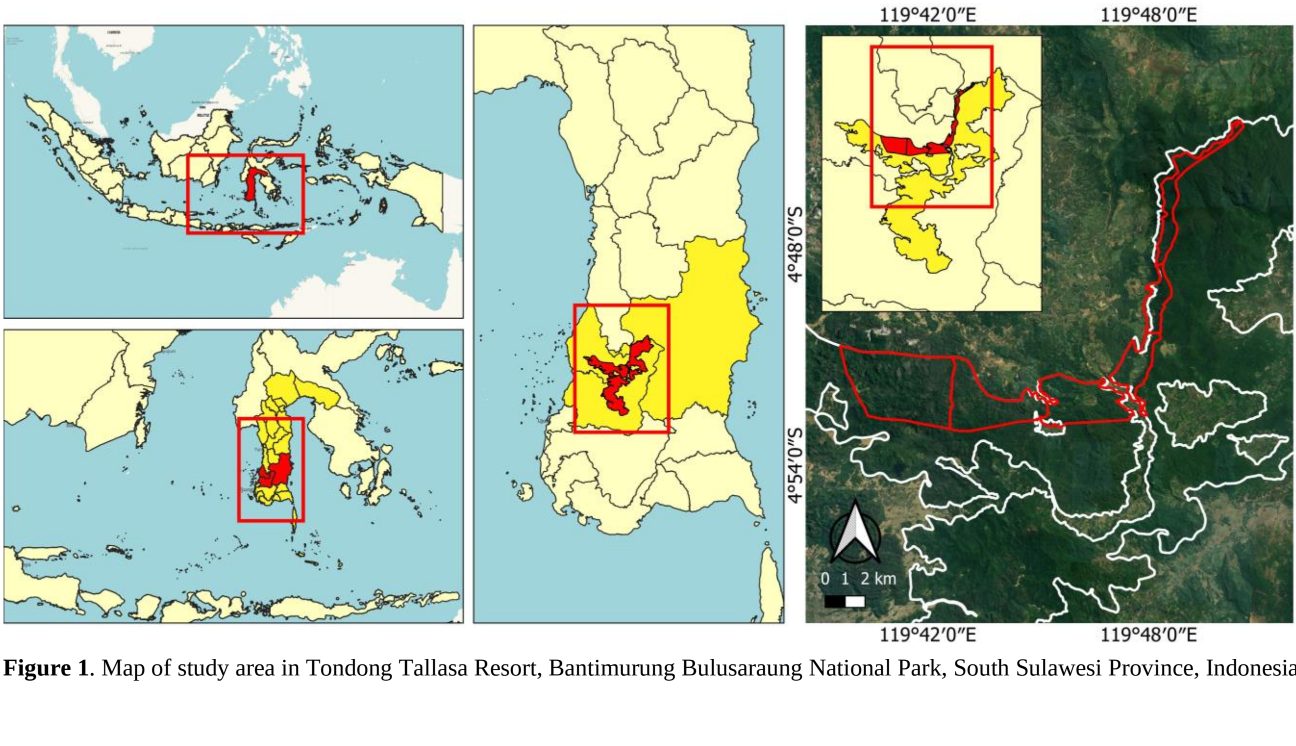

Figure 1. Map of study area in Tondong Tallasa Resort, Bantimurung Bulusaraung National Park, South Sulawesi Province, Indonesia

Species composition and distribution patterns of invasive alien plants

Five line transects were established in every village bordered with Babul National Park. The transects were purposively set at sites with anthropogenic disturbances, including abandoned lands, rural roads, settlements, gardens or rice fields. The length of each line transect was 200 m, and five observation plots, each measuring 20m x 20m, were arranged systematically along the transect line. Within the main plot, nested plots (sub-plots) of different sizes were created and vegetation inventory was conducted based on the growth stage of the plants, i.e. trees (greater than 20cm in diameter) within the 20×20 m plots; poles (trees from 10 cm to 20 cm in diameter) within the sub-plots measuring 10m x 10m; and saplings (trees with diameters from 5 cm to 10 cm) within the sub-sub-plots measuring 5×5 m. Seedlings, herbs, lianas, and other undergrowth were also inventoried in sub-plots measuring 5×5 m. To calculate the basal area, the diameters of trees, poles, and saplings of all IAPS found in the plots were measured at 130cm above the ground. For seedlings and other understory plants, IAPS were counted in their individual numbers to calculate their density.

Measurement of physical environmental factors

Physical environmental factors measured were those that change in line with changes in environmental conditions gradually from the edge into the forest interior. The physical environmental factors that were measured in every plot included light intensity, soil moisture, air humidity, canopy cover intensity and distance from the edge. Light intensity was measured using a lux meter AS803, soil moisture was measured using a soil tester SPH004, air humidity was measured using a hygrometer UT333, and distance from the edge was measured using GPS Garmin 64S. Measurement of physical environmental factors was carried out in the middle of the dry season (August 2022). Light intensity was measured between 11:45am and 12:15pm in clear, cloudless weather. Light intensity, soil moisture, and air humidity measurements were repeated three times at different locations on each plot. For the measured distance from the edge to the forest interior, the border between the intensively managed land and the abandoned area in front of the forested area was determined as the edge border. In addition, the percentage of tree canopy cover using cover intervals was measured: 0-25%, 25-50%, 50-75%, and 75-100% (Hattori et al. 2013; Mandl et al. 2023).

Data analysis

Vegetation data were analyzed to determine species composition, density, dominance, frequency, and Importance Value Index (IVI). The IVI was calculated by adding up the Relative Density (RD), Relative Frequency (RF), and Relative Dominance (RDi) values. RD is the ratio of a species' density to all species' total density. RF is the ratio of one species' frequency to all species' total frequencies. RDi is the ratio of a species' dominance to all species' total dominance. The IVI for seedlings, herbs, and other understory plants is calculated by adding the RD and RF (Indriyanto 2006).

The distribution pattern of each IAPS indicates the tendency of the distribution of a species in a community. To find out the pattern of distribution of each IAPS in the Tondong Tallasa Resort, Babul National Park, an analysis was carried out using the I delta (Id) equation (Morisita 1959) as follows:

$$Id = n\frac{\sum X^2 - N}{N(N-1)}$$

Where:
N : the number of individuals in all subplots.
$\sum X^2$: the sum of squares for individual numbers in one subplot
n : the number of subplots

When Id = 1, the distribution pattern is random. When Id<1, the distribution pattern is uniform, and when Id>1, the distribution pattern is clumped. Furthermore, to find out whether the distribution pattern of the IAPS is clumped or not, a test was carried out with the Chi Square test as follows (Soegianto 1994):

$$X^2 = \frac{n\sum X^2}{N} - N$$

Where:
N : the number of individuals in all subplots
$\sum X^2$: the sum of squares for individual numbers in one subplot
n : the number of subplots

The calculated χ^2 value obtained from the Chi Square test is then compared with the χ^2 table. If the χ^2 value is greater than that on the χ^2 table, it means that the distribution is significantly different, which indicates that the distribution pattern is clumped. If χ^2 value is less than the χ^2 table value, the distribution is not significantly different, which means that the distribution pattern is random.

Physical environmental factor data from each plot across all transects was averaged for display in a single graph based on the distance of the plot from the outer edge to the interior of the forest. Linear regression analysis was applied to investigate the relationship between each physical environmental factor and the distribution of IAPS along the transect. The Principal Component Analysis (PCA) method was used to determine the physical environmental factors that have the highest correlation with the distribution of IAPS. Linear regression analysis and PCA were performed using R Studio 4.3.1 software (R Core Team 2021).

RESULTS AND DISCUSSION

Species composition and distribution patterns of invasive alien plant species

As many as 99 plant species from 48 families were found across all plots, of which 21 species were confirmed to be IAPS. In Table 1, we differentiated the 21 IAPS into four life stages: seedling and undergrowth (including herb, shrub, liana, etc.), sapling, pole, and tree stages. At the seedling stage and undergrowth, the IAPS were dominated by short-lived shade-tolerant pioneer species such as *Chromolaena odorata* (L.) R.M.King & H.Rob. and *Piper aduncum* L. (Table 1). Among the 21 IAPS, eight species belong to the tree stage. *Swietenia macrophylla* King is a long-lived pioneer tree species that dominates the sapling, pole, and tree stages. 95% (20 out of 21) of the IAPS were found to spread in clumps, while only one, *S. macrophylla*, was distributed randomly. Among those scattered in clumps, most of the clumps were found on the outer part of the edges. Meanwhile, *S. macrophylla*, which was randomly distributed, was sometimes found in stands close to the forest interior and sometimes scattered at the sapling and pole stages at the other part of the edge.

Table 1. Species composition and structure of IAPS at the Tondong Tallasa Resort, Babul National Park. Invasive species referred to Weber (2003), Setyawati et al. (2015), and Tjitrosoedirdjo et al. (2016)

Life stage	Life form	Species	Family	D ind./ha	F %	BA m^2/ha	IVI %
Seedling, herb, scrub, and other undergrowth	Herb	*Centella asiatica* (L.) Urb. *	Apiaceae	3.80	5	-	10.63
	Shrub	*Brugmansia suaveolens* (Willd.) Bercht & J. Presl.*	Solanaceae	2.00	4	-	6.78
		Calliandra houstoniana var *calothyrsus* (Meis.) Barn.*	Fabaceae	1.40	2	-	4.43
		Chromolaena odorata (L.) R. M. King & H. Rob.*	Asteraceae	11.60	21	-	37.41
		Clidemia hirta (L.) D. Don.*	Melastomata.	1.60	4	-	6.07
		Gigantochloa apus (Schult.f) Munro.*	Poaceae	4.60	14	-	19.15
		Jatropha curcas (L.)*	Euphorbia.	1.80	4	-	6,43
		Jatropha gossypifolia (L.)*	Euphorbia.	0.40	5	-	4.58
		Lantana camara (L.)*	Verbenaceae	3.80	8	-	13.21
		Melastoma malabathricum (L.)*	Melastomata.	2.40	6	-	9.43
		Piper aduncum (L.)*	Piperaceae	5,20	10	-	17.64
		Solanum torvum Sw.*	Solanaceae	3.60	7	-	12.21
		Stachytarpheta jamaicensis (L.) Vahl.*	Verbenaceae	3.00	8	-	11.79
	Tree	*Acacia auriculiformis* Benth.**	Fabaceae	0.20	1	-	1.00
		Acacia mangium Willd.**	Fabaceae	1.00	2	-	3.71
		Muntingia calabura (L.)**	Elaeocarpa.	0.20	1	-	1.00
		Psidium guajava (L.)**	Myrtaceae	3.00	7	-	11.14
		Senna siamea (Lam.) H. S. Irwin & Barn.**	Fabaceae	1.20	2	-	3.43
		Maesopsis eminii Engl.***	Rhamnaceae	1.40	3	-	5.07
		Swietenia macrophylla King.***	Meliaceae	2.80	7	-	10.79
		Syzygium cumini (L.) Skeels.***	Myrtaceae	1.20	2	-	4.07
Sapling	Shrub	*Jatropha gossypifolia* (L.)*	Euphorbi.	0.40	2	0.10	6.74
		Piper aduncum (L.)*	Piperaceae	4.00	9	1.07	51.56
	Tree	*Acacia auriculiformis* Benth.**	Fabaceae	0.20	1	0.16	4.48
		Muntingia calabura (L.)**	Elaeocarpa.	0.80	2	0.68	14.62
		Psidium guajava (L.)**	Myrtaceae	2.40	7	1.07	39.71
		Senna siamea (Lam.) H. S. Irwin & Barn.**	Fabaceae	0.80	1	0.29	8.87
		Maesopsis eminii Engl.***	Rhamnaceae	1.60	2	0.88	22.62
		Swietenia macrophylla King.***	Meliaceae	8.40	18	5.08	134.96
		Syzygium cumini (L.) Skeels.***	Myrtaceae	1.00	2	0.57	16.45
Pole	Tree	*Acacia auriculiformis* Benth.**	Fabaceae	0.40	2	1.01	14.09
		Muntingia calabura (L.)**	Elaeocarpa.	0.20	1	0.24	5.95
		Psidium guajava (L.)**	Myrtaceae	0.60	2	1.02	19.12
		Senna siamea (Lam.) H. S. Irwin & Barn.**	Fabaceae	0.60	2	0.44	13.62
		Maesopsis eminii Engl.***	Rhamnaceae	0.40	2	0.57	12.27
		Swietenia macrophylla King.***	Meliaceae	8,20	6	20,17	221.12
		Syzygium cumini (L.) Skeels.***	Myrtaceae	0.40	2	0.94	13.82
Trees	Tree	*Acacia auriculiformis* Benth.**	Fabaceae	0.80	3	4.45	13.88
		Acacia mangium Willd.**	Fabaceae	0.80	2	4.70	12.30
		Senna siamea (Lam.) H. S. Irwin & Barn.**	Fabaceae	0.20	1	0.79	3.28
		Muntingia calabura (L.)**	Elaeocarpa.	0.20	1	0.79	3.28
		Maesopsis eminii Engl.***	Rhamnaceae	3.80	10	35.05	63.80
		Swietenia macrophylla King.***	Meliaceae	11.20	25	108.71	178.63
		Syzygium cumini (L.) Skeels.***	Myrtaceae	1.40	04	14.56	24.84

Note: D: Density; F: Frequency; BA: Basal Area; IVI: Important Value Index at each stage; *: Short-lived herb/shrub; **: Short-lived tree; ***: Long-lived tree

Physical environmental factors

Along the 200 m transect line from the edge into the forest interior, the mean values of soil moisture (Figure 2.A) and air humidity (Figure 2.B) did not change markedly. The canopy cover increased markedly with increasing distance from the edge to the forest interior (Figure 2.C). As the canopy cover increases, light intensity decreases with distance from the edge into the forest interior (Figure 2.D).

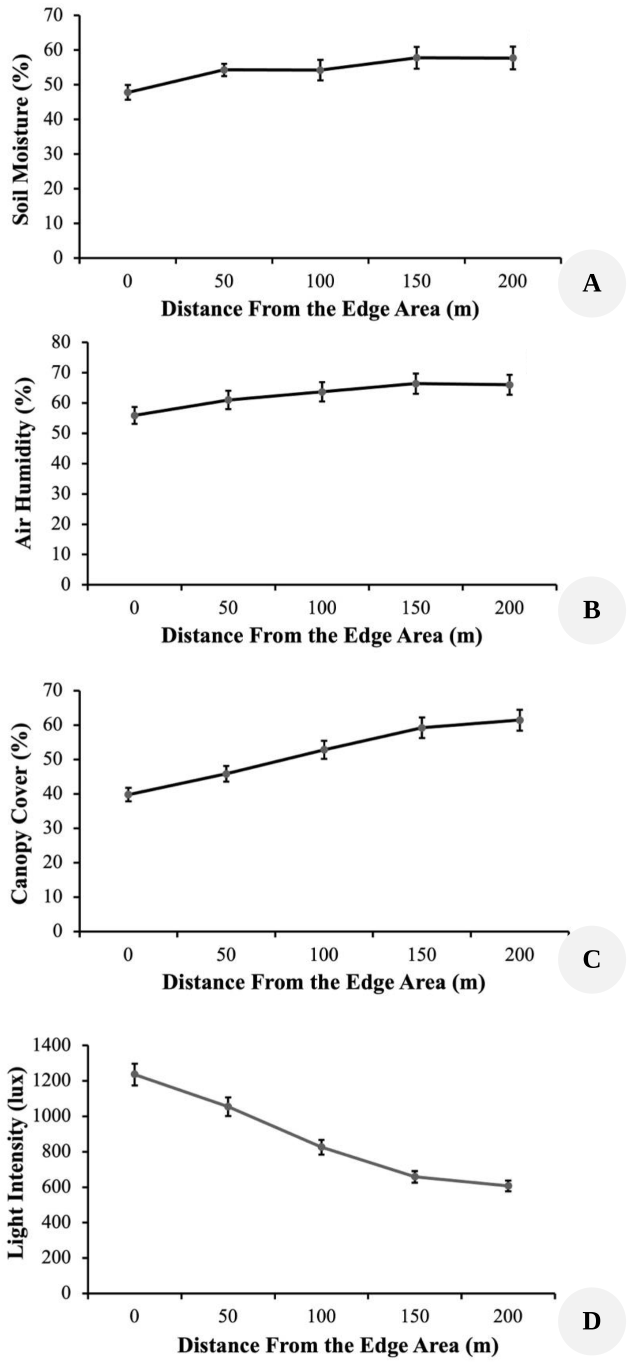

Figure 2. The change in physical environmental factors along the distance gradient from the edge to the forest interior: (A) soil moisture; (B) air humidity; (C) canopy cover; (D) light intensity

Impacts of physical environmental factors on the distribution of invasive alien plant species

The number of individual of IAPS had significant and negative relationship (r = -0.512; p = 0.0001) with the distance from the edge to the interior of the forest, meaning that the further is distance from the edge, the lower is number of individuals of IAPS. Significant negative relationship was also detected between the number of individual IAPS and the canopy cover intensity (r = -0.265; p = 0.010). In contrast, a significant positive relationship was detected between light intensity and the number of IAPS individuals (r = 0.042; p = 0.029). No significant relationship was detected between air humidity and number of IAPS individuals (r = -0.333; p = 0.254). While air humidity ranged from 45% to 79%, most individuals with IAPS were found at sites with humidity between 51% and 75%. No significant relationship was also detected between soil moisture and number of individuals of IAPS (r = -0.229; p = 0.066). Most of the IAPS individuals were found in the 26%-75% soil moisture interval (Figure 3).

PCAs were used to avoid data multicollinearity between independent variables (physical environmental factors with edge effects) and to find out the physical environmental factors that have the greatest influence on the distribution of IAPS individuals. The PCA results showed only one new component that has an eigenvalue >1, which means that the other components are automatically excluded from the analysis model. The main components can explain 65.79% of the variation in the distribution of IAPS individuals. Determining the value of each physical environmental factor's variable edge effect on the main component shows that the canopy cover has the highest component value (Table 2). This means that canopy cover is the most influential factor in determining the distribution of IAPS individuals.

Discussion

A total of 21 IAPS were found across the five study sites in the Tondong Tallasa Resort, Babul National Park. Srivastava et al. (2014) and Dubyna et al. (2022) revealed that most IAPS are pioneer species, which usually invade habitats in the early stages of succession. For further discussion, we distinguished the IAPS into 3 categories: short-lived herbs/shrubs, short-lived trees, and long-lived trees. Short-lived herbs/shrubs of IAPS are shade-intolerant plant species that grow no higher than the undergrowth.

Table 2. The value of the physical environmental factor variable of the edge effect on the main components

Variable	Component value
Distance from the edge	0. 674
Light intensity	0. 897
Canopy cover	0. 921
Soil moisture	0. 716
Air humidity	0. 818

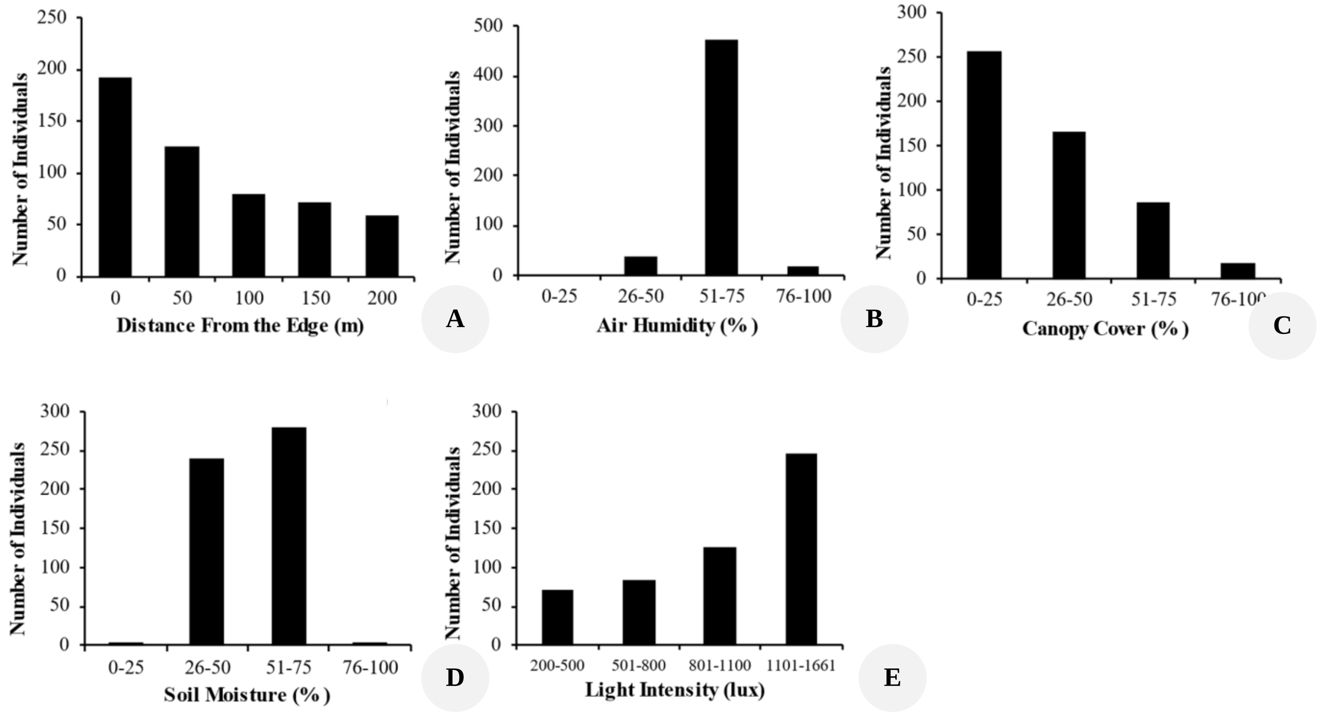

Figure 3. Number of individual IAPS found at Tondong Tallasa Resort along the gradient of: (A) distance from the edge; (B) air humidity; (C) canopy cover; (D) soil moisture; (E) light intensity

These species usually cannot survive in a habitat where there are trees that shade them. Short-lived IAPS trees are also shade-intolerant tree species that can grow into small trees no more than 80-100 years old. This tree species cannot survive when other trees grow beside it and shade it. Long-lived IAPS trees are those that can grow to the highest forest canopy more than 80-100 years old, allowing no other tree species to shade them (Larson 2001; Spînu et al. 2023). Long-lived IAPS trees may be shade-semi-tolerant species. When the seeds of these species germinate under their parent tree stand, the juveniles are capable to grow under the shade of their parent tree, and they will occupy this habitat permanently.

Among the 21 IAPS, 13 belong to the short-lived herb/shrubs species category, five fall into the short-lived tree species category, and three fall into the long-lived tree species category. The *C. odorata* and *P. aduncum* were the most common short-lived herbs/shrubs IAPS. In the category of short-lived tree species, *Psidium guajava* L. and *Acacia* trees were the most common. *S. macrophylla* and *Maesopsis eminii* Engl. were the most common long-lived invasive alien tree species.

This study found a significant negative relationship between the distance from the edge to the forest interior and the density of all IAPS. This finding aligns with other results, which show that light intensity decreased significantly as canopy cover increased with distance from the edge to the forest interior. Given that decreased canopy cover correlates with forest destruction, these findings suggest that denser IAPS are found in more disturbed forests. This proves that invasive species are generally pioneer species that cannot survive under the cover of other species and are primarily found in disturbed forests (Hermawan et al. 2014; Bradley et al. 2015; Lapin et al. 2019; Liu et al. 2022).

Short-lived herb/shrub IAPS may only temporarily colonize degraded forest areas, and their populations will decline as other species with higher habitus come to exist. Therefore, their presence on newly cleared forest land may be necessary to cover the soil surface and prevent erosion. However, this may not apply to species with liana lifeforms, whose growth may extend into the tree canopy. Master et al. (2013) reported that *Merremia peltata* (L.) Merr. (Convolvulaceae), an IAPS with liana habitus, has caused severe ecological problems in Bukit Barisan Selatan National Park. Due to its rapid growth, its liana habitus allows the species to spread rapidly, covering and killing other tree species it climbs on, including native trees growing in non-degraded forests (Marshall et al. 2020). Fortunately, none of the 21 IAPS found in this study had a liana habitus.

Among the five species of short-lived IAPS trees, we found two species of *Acacia* trees, namely *A. auriculiformis* and *A. mangium* at all life stages. Even though these two species were less dominant than *P. guajava*, they need serious attention. This is because several studies show that *Acacia* species are known as very aggressive IAPS (Koutika and Richardson 2019; Minteer et al. 2020). They produce long-lived seeds daily that are capable of long dormancy and long-distance dispersal by birds (Low 2012; Koutika and Richardson 2019). Seeds accumulate in the soil as a seed bank waiting for the right conditions to initiate a burst of germination. When a forest burns, the accumulation of seeds in the soil breaks dormancy and triggers germination, forming dense seedlings on the forest floor. Jambul et al. (2020) revealed that the dominance of *A. mangium* can be used to determine the level of disturbance in healthy forests so that it can be used as an indicator of forest health.

Muntingia calabura L. and *P. guajava* are short-lived IAPS trees that produce fleshy fruits containing abundant tiny seeds. These fruits are favored by moor macaque (*M. maura*) and many other frugivores. Frugivores eat the fruits, swallow them with the seeds intact, and disperse the seeds within their home range. However, both species are species that are intolerant of the shade of other trees and their seeds will not germinate and grow under dense forest stands (Nghiem et al. 2015). Both species will only grow in completely open areas. The *S. macrophylla and M. eminii* are long-lived invasive alien tree species (Moghadamtousi et al. 2013; Epila et al. 2017). The seeds of *S. macrophylla* have good wind dispersal ability (Telrandhe et al. 2022), while the seeds of *M. eminii* are well dispersed by animals because many wild animal species as well as cattle and dogs prefer its fleshy fruit (Commonwealth Agricultural Bureaux International 2019; First author's field observation, November 2022). These two species of trees were deliberately planted in this area as reforestation plants in the 1980s-2000s (Nawir et al. 2007). Currently, the juveniles of these two tree species have begun to spread outside the area where their parents were planted. The *M. eminii* has been reported to invade natural forests in Tanzania, threatening local biodiversity, and the invasion of *S. macrophylla* inhibits seedling growth of native trees in the Philippines (Mwendwa et al. 2020a; Galano and Rodriguez 2021). This study found *S. macrophylla* and *M. eminii* at all life stages: trees, poles, saplings, and seedlings. The density of *S. macrophylla* was higher compared to that of *M. eminii*.

Seedlings of *S. macrophylla* showed better adaptability to growing under the forest canopy than *M. eminii*. The *S. macrophylla* were not only found under the canopy of their parent trees, but had spread some distance into the dense forest canopy. Meanwhile, *M. eminii* seedlings were found in open areas. Therefore, we assume that these two species might have different invasion strategies. Because the karst forest canopy is usually not very dense, *S. macrophylla* seeds that are dispersed by the wind may still germinate under the shade of the karst forest canopy, and grow into mature trees, and regenerate there. Slowly but surely, *S. macrophylla* can permanently dominate the karst forest, even though the forest is not disturbed. Given that its seedlings do better in open areas (Moe et al. 2016), *M. eminii* invasions may need to wait for severe forest degradation. Once *M. eminii* invades open forest areas, it has the potential to dominate the area at one level of the seral community. However, seral communities dominated by *M. eminii* may not be permanent and will be replaced by climax communities consisting of tree species whose seeds can germinate under the dense canopy of the mother tree (Mwendwa et al. 2020b).

Previously, Nasri and Ngakan (2022) also studied the invasion of the worst invasive tree species, *S. campanulata*, also in the Bantimurung Bulusaraung National Park. They report that this species is rapidly overtaking the natural biodiversity in two separate areas, the Karaenta and Pattunuang forest areas. In the sample transects of this study, we found no individuals of this species. However, several small trees of this species grew in settlement areas near the study site. Nghiem et al. (2015) reported that seedlings of this species have good ability to grow under dense forest canopy.

Based on the findings of this study, we conclude that the invasion of alien plant species as the impact of edge effect aligns with changes in several physical environmental factors along the edge effect gradient, especially the light intensity associated with the vegetation cover. Distance was also found to be negatively correlated with IAPS distribution; the further the site is located from the edge, the abundance of IAPS decreases. Most of the plant species that invade the area along the edge-effect gradient are short-lived undergrowth species, which die if nearby trees grow and shade them. IAPS trees that need attention at the research location are two short-lived IAPS trees namely *A. auriculiformis* and *A. mangium* and two long-lived IAPS trees, namely *S. macrophylla* and *M. eminii*. The latter two species are widely used in reforestation projects (Nawir 2007; Telrandhe et al. 2022) and may be profitable because they quickly grow to cover abandoned land and also produce good-quality of wood. However, their existence in national park areas can cause serious problems because it has the potential to threaten the diversity of native plant species that are protected in the area.

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