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Distribution of invasive alien plant species, *Bellucia pentamera*, in forest conservation of oil palm plantation, West Sumatra, Indonesia

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Abstract. *Solfiyeni, Mukhtar E, Syamsuardi, Chairul. 2022. Distribution of invasive alien plant species,* Bellucia pentamera*, in forest conservation of oil palm plantation, West Sumatra, Indonesia. Biodiversitas 23: 3667-3674. Bellucia pentamera* has been found in disturbed forests across Indonesia, but little is known about how it spreads under its tree canopy. The spread of the invasive plant *B. pentamera* in the PT KSI conservation forest area was investigated. The goal of this research is to study *B. pentamera'*s strategy for exploiting forest gaps horizontally and vertically on degraded forest vegetation invaded by *B. pentamera* at various degrees of invasion. An Unmanned Aerial Vehicle (UAV) and direct field mapping are used for the mapping approach. Aerial photographs revealed 40 *B. pentamera* trees and 32 non-*B. pentamera* trees in forest areas with varying degrees of *B. pentamera* invasion (based on the ratio of *B. pentamera* non-*B. pentamera*: dense and loose). *Bellucia pentamera* trees were distributed evenly in a large gap and randomly in a small gap/space between the canopy, whereas sapling and seedling *B. pentamera* trees were distributed in groups, uniformly and randomly, according to microhabitat conditions under the canopy of *B. pentamera* and non-tree trees. *Bellucia pentamera* seedlings and saplings were detected under the parent tree's canopy rather than in the canopy gaps. Different responses were seen in seedlings, saplings, and juvenile stages concerning the explanatory factors investigated and between the two stands. The purpose of the study was to determine the factors that influence the distribution of the *B. pentamera* species in conservation forest areas with different compositions of existence, both vertically and horizontally, using drones and direct measurements in the field.

Keywords: *Bellucia pentamera*, distribution, invasive, oil palm plantation, UAV

INTRODUCTION

Invasive species' effects and contributions to global biodiversity loss have reached levels that have attracted the interest of all scientists concerned (Dyderski and Jagodzinski 2020). One of the reasons for biodiversity loss is the introduction and spread of invasive alien species in varied ecosystems. An invasive plant species has expanded outside of its native region. Once naturalized, these species might survive and reproduce (Dillis et al. 2017; Iqbal et al. 2020).

As the world's biodiversity has altered, an increasing number of non-native invasive trees have encroached on the ranges and habitats of native plant species, disrupting long-term ecological equilibrium. Invasive species, or non-native species introduced from beyond the local scope, may devastate the local ecological balance and represent a major danger to the economy and ecology by pushing out native plants in the ecosystem (Dyderski and Jagodzinski 2020; Handayani et al. 2021). When exotic tree species spread beyond their point of introduction, they are potentially more destructive than smaller plants and create shade, which is a barrier to native species' re-establishment (Junaedi and Dodo 2014; Rundel et al. 2014; Staska et al. 2014; Handayani et al. 2021a,b). Invasive species will spread to new locations, where they will naturally survive and reproduce. Ecological risk analysis of potentially invasive species is necessary in order to estimate steps to prevent future spread for ecosystem protection (Handayani et al. 2021; Maulidyna et al. 2021).

Invasive species spread is very concerning because, in addition to their ability to grow quickly, they have a negative impact. The spread of invasive tree species is one of the most serious threats to native ecosystems (Brundu et al. 2016; Hejda et al. 2017). Due to species-specific effects on light availability and nutrient cycling, invasive tree species significantly alter the functioning of the ecosystem under attack (Dyderli et al. 2019). (Castro-Diez et al. 2019; Gentil et al. 2019). One of the most serious ongoing threats to biodiversity has been identified as invasive species (Dyderski and Jagodzinski. 2020). The impact of invasive species on natural regeneration, species composition, and diversity is also significant (Dyderski et al. 2020).

Beluccia pentamera is an invasive pioneer tree species that spreads through forest destruction (Junaedi and Dodo 2014; Dillis et al. 2017; Handayani et al. 2021a,b). In the last decade, the rate of forest destruction in Indonesia has been very rapid, resulting in *Bellucia pentamera* rapidly growing and developing in many places (Briggs et al. 2012, Junaedi 2014; Kudo et al. 2014; Dillis et al. 2017; Yeni 2017; Dillis et al. 2018). Although this species is exotic and includes an invasive species, this can also be used as food by birds and primates (Handayani and Hidayati 2020). Currently, Sumatra's forests have been largely replaced by three major tree monocultures: oil palm, rubber, and *Acacia mangium* (Wahyuni et al. 2016). PT Kencana Sawit

Indonesia, located in West Sumatra, is one of the oil palm plantation companies, with an area of 10216 ha, 981 ha of which is used for conservation forest. This research is one of the strategies for preventing the spread of invasive species. UAVs have been widely used for research purposes, such as assessing tree height and canopy area (Panagiotidis et al. 2017), tree distribution estimation (Mweresa et al. 2017; Martinez-Sanchez et al. 2019); integrating satellite data with uav (Kattenborn et al. 2019); analysis of tree height accuracy (Pachechkenari 2020), canopy cover and calculation of photosynthetic pigment (Mohan et al. 2021). Furthermore, UAVs are also used in mangrove forests, including the Matang Mangrove Forest Reserve in Malaysia (Otero et al. 2018), the Pacific coast of Casta Rica (Yaney-Keller et al. 2019), Mandeh Bay in West Sumatra (Raynaldo et al. 2020; Mukhtar et al. 2021), for Mapping Mangrove Ecosystem (Sugara et al. 2021) and coastal vegetation (Morgan et al. 2022). Furthermore, there has been a significant amount of study on invasive plant species conducted with the use of UAVs. Some examples are *Hakea sericea* (Alvarez-Taboda et al. 2017), *Abies alba* and *Fagus sylvatica* (Brovkina et al. 2018), *Chamaecyparis obtusa* (Iizuka et al. 2018), *Firmiana danxianens* (Marzialetti et al. 2021). The use of unmanned aerial vehicles (UAVs) as a strategy for combating invasive species has been tested in Indonesia. One such test was conducted in the forest of Meru Betiri National Park against the invasive species *Lantana camara* (Sulistiyowati et al. 2021). On the other hand, UAV applications against Bellusia have never been carried out. Moreover, our previous research on permanent plots in this area (Mukhtar et al. 2014, unpublished data) reveals that the invasive plant species *B. pentamera* is the most dominant, indicating that the condition of this species is extremely threatening to the forest ecosystem. The purpose of the study was to determine the factors that influence the distribution of the *B. pentamera* species in conservation forest areas with different compositions of existence, both vertically and horizontally, using drones and direct measurements in the field.

MATERIALS AND METHODS

Study area

This research was conducted at PT Kencana Sawit Indonesia's conservation forest area (KSI). The topography of this region ranges from flat to wavy to hilly, with elevations ranging from 350 to 800 meters above sea level. PT KSI is located approximately 168 kilometers south of Padang City in the Sangir Balai Janggo District, Nagari Sei Kunyit, Jorong Koto Sungai Kunyit, South Solok Regency, West Sumatra. This study consists of two plots, the first of which has been invaded by Bellucia, and the second of which has not been invaded (non-invaded). The area where the research is being done has a topography that is hilly. This area receives an average annual rainfall of 3885 mm and has an average air temperature of 230 C. There are three distinct soil types present here: Lita sandy, Andosol, and Litisol. Plot A is situated at 330 m asl, 01°46'27" S, 101°52'69" E, while plot B is situated at 380 m asl, 01°46'91" S, 101°52'50" E.

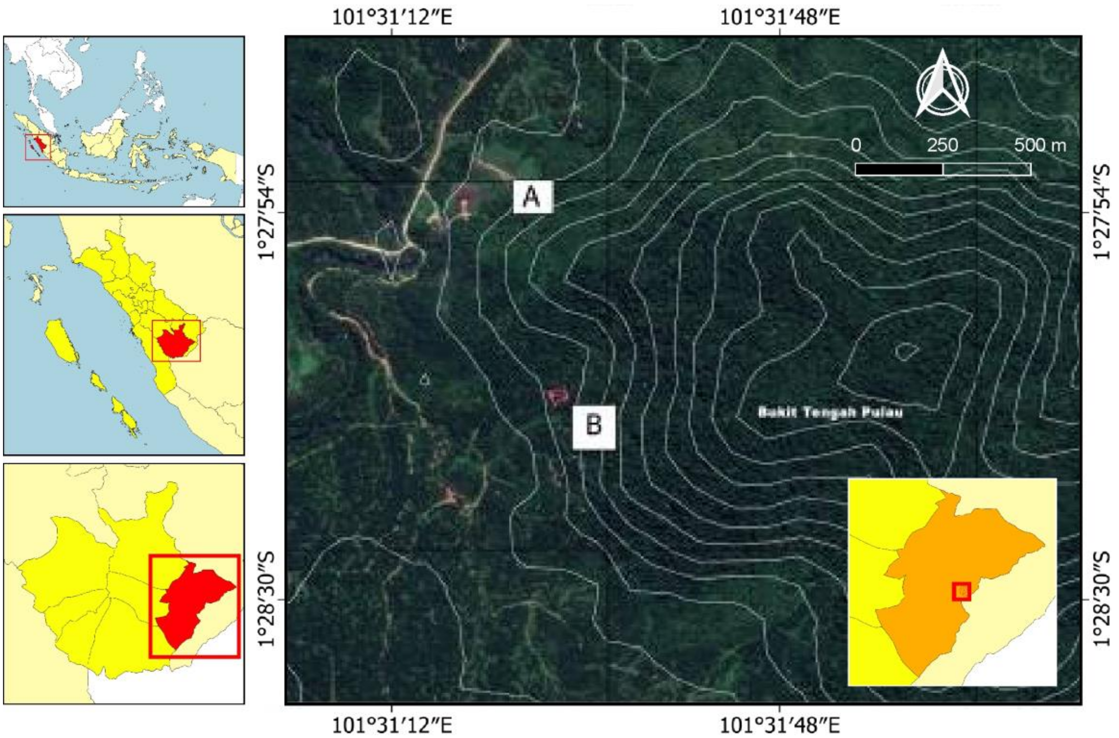

Figure 1. Research location map. Description: A: First Plot, B = Second Plot

Data collection

A rapid survey of the young secondary forest was carried out using an Unmanned Aerial Vehicle (UAV, DJI Phantom 4 drone, equipped with a 12.4 pixel CMOS camera,.3" sensor, 94o 20 mm FOV lens), to observe the distribution and level of invasion of *B. pentamera* in two locations. The survey, data collection, and analysis with this drone were carried out in two stages, first, data acquisition was carried out by flying the drone 70 meters above the canopy, controlled using absolute GPS coordinates. To minimize light shadows, the drones fly around noon (11 a.m. - 2 p.m.). Photos are automatically collected to x and y coordinates and stored directly on the drone's memory card. Second, photo processing techniques such as automatic aerial triangulation (AAT), noise filtering, Digital Surface Model (DSM), Digital Elevation Model (DEM), and orthomosaic image compilation are used. Orthomosaic images are images of 590 photos taken throughout the study area, with an estimated overlap of about 80%, making them more efficient for further analysis.

Based on the orthomosaic images, two plots measuring 40 x 50 m with different proportions of *B. pentamera* were determined. Each plot's vegetation structure was defined as follows: The first location had a higher proportion of *B. pentamera* trees than non-Bellucia trees. The second location must have fewer Bellucian trees than non-Bellucian trees. As a guide for direct vegetation surveys in the field, the selected locations are marked with coordinate points. All trees with DBH 10 cm were measured directly in the field in each plot using a DBH meter, and the height and canopy area was estimated using orthomosaic drawings.

The following equation is used to calculate tree height (Ota et al. 2015):

$$CHM = DSM - DTM$$

The difference between a digital surface model (DSM) and a digital terrain model (DTM) is defined as the canopy height model (CHM) (DTM). DSM is the surface height including the contour of the horizontal vegetation form, whereas DTM only represents the ground surface height.

The DSM is determined automatically from drone photo analysis using Pix4D software (trial version), and the DTM is analyzed using the point cloud method. The CHM is calculated using the Combine Terrain Layers function in the Global Mapper 18.10 software. Because the canopy of the *B. pentamera* tree is relatively flat, the software has difficulty identifying the top of each tree; therefore, the position of each treetop is determined manually by another function called analysis/measure, which displays the highest part of the canopy of each tree. The canopy area is calculated using the polygons of the canopy on a two-dimensional orthomosaic image.

To determine the distribution index of the Bellucia tree, 20 subplots measuring 40 x 50 m were established in each plot and the number of individual trees in each subplot was counted. Furthermore, this plot was divided again into two 20 x 50 m plots to determine the distribution of Bellucia saplings and seedlings. One of the two plots was chosen as representative of the number of Bellucia trees. The position of each Bellucia sapling and seedling was determined and mapped manually on millimeter paper in each of the selected 20 x 50 m plots based on the actual distance between tillers in the field, and each tree position was equipped with x and y-axis data.

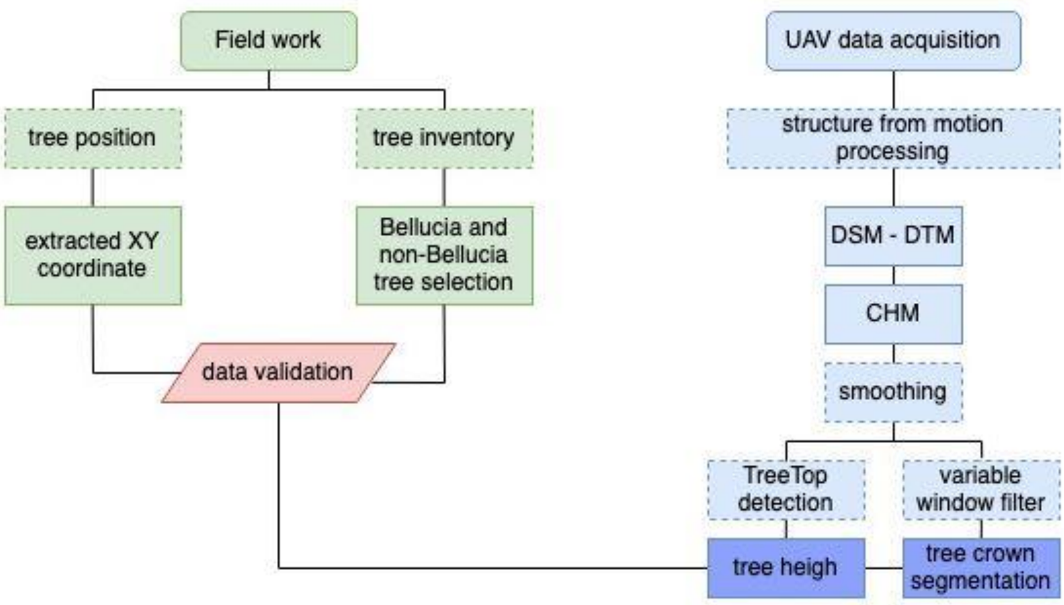

Figure 2. A flowchart demonstrating how to collect UAV data in the field and analyze it to determine tree height and canopy area

Data analysis

A tree distribution map was formed to illustrate the distribution of Bellucia trees in each 40 x 50 m plot. The tree used for this mapping has a measurable height. Each tree's position is indicated by a round symbol that also represents the diameter of the tree. The tree distribution map was created using the R (R core team 2017) computer program, as well as the ggplot2 and cow plot packages (Wickham 2016; Wilke, 2020). To see the distribution pattern of Bellucia saplings (sapling and seedling) on the forest floor under the tree canopy gap on each 20 x 50 m plot, the frame plot layout was combined with the distribution points of sapling and seedling *B. pentamera.*

The distribution pattern of the species was calculated using the Morisita index (Id) following the Krebs (2014):

$$Id = n \frac{(\sum x^2 - \sum x)}{(\sum x)^2 - \sum x}$$

Id : morisita's index of dispersion

n : Sample size

$\sum x^2$: The sum of the squares of the total number of *Bellucia pentamera* individuals in a community

$\sum x$: Total number of *Bellucia pentamera* individuals in a community

If: Id = 1 random spread, Id > 1 Group spread and Id < 1 uniform/regular distribution

The R (R core team 2020) computer program was used to analyze data on canopy height and area. Several individual trees are under the tree canopy beside them, so the height and area of the canopy cannot be calculated; trees in this category are not included in the analysis. Differences in the density of *B. pentamera* saplings on the forest floor were also investigated in relation to differences in vegetation structure, the number of trees, and canopy cover.

RESULTS AND DISCUSSION

Distribution of vegetation structure and composition

The study's study results on Bellucia-dominated vegetation differed from those on vegetation that was slightly dominated by *B. pentamera* (Table 1). The proportion of individuals and species in the two observation plots followed the same pattern. However, when viewed at the seedling level, it becomes clear that other species were not found in plot 1. This is presumably because the Bellucia species has dominated the area of Plot 1, making seedling development difficult. The implication is that it will be difficult for saplings other than *B. pentamera* to grow under the tree canopy. This is a common occurrence in second-growth forests.

***Bellucia pentamera* tree distribution**

The shape of the canopy of non-Bellucia trees appears to affect the distribution and development of the canopy of Bellucia trees. *Belucia* trees grow at a certain distance from non-Belucian trees with large and dense canopies (Figure 3) and leave a canopy gap between them; on the other hand, *Bellucia* trees grow closer to non-Bellucia trees with wide, flat, and loose canopies.

Bellucia trees with smaller diameters are typically found in gaps between large trees, both among non-Bellucia trees and among Bellucia trees. Based on the findings of this study, it was assumed that trees with small trunk diameter, height, and narrow canopy cover invaded after the canopy in the gap was formed by Bellucia trees or non-Bellucia trees with large trunks, height, and wide canopy cover.

Distribution sapling and seedling of *Bellucia pentamera*

In general, Bellucia saplings and seedlings were found under small canopy gaps between parent tree canopies, with only a few found directly under large canopy gaps, either between Bellucia and non-Bellucia trees or canopy gaps between non-Bellucia trees (Figure 4). Bellucia saplings fill the canopy gaps between Bellucia and non-Bellucia trees. Bellucia saplings are widely distributed in groups under the parent tree. However, some of the saplings were scattered outside the canopy of the parent tree (canopy marked blue in Figure 4), which could be due to hilly field conditions causing the fruit to fall far from the mother tree or because the fruit was carried by the disperser under non-Bellucia trees.

Table 1. Number and proportion of *Bellucia pentamera* and Non-*B. pentamera* trees

Plot	Habit	Species	No of species	No of trees	(%)
1	Tree	*B. pentamera*	1	33	73.3
		Non- *B. pentamera*	9	12	26.7
	Sapling	*B. pentamera*	1	29	82.9
		Non- *B. pentamera*	5	6	17.1
	Seedling	*B. pentamera*	1	5	100
		Non- *B. pentamera*	0	0	0
2	Tree	*B. pentamera*	1	8	20.5
		Non- *B. pentamera*	28	31	79.5
	Sapling	*B. pentamera*	1	3	10.7
		Non- *B. pentamera*	19	25	89.3
	Seedling	*B. pentamera*	1	3	25
		Non- *B. pentamera*	8	9	75

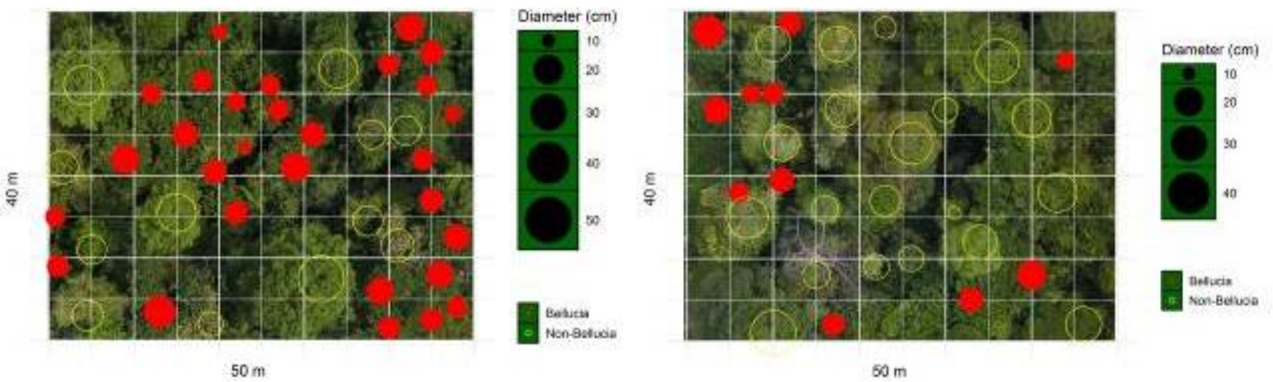

Figure 3. Distribution of *Bellucia pentamera* (red circle) and Non-*B. pentamera* (yellow circle) trees in two research plots (A) Plot 1, (B) Plot 2

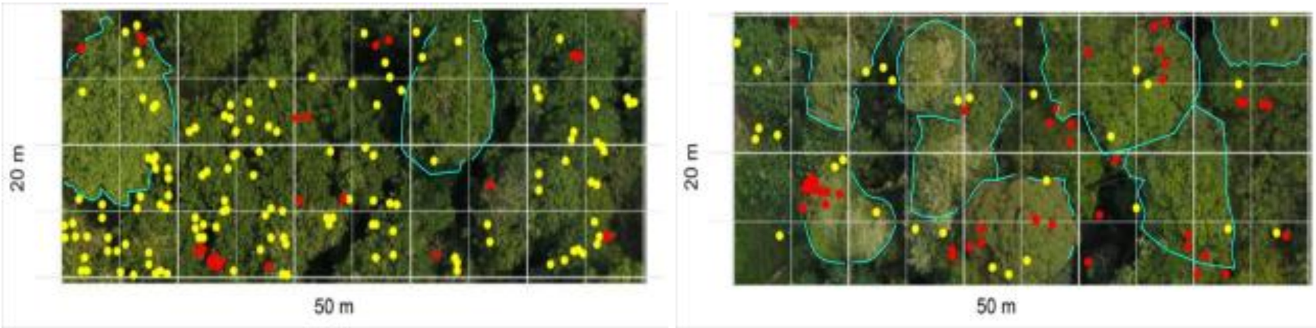

Figure 4. Distribution of sapling *Bellucia pentamera* (yellow color) and seedling *Bellucia pentamera* (red color) on two different vegetation structures. Location 1 (A). The dominant vegetation structure of Bellucia and Location 2 (B). Slight vegetation structure of *Bellucia pentamera.* The blue markings are non-Bellucia tree canopies

Even though the number of individuals is small, sapling *B. pentamera* fills almost every gap between dense tree canopy cover and under a wide and loose canopy, ensuring an even distribution. These findings suggest that the *B. pentamera* species does not always require wide-open areas with high light intensity to grow and develop, nor does it imply that this species cannot grow in areas with low light intensity, such as under the canopy of non-Bellucia trees with a dense and dense canopy (Figure 4A). The difference between these two findings is that the first invasion of this species may occur in a large gap, but once a seed source from the parent tree is available, the invasion is extended to the surrounding area, even with a small gap (Figure 4).

However, because this study is limited to distribution and growth position, it cannot explain whether *B. pentamera* saplings found under a small canopy gap will grow and develop well. The saplings may grow slowly, stunted, or die due to competition with the parent tree and non-Bellucia trees. In the parent tree population, Bellucia sapling density was higher than in the non-Bellucia tree population.

The difference in sapling density between far and near the mother tree explains the role of dispersal animals in fruit and seed dispersal, where the number of fruit and seeds dispersed may be less than the number of fruit or seeds that fall near the mother tree (Dyderski et al. 2020). Furthermore, the shape of the canopy of non-Bellucia trees influenced the chance of germination and the growth of scattered seeds, with Bellucia saplings found growing on the edge of the canopy of non-Bellucian trees with a large and dense canopy (Figure 4), while Bellucia saplings could grow under the canopy of non-Bellucia with wide, sparse canopies (Fig. 4).

This condition supports the previous statement that *B. pentamera* can grow in small canopy gaps with moderate light intensity but not in low light intensity areas. This assumption can also explain the initial invasion of this species in gap areas, where when human activities such as cultivating and burning land cause the destruction of vegetation, succession will be initiated by low plants and high light tolerant species such as alang-alang, ferns, shrubs, and shrubs, and after the microclimate changes, saplings of pioneer trees and other species with the same ecological characteristics as *B. pentamera* trees will grow and thrive (Dyderski et al. 2020).

Distribution Index of *Bellucia pentamera*

Bellucia's distribution pattern is influenced by environmental factors. According to the Morisita Index (Id), the distribution pattern of *Bellucia* on trees, saplings, and seedlings differs between the two locations. The Bellucia trees were evenly distributed at location 1 (Figure 3A), particularly in the plot's center, with a morisita index value (Id = 0.92). In contrast to Location 1, Bellucia trees at Location 2 were distributed at random with Id = 1.

Location 1 was suspected before being invaded by Bellucia, as previously assumed; the location experienced a higher level of forest disturbance than location 2. This situation creates a fairly large gap, as well as a loss of some canopy cover, and has a high light intensity, allowing the invasive Bellucia species to grow and develop properly. Because of the large number of individual Bellucia trees at location 1, there is strong competition among members of the Bellucia population, which encourages the same spatial distribution, resulting in uniform distribution. Similar distribution patterns are almost always observed in invasive trees (Dillis et al 2017; Divisek et al. 2020; Handayani et al. 2021). Bellucia grows in a small gap at random in Location 2, which has less forest damage. The value of the Morisita Index (Id) for each *B. pentamera* stand at each location is shown in Table 2, which describes the horizontal distribution of the population of this invasive alien plant species.

The sapling distribution at Location 1 is grouped, whereas it is uniform at Location 2. Because it took advantage of the remaining canopy gaps from trees and saplings at the plot location, seedlings were distributed at random at Location 1. Environmental conditions such as the presence of canopy gaps and hilly topography, which causes non-uniform microclimate conditions due to varying canopy cover in the plot, influence the different distribution patterns in saplings and seedlings (Pysek et al. 2011; Handayani et al 2021). There is a dense tree canopy and some that are loose, resulting in different light reaching the sapling and seedling plots.

Estimated canopy area and height of *Bellucia pentamera*

The correlation between height and canopy area demonstrates Bellucia's strategy for using vertical gaps. Based on observations made with drones in the field, the overall average height and canopy area of Bellucia trees are 9 m and 15 m2, respectively, while the average height and canopy area of trees other than Bellucia is 14 m and 38 m2. The correlation between height and canopy area reveals Bellucia's strategy for using vertical gaps (Figure 5).

This is because there are trees that are not as tall but have a wider canopy because they do not have to compete for space with other trees to get light. Some, on the other hand, grow tall but have a small canopy due to competition for light. The relationship between height and canopy area helps to explain how the Bellucia population evolved. Some trees grow tall with a wide canopy in the gap with high light intensity, while others grow tall with a slender trunk and a narrow canopy to access light above the canopy (Pisek et al. 2011; Divisek et al 2020). The Bellucia tree's variation in energy allocation indicates that it can be flexible in allocating its growth energy and that it is a growth to adapt to the location and environmental conditions.

Based on the above correlation, different trees in the population may have different invasion times. There is no clear data on this, but it may be hypothesized that individuals with tall, big trunks and broad canopies invade initially while the gap is still open, and individuals with tall, thin trunks and narrow canopies enter later after the canopy has been established by the first set of trees. These findings suggest that the Bellucia canopy's monodominance is caused by variable tree canopy areas with similar tree heights (monolayer).

Figure 6 depicts the relationship between Non-Bellucian tree height and canopy area at Locations 1 and 2. Location 1 has a good association between height and canopy area of Non-Bellucian trees, with R2 = 0.57, but Location 2 has a weak correlation, with R2 = 0.11. (Figure 6). The substantial association at Location 1 is assumed to be because of a wide gap in logging before being invaded by Bellucia, which can be used by local non-Bellucian plants to grow optimally so that individual competition is not too strong. Because of this, each Non-Bellucian tree can reach its maximum height and canopy area.

Table 2. Value of Morisita Index (Id) *Bellucia pentamera* at each location

Location	*B. pentamera* stand	Indeks Morisita (Id)	Information
1	Tree	0,92	Uniform
	Sapling	1,34	group
	Seedling	1	Random
2	Tree	1	Random
	Sapling	0,77	Uniform
	Seedling	1,01	group

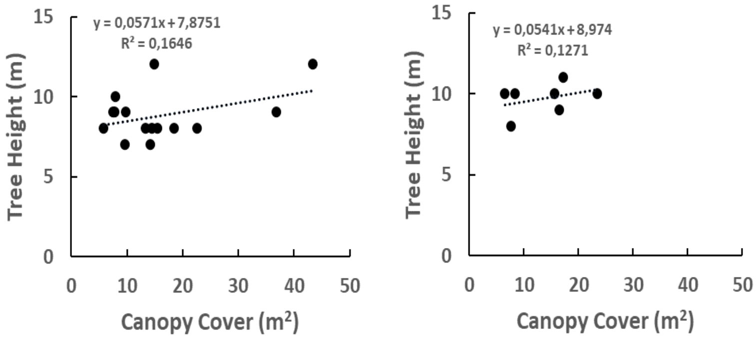

Figure 5. Correlation between tree canopy height and area *Bellucia*. Left = Plot 1, Right = Plot 2

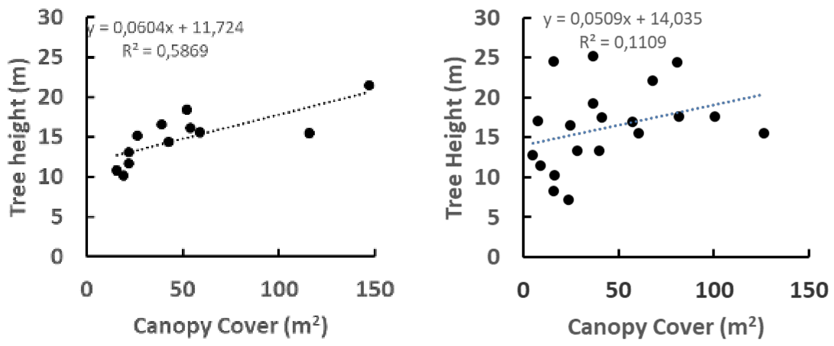

Figure 6. Correlation between height and canopy area of Non-*B. pentamera* Trees. Left Plot 1, Right= Plot 2

The findings of this study indicate that the microsites created by the tree canopy have a significant impact on the establishment of invasive species in this forest. After the canopy in the gap was formed by Bellucia trees or non-B trees pentamera with a large, tall trunk and a wide canopy cover, trees with a small trunk diameter, height, and a narrow canopy cover invaded. Dillis et al. 2017 discovered the same thing: Bellucia is a pioneer tree species with rapid growth, the ability to quickly invade forest gaps caused by fallen trees or logging, and the ability to reconstruct forest structure and form a monodominant canopy. As a result of this, Grigorescu et al. (2020) say that invasive species help us better understand how driving factors play a role in their spread and spread across different habitats and ecosystems. The diversity of Invasive Plant Species was influenced by environmental factors, especially canopy openness (Wahyuni et al. 2016). Given that these invasive plants are strongly associated with a variety of biophysical and anthropogenic stressors, the present study effort to improve knowledge of invasive species and to serve as a starting point for study on their spread and threat to native plant species. Furthermore, understanding how invasive species evolve and vary across geographic spaces is important for understanding native ecosystem conservation and implementing necessary management strategies for non-native species control (Grigorescu et al. 2020).

Naturalized non-invasive species are functionally similar to native species in the same habitat type, but invasive species are different as they occupy the edge of the plant functional trait space represented in each habitat. This pattern was driven mainly by the greater average height of invasive species. These results suggest that the primary determinant of the successful establishment of alien species in resident plant communities is environmental filtering, expressed in similar trait distributions. However, to become invasive, established alien species need to be different enough to occupy novel niche space, i.e., the edge of trait space (Divisek 2018).

Based on the findings, it can be concluded that the *B. pentamera* tree's method for utilizing the horizontal vegetation gap is to fill the huge vegetation gap equally and randomly in a tiny space between the canopy. Meanwhile, Bellucia saplings and seedlings were scattered in groups, uniformly and randomly, under the canopy of Bellucian and non-Bellucian trees, according to microhabitat conditions. Bellucia's strategy is to take advantage of the vertical vegetation gap with flexible growth in allocating energy as a strategy to adapt to environmental conditions, resulting in tall trees with a small canopy, short individuals with a wide canopy, and tall trees with a wide canopy, resulting in a very weak correlation between height and canopy area.

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