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Determination of Optimal Sample Plot Dimension For Measuring Species Diversity of Plants in Beach Forest Ecosystem

(Penentuan Dimensi Petak Contoh Optimal untuk Pengukuran Keanekaragaman Spesies Tumbuhan pada Ekosistem Hutan Pantai)

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ABSTRACT

Biodiversity measurement served as baseline data for the development of effective conservation plans. The accuracy of the measurement was highly dependent on the size of the sample plot. Even though Indonesia had various ecosystems, the standard sample plot size for measuring plant species diversity was only available for lowland, lower montane, and mangrove forests. Therefore, this study aimed to determine the optimal dimension of plots for measuring plant species diversity in beach forest ecosystems. The data was collected in Ujung Kulon National Park using various dimensions of sample plots ranging from 2 m × 2 m to 150 m × 50 m. Furthermore, the rarefaction method and species-area curve were used to examine the data. The curves showed that the optimal sample plot dimensions for seedling, sampling, and pole levels were 110 m × 50 m and 150 m × 50 m for tree stages.

INTISARI

Pengukuran keanekaragaman hayati menyediakan data dasar untuk penyusunan rencana konservasi yang efektif. Pengukuran keanekaragaman hayati sangat bergantung pada ukuran petak contoh. Indonesia memiliki beragam tipe ekosistem, namun hingga saat ini hanya hutan dataran rendah, hutan pegunungan bawah, dan hutan mangrove yang memiliki standar ukuran petak contoh untuk pengukuran keanekaragaman spesies tumbuhan. Penelitian ini bertujuan menentukan dimensi petak optimal untuk pengukuran keanekaragaman spesies tumbuhan pada ekosistem hutan pantai. Pengambilan dilaksanakan di Taman Nasional Ujung Kulon dengan menggunakan berbagai dimensi petak contoh mulai dari dimensi 2 m × 2 m sampai 150 m × 50 m. Data yang diperoleh dianalisis dengan metode rarefaksi dan kurva spesies area. Kurva rarefaksi dan kurva spesies area menunjukkan hasil yang sama, yaitu petak berdimensi 110 m × 50 m merupakan dimensi petak contoh optimal untuk tingkat semai, pancang, dan tiang, sedangkan dimensi 150 m × 50 m merupakan dimensi petak contoh optimal untuk tingkat pohon.

Introduction

Law Number 5 of 1994 on the ratification of the Convention on Biological Diversity and Law Number 13 of 2013 on the ratification of the Kyoto Protocol emphasize that continuous development of biodiversity inventory, monitoring, and measurement are required to maintain its sustainability. The biodiversity measurements provide an overview of its current and predict future conditions. The measurement data became the basis for conservation plans and monitoring protocols development, and research requirements (Stohlgren et al. 1995).

Effective biodiversity conservation planning requires accurate data obtained through a census. However, a biodiversity census is costly, time-consuming, and labor-intensive. The line plot method currently used for various purposes cannot measure biodiversity accurately because there is no exact distance between plots (Mostafa & Ahmad 2017). Other methods, such as randomized plots, produce inconsistent diversity measurements. Stohlgren et al. (1998) showed that random plots produced lower plant species richness than single and transect methods. Güler et al. (2016) revealed that randomized plots produced better species richness than single plots. Those research showed a need for a standardized sample plot dimension to capture all ecosystems' biodiversity.

The area-species relationships idea is promising and could become a method for measuring the total ecosystem diversity (Zhao et al. 2010). The relationships suggested that large areas have high species richness (Triatis et al. 2012; Tjørve et al. 2018), often depicted in curves with the number of species and sample plot size as axis and ordinate (Tjørve 2003). The curve increased sharply and leveled off when the number of species was saturated. The curve indicates the optimal plot dimension (Zhao et al. 2010), which is the minimum plot dimension for all species in the ecosystem (Werger 1972).

Indonesia, a mega biodiversity country, has a variety of ecosystem types. However, only lowlands (Kusuma 2007), lower montane forest (Ali 2018), and mangrove forests (Mulya 2021) have standardized sample plots for measuring plant species diversity. The beach forest becomes one of the ecosystems without a standard sample plot for measuring plant species diversity. Therefore, there is a need to conduct a study related to the standard sample plot for beach forest ecosystems. This research aimed to determine the optimal plot dimensions for measuring plant species diversity in beach forest ecosystems using rarefaction curves.

Methods

Study Site and Time

Data were collected from March to April 2022 at three sites, two in Karang Ranjang Resort and one in Legon Pakis Resort, Ujung Kulon National Park. Beach forest ecosystems have Pescaprae (dominated by *Ipomea pescaprae* and shrubs) and Barringtonia (dominated by trees up to 25 m tall) formations (MacKinnon et al. 1996). The tree species have thick leaves, such as butun (*Barringtonia asiatica*) and ketapang (*Terminalia catappa*). Sometimes there also a beach forest with mixed formation of pescaprea and barringtonia formations. The beach forest ecosystem in Ujung Kulon National Park had both types of beach forest formations. However, this research used the Barringtonia formation.

Tools and Materials

This research used a tally sheet, office stationery, GPS, tape meter, and camera for data collection. The data analysis used Microsoft Excel and PAST (Paleontological Statistics) 4.03. software.

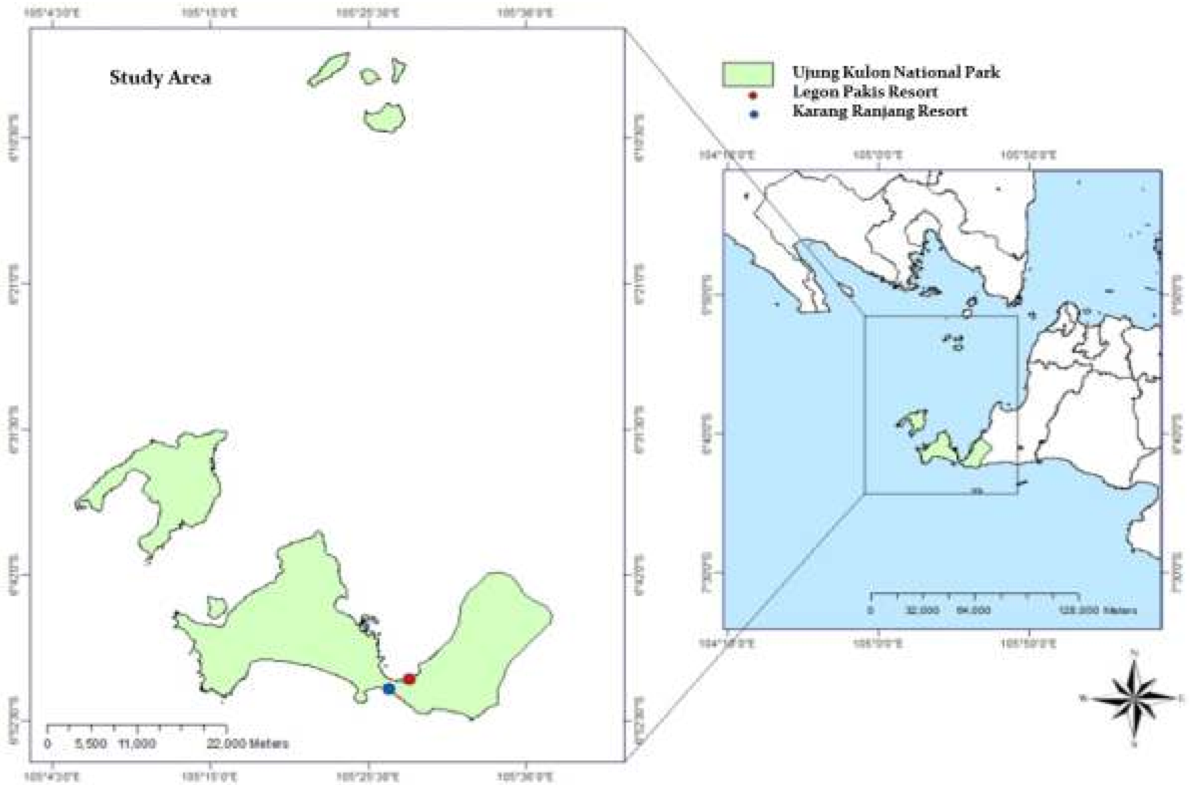

Figure 1. Ujung Kulon National Park

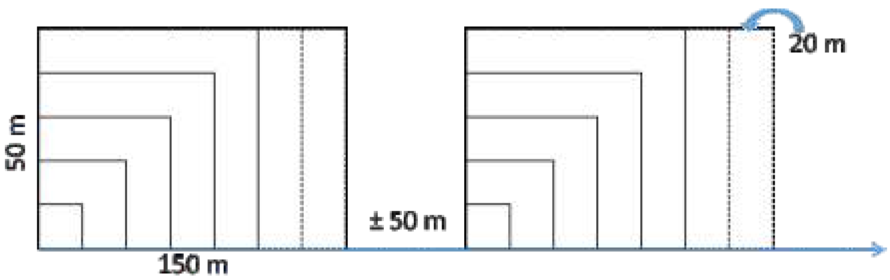

Figure 2. Sample plot dimension

Data Collection

The data collection of the number of species and individuals for each species used a nested rectangular plot with three repetitions (Figure 2). The plot length was parallel to the shoreline and perpendicular to the slope aspect. The data collection used a 2 m × 2 m, 5 m × 5 m, 10 × 10 m, and 20 m × 20 m for seedlings, saplings, poles, and trees, respectively. For tree measurement, the plot's dimension could reach a maximum of 50 m x 50 m because the maximum width of the beach forest was 50 meters (Göltenboth et al. 2006). This maximum width includes the transitional area or ecotone between beach and lowland forests because they were indifferent, and Indonesian beach forests were relatively similar (Göltenboth et al. 2006). When the square plots reached their maximum width, the data collection continued by increasing the plot length parallel to the shoreline by 20 meters each time until the number of species was saturated. In this research, the maximum plot length was 150 meters. The distance between plots was 50 meters (Figure 2).

Data Analysis

Sanders (1968) introduced the rarefaction method ($E(\hat{S}_n)$), which resulted in an overestimated estimation. Hulbert (1971) improved this rarefaction method by using the following formula to address this overestimation.

$$E(\hat{S}_n) = \sum_{i=1}^{s}\left[1 - \frac{\binom{N-N_i}{n}}{\binom{N}{n}}\right]$$

with

$$\binom{N-N_i}{n} = \frac{(N-N_i)!}{(n)!\,([N-N_i]-n)!}$$

$$\binom{N}{n} = \frac{N!}{n!\,(N-n)}$$

where $E(\hat{S}_n)$ = expected number of species from the sample data; s = number of species; n = standardized sample size; N = number of individuals recorded; Ni = number of individuals of the i^{th} species.

The rarefaction method resulted in species rarefaction curves. The rarefaction curves progressively rose as the plot dimensions increased and reached a point of saturation where a further increase in plot dimension resulted in no additional species. The starting point of flattened curves indicated the optimal sample plot dimensions. The PAST (Paleontological Statistics) 4.03 software produced rarefaction curves for each sample plot dimension, ranging from 2 m × 2 m to 50 m × 150 m.

This research compared the results of rarefaction curves and the species-area curves introduced by Cain (1938). Cain (1938) suggested that the optimal sample plot dimension can be determined when 10% of the total plot produces 10% of the recorded species. The method first determined the coordinate (x, y), where the x was at 10% of the total size of sample plots, and y was at 10% of the total species recorded. A line m connected the (x,y) coordinate and the origin O (0, 0). A line n was drawn parallel to line m as a tangent to the species-area curve. The projection of the tangent point on the x-axis was the optimal plot dimension (Figure 3).

Results and Discussion

Optimal Plot Dimensions

The rarefaction curves of all three research sites increased by one to four species as the sample plot dimensions increased. At Karang Ranjang 1, the rarefaction curves flattened after reaching 50 m × 50 m and captured 16 species. However, at Karang Ranjang 2 and Legon Pakis the rarefaction curves flattened after reaching 110 m × 50 m and 90 m × 50 m, which could

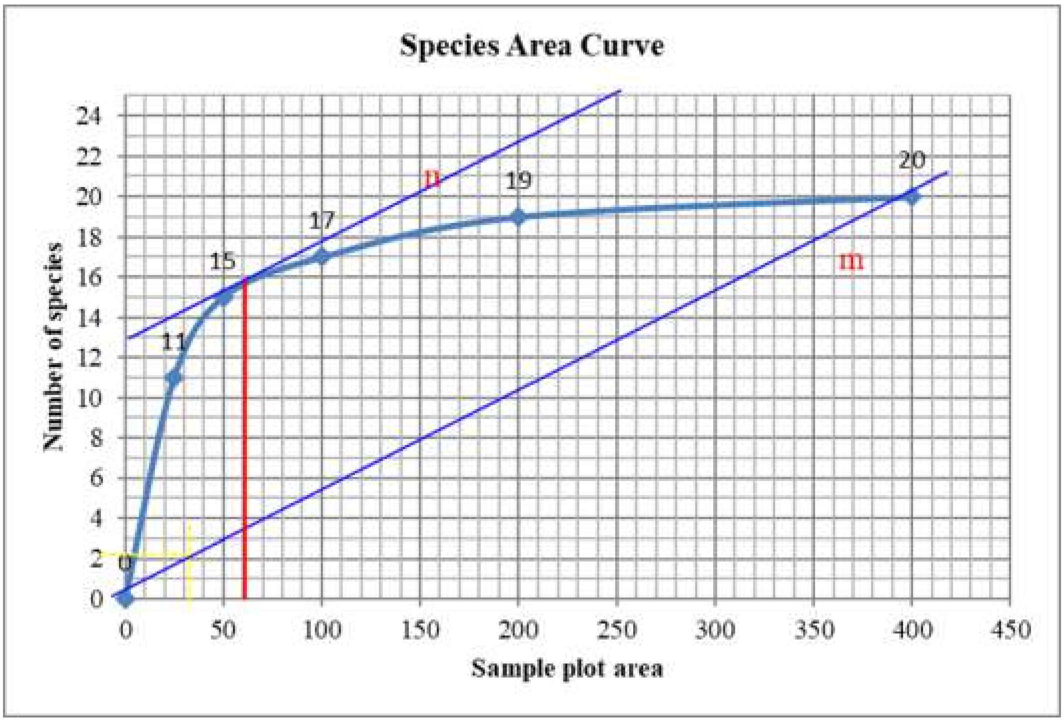

Figure 3. Illustration of species-area curve

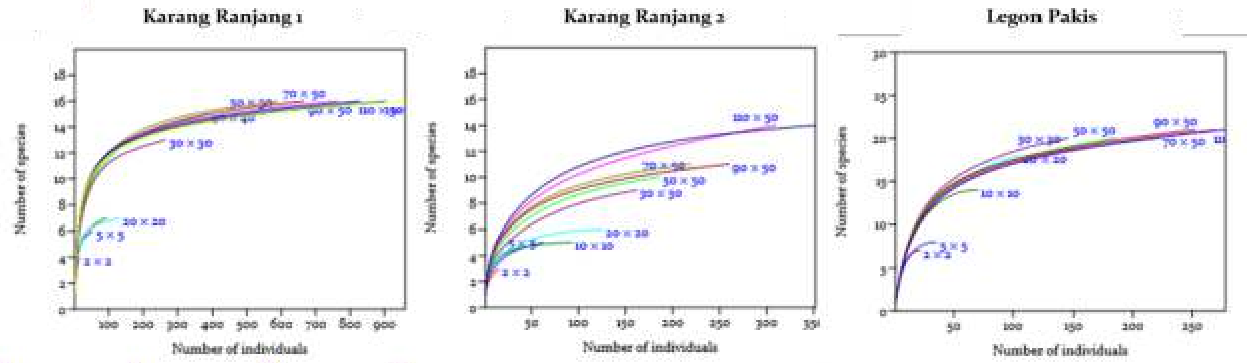

Figure 4. Rarefaction curves for seedlings

capture 14 and 21 species. The 110 m × 50 m was the optimal sample plot dimension because this dimension could capture all seedling-level species at the research sites.

The number of species increased as the sample plot dimension increased (Table 1). At the optimal plot dimension, the number of seedling species also reached the maximum. The species-area curves also indicated similar results (Figure 5). As the sample plot dimension increased, the species-area curves increased. The 110 m × 50 m dimensions captured all seedling species.

The dimensions of the sample plots were different for each ecosystem. An 80 m × 40 m plot dimension could capture all mangrove forest ecosystem seedling species (Mulya 2021). Meanwhile, the 200 m × 50 m was the optimal plot dimension for the lower montane forest of Gunung Ciremai National Park because it could capture more plant species richness than other sample plot dimensions (Ali 2018).

The optimal sample plot dimensions depended on the forest ecosystem characteristics, especially their size. The optimal sample plot dimension for beach forest seedlings was smaller than the lower montane forest (Ali 2021) and lowland forest (Kusuma 2007) but larger than the mangrove forest (Mulya 2021). Beach forests were smaller than lower montane and lowland forests. Ecosystems with a large area could accommodate various plant and animal species (Connor & McCoy 2013).

The rarefaction curves for saplings also increased as the sample plot dimensions increased (Figure 6), capturing one to four species. At Karang Ranjang 1 and Legon Pakis, the rarefaction curve flattened after reaching 90 m × 50 m and could capture 14 and 20 species. However, at Karang Ranjang 2, the rarefaction curves flattened after reaching 110 m × 50 m and could capture 12 species. Therefore, the optimal sample plot dimension for the saplings was 110 m × 50 m.

The number of sapling species increased as the

Table 1. Number of seedling species for each sample plot dimension

Dimension	Karang Ranjang 1 S	Karang Ranjang 2 S	Legon Pakis S
2 × 2	4	3	7
5 × 5	6	5	8
10 × 10	7	5	14
20 × 20	7	6	18
30 × 30	11	9	20
40 × 40	15	9	20
50 × 50	16	10	20
70 × 50	16	11	20
90 × 50	16	11	21
110 × 50	16	14	21
130 × 50	16	14	21
150 × 50	16	14	21

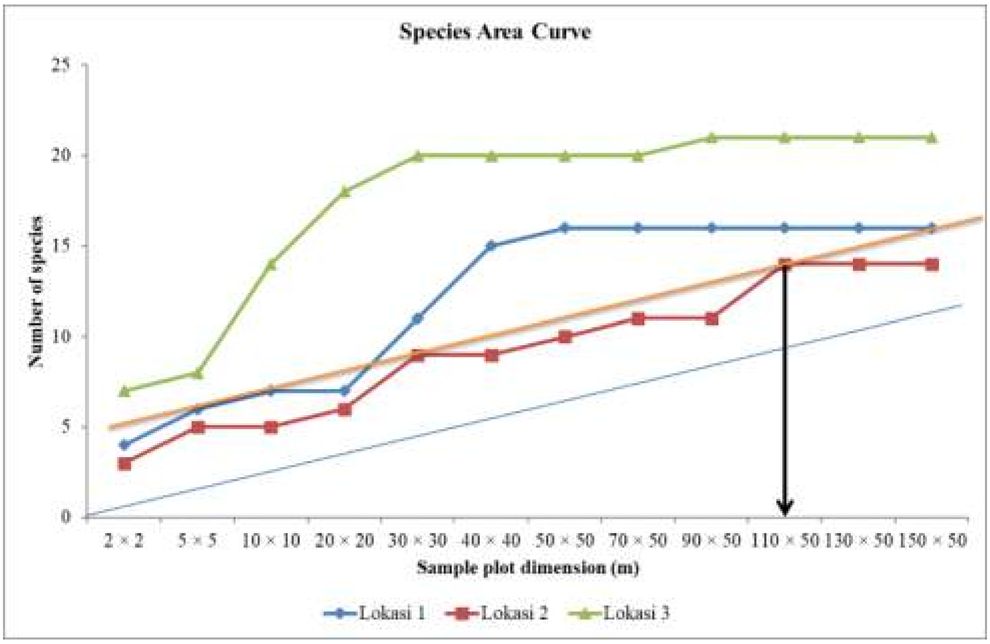

Figure 5. Species area curves for seedlings

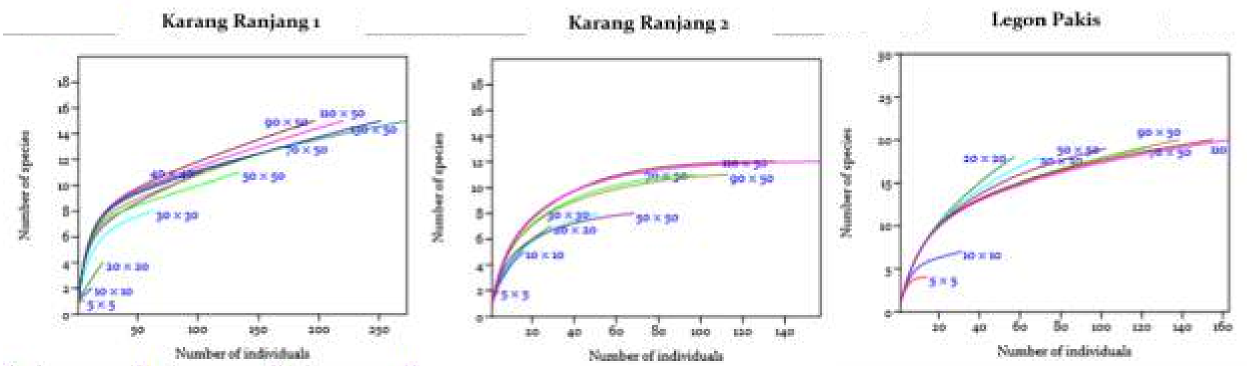

Figure 6. Rarefaction curves for saplings

Table 2. Number of sapling species for each sample plot dimension

Dimension	Karang Ranjang 1 S	Karang Ranjang 2 S	Legon Pakis S
5 × 5	1	2	4
10 × 10	2	5	7
20 × 20	4	7	17
30 × 30	7	8	17
40 × 40	11	8	17
50 × 50	11	8	18
70 × 50	13	11	19
90 × 50	14	11	20
110 × 50	14	12	20
130 × 50	14	12	20
150 × 50	14	12	20

sample plot dimension increased (Table 2). The optimal plot dimension could capture the maximum number of sampling species at each site. The species-area curves also indicated similar results to the rarefaction curves (Figure 7). The species-area curves increased as the sample plot dimensions increased and flattened after reaching 110 m × 50 m because the number of sapling species was saturated.

Stohlgren et al. (1995) suggested that a 4: 1 plot dimension could capture 30% more plant species richness than others, such as a 1:1 plot dimension (Güler et al. 2016). In Gunung Halimun Salak National

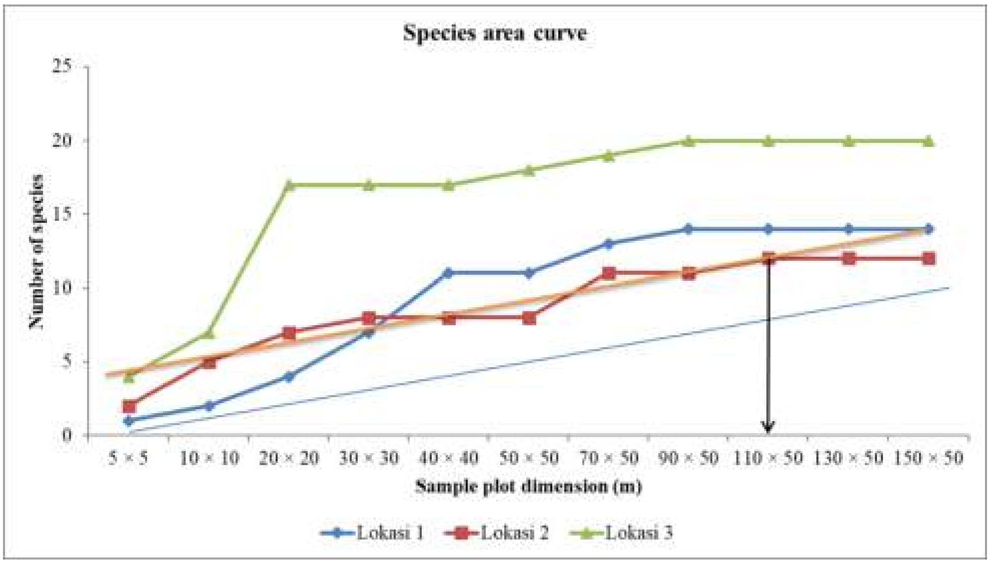

Figure 7. Species area curves for saplings

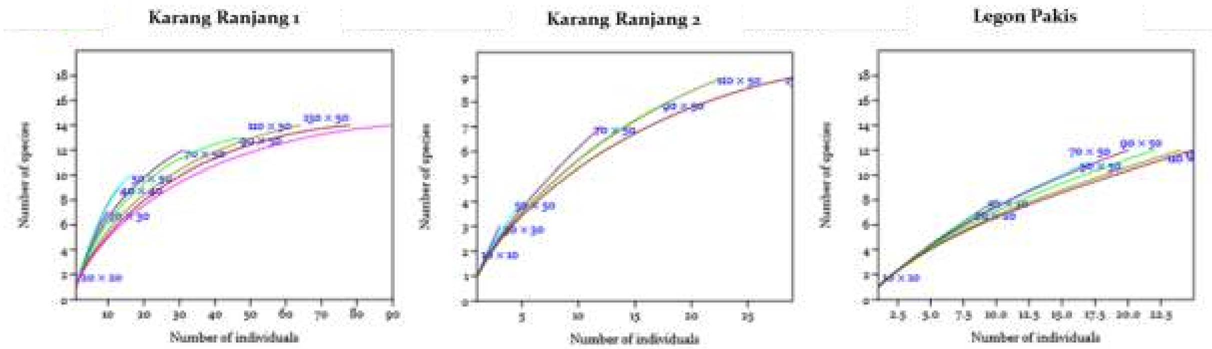

Figure 8. Rarefaction curves for poles

Park mountain forests, the 160 m × 20 m sample plot dimension captured more sapling species than other plots (Nahla 2018). However, the 80 m × 40 m sample plot dimension in mangrove forests captured more sapling species than plots with 4: 1 dimension (Mulya 2021). Previous research suggested that the size of the forest ecosystems determined the optimal sample plot dimensions. Ecosystems with a large area could accommodate many species of plants and animals, even in homogeneous habitat conditions (Kallimanis et al. 2008). Therefore, the optimal sample plot dimension of lowland and lower montane forests was larger than the optimal sample plots of beach forests.

The rarefaction curves for poles increased as the sample plot dimensions increased (Figure 8), capturing one to three species. At Legon Pakis, the rarefaction curves flattened after reaching 70 m × 50 m and captured 12 pole species. However, the rarefaction curves flattened at the other two sites after reaching 110 m × 50 m and captured 14 species at Karang Ranjang 1 and nine at Karang Ranjang 2. The optimal sample plot dimension for poles was 110 m × 50 m to capture all pole species at all research sites.

The number of pole species increased as the sample plot dimension increased (Table 3). The species-area curves increased as the sample plot dimension increased (Figure 9). The 110 m × 50 m sample plot dimension could capture all pole species at the three research sites.

The 200 m × 50 m became the optimal plot dimension for the lower montane forest of Mount

Table 3. Number of pole species for each sample plot dimension

Dimension	Karang Ranjang 1 S	Karang Ranjang 2 S	Legon Pakis S
10 × 10	0	2	2
20 × 20	2	3	7
30 × 30	7	3	8
40 × 40	8	3	8
50 × 50	10	4	11
70 × 50	12	7	12
90 × 50	13	8	12
110 × 50	14	9	12
130 × 50	14	9	12
150 × 50	14	9	12

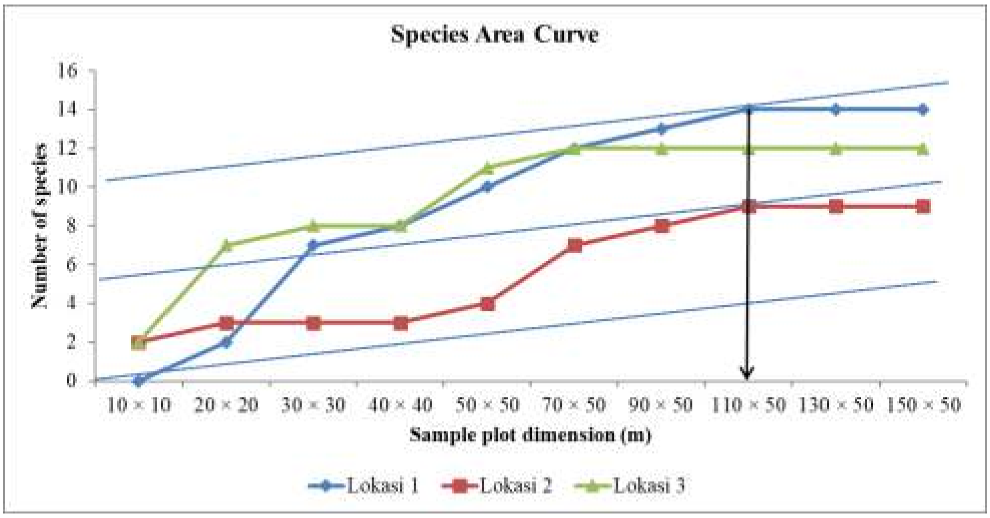

Figure 9. Species area curves for poles

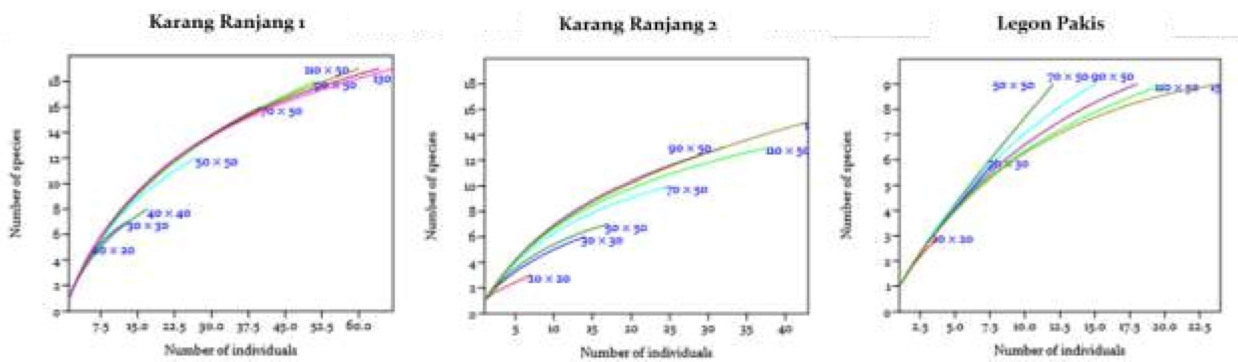

Figure 10. Rarefaction curves for trees

Ciremai National Park (Ali 2018). However, the 250 m × 40 m dimensions in the Central Amazon lowland forest captured more tree species richness than the 100 m × 100 m (Laurance et al. 1998). Both results suggested no universal optimal plot dimension for all ecosystem types. A Larger ecosystem would have a larger optimal sample plot dimension. For example, the optimal sample plot size for poles in this research was smaller than lowland forest, which was 113.4 m × 113.4 m (Kusuma, 2007)but larger than mangrove forest.

The rarefaction curves for trees increased as the sample plot dimensions increased (Figure 10) and captured one to four species. At Legon Pakis, the rarefaction curves flattened after reaching 50 m × 50 m, capturing nine species. However, at Karang

Ranjang 1, the rarefaction curves flattened after reaching 110 m × 50 m and captured 19 species. At Karang Ranjang 2, the rarefaction curves flattened after reaching 150 m × 50 m and captured 15 species. This optimal sample plot dimension was 150 m × 50 m to capture all tree species in all research sites.

The number of tree species increased as the sample plot dimension increased (Table 4), with the optimal plot dimension of 150 m × 50 m. The species-area curves increased as the sample plot dimension increased (Figure 11), indicating that the 150 m × 50 m dimension captured all tree species in all research sites.

The rarefaction and species-area curves did not flatten at 150 m × 50 m. However, increasing the sample plot dimension larger than 150 m × 50 m did not affect the number of tree species. Although previous research suggested that the maximum width of the beach forests was 50 meters, including ecotones between the beach and lowland forests (Göltenboth et al. 2006), their actual maximum width was unknown. In addition, Indonesia's beach forests were relatively alike among regions and hosted similar plant species but had various formations. The ecotones had higher plant species richness than the beach forests.

Condit et al. (1996) revealed that a 1000 m × 1 m plot dimension could capture more tree species richness than other sample plot dimensions in the lowland forests of Malaysia, Colorado Barro Island, and the deciduous forests of India. An 80 m × 20 m plot dimension could capture all tree species in the mangrove forest ecosystem (Mulya 2021). Meanwhile, the 113.4 m × 113.4 m plot dimension could capture all tree species in lowland forests (Kusuma, 2007). Based on the species-area relationship, a more extensive ecosystem area could accommodate more species than smaller ones and require larger sample plot dimensions. Therefore, the optimal sample plot

Table 4. Number of tree species for each sample plot dimension

Dimension	Karang Ranjang 1 S	Karang Ranjang 2 S	Legon Pakis S
20 × 20	5	3	3
30 × 30	7	6	6
40 × 40	8	6	6
50 × 50	12	7	9
70 × 50	16	10	9
90 × 50	18	13	9
110 × 50	19	13	9
130 × 50	19	13	9
150 × 50	19	15	9

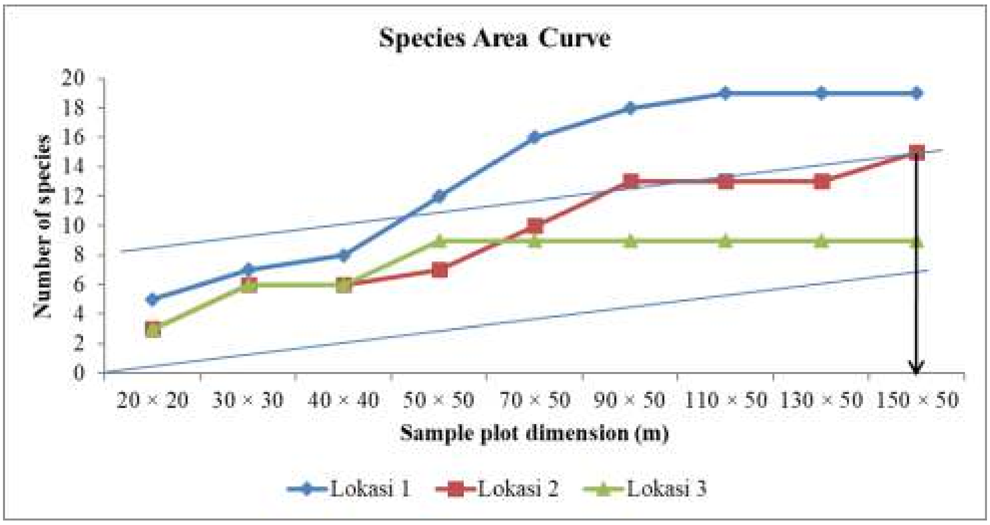

Figure 11. Species area curves for trees

dimension for beach forest trees was smaller than lowland and montane forests but larger than mangrove forests.

The rarefaction method used in this research produced similar results, but using the results should be careful. The rarefaction method is a statistical method to estimate and compare an ecosystem's species richness (Zhao et al. 2010). This measurement could yield a reasonable estimate if the ecosystem, area, or taxa were comparable or similar. For example, the species richness of lowlands was different from and not comparable with beach forests. The rarefaction method would also produce a good measurement for the same sample plots dimension because different plot area resulted in different species richness.

Cain's (1938) species-area curve was more straightforward than the rarefaction method. Individuals without quantitative ecology backgrounds could use this method to determine the optimal sample plot dimension. However, this method involved subjective judgment (Werger 1972), and ecologists seldom used it. The rarefaction method was more popular than the species-area curve method for determining optimal sample plots (Zhao et al. 2010; and Mulya 2021). Despite being used frequently, the rarefaction method required a random species distribution. However, in their natural habitats, species tended to be clustered. This clustered species distribution tended to overestimate species richness because samples from a single site contained only a limited number of species with high abundance (Collins and Simberloff 2009).

Conclusion

The results suggested that the rarefaction and the species-area curves increased as the sample plot dimension increased and flattened when the number of species was saturated. The plot dimensions of 110 m × 50 m captured all seedling, sapling, and pole species, while 150 m × 50 m captured all tree species. The 150 m × 50 m became the optimal sample plot dimension because increasing the sample plot dimension larger than 150 m × 50 m did not affect the number of beach forest species. As the maximum width of the beach forest was 50 m, including ecotone, increasing the sample plot dimension would only increase the number of ecotone species. The rarefaction and species-area curve methods resulted in similar sample plot dimensions for seedling, sapling, pole, and tree species.

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