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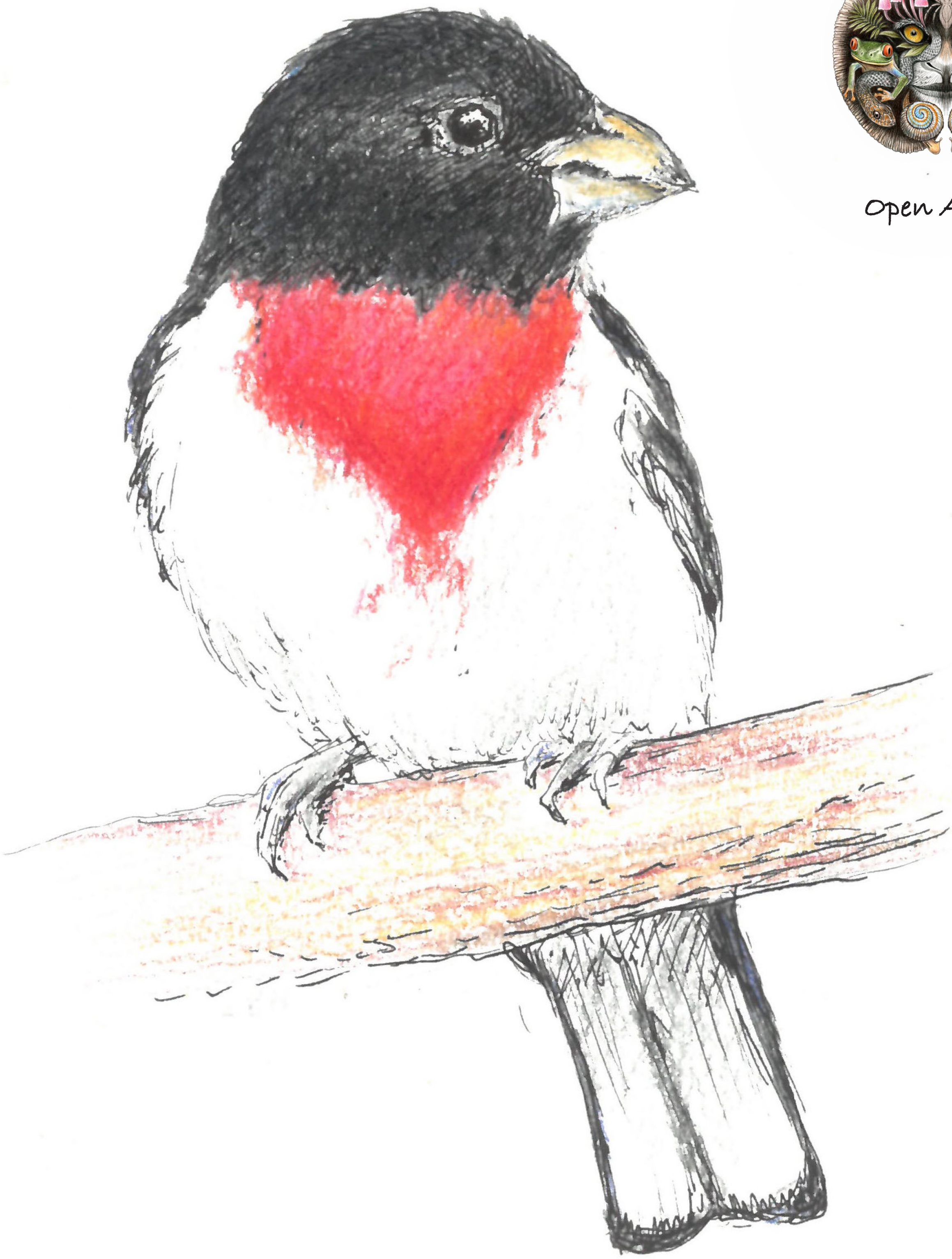

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Cover: Rose-breasted Grosbeak *Pheucticus ludovicianus*, pen & ink with colour pencil. © Lucille Betti-Nash.

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ARTICLE

Tree architecture model of Sumatran Orangutan *Pongo abelii* Lesson, 1827 (Mammalia: Primates: Hominidae) nests at Soraya Research Station, Leuser Ecosystem, Indonesia

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Abstract: The relationship between tree architectural models and the nesting behavior of the Sumatran Orangutan *Pongo abelii* Lesson, 1827 at the Soraya Research Station, Sumatra, Indonesia was determined by examining the preference for particular nest tree architectural models in relation to the frequency of nest occurrence. This investigation included the study of tree architectural models, tree types, nest profiles, vegetation, environmental factors, and geospatial data, collected within a 20 × 1,000 m (2 ha) observational area during a nest survey. A total of 59 orangutan nests were identified across 47 trees, categorized into 31 species and nine varied tree architectural models. Among these, the most prevalent models observed were Cook, Scarrone, and Attims, which exhibit features assumed to enhance orangutan nesting behaviors. Based on the Neu approach to nest qualities, the analytical test findings show a correlation between the preference ratings for nesting trees. Our results are expected to serve as a reference for selecting tree species in rehabilitation or habitat restoration programs and the development of separated forest block corridors as conservation efforts for orangutans.

Keywords: Animal behavior, arboreal animal, conservation, forest, habitat restoration, preferences, primate.

Bahasa Abstrak: Hubungan model arsitektur pohon dengan perilaku bersarang Orangutan Sumatera *Pongo abelii* Lesson, 1827 di Stasiun Penelitian Soraya, Sumatra, Indonesia ditentukan dengan memeriksa preferensinya terhadap model arsitektur pohon sarang tertentu dalam kaitannya dengan frekuensi kehadiran sarang. Penelitian ini mencakup studi model arsitektur pohon, jenis pohon, profil sarang, vegetasi, faktor lingkungan, dan data geospasial, yang dikumpulkan dalam area observasi seluas 20 × 1.000 m (2 ha) selama survei sarang. Sebanyak 59 sarang orangutan teridentifikasi di 47 pohon, dikategorikan ke dalam 31 spesies dan sembilan model arsitektur pohon yang bervariasi. Di antara model-model tersebut, model yang paling umum diamati adalah Cook, Scarrone, dan Attims, yang menunjukkan fitur-fitur yang diasumsikan meningkatkan perilaku bersarang orangutan. Berdasarkan pendekatan Neu terhadap kualitas sarang, hasil analisis menunjukkan adanya korelasi antara tingkat preferensi terhadap model pohon sarang tertentu. Hasil penelitian ini diharapkan dapat menjadi acuan awal dalam memilih jenis pohon yang sesuai untuk program rehabilitasi atau restorasi habitat dan pengembangan koridor blok hutan terpisah sebagai upaya konservasi orangutan.

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Author contributions: AGPL—designed the project, analyzed the data, and wrote the first draft of the manuscript. NP—proofread and assisted in the project and final editing of the manuscript.

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FORUM KONSERVASI LEUSER

PANCACITA

INTRODUCTION

Tree architecture refers to the morphological progression observed in tree-like plant development. It characterizes a sequence of structural stages of trees (Halle et al. 1978). Various species are identified by distinct architectural models, presenting 24 different models. Architecture significantly influences the ecological role of trees in the environment and plays a vital role in understanding their interactions with other life forms, particularly arboreal animals (Halle et al. 1978; Turner 2004).

Arboreal animals, particularly certain primate species, are often observed on trees with specific architectural features (Larson 2018). For instance, Javan Langurs *Trachypithecus auratus* have been seen using trees with the Schoute and Cook architectural models while feeding (Ayunin et al. 2014). When moving, resting, and seeking shelter, they were observed using trees with the Cook and Leeuwenberg models (Hendrawan et al. 2019). The Schoute model involves growth from meristems, producing orthotropic or plagiotropic trunks with equal dichotomy at regular but distant intervals, and lateral inflorescences. The Leeuwenberg model consists of equivalent orthotropic modules determined by terminal inflorescence production, while the Cook model results from continuous growth with spiral or decussate phyllotaxis, producing phyllomorphic branches (Halle et al. 1978). Proboscis Monkeys *Nasalis larvatus* favor the Rauh or Attims architectural models, where the Rauh architecture involves rhythmic growth of a monopodial trunk with tiered branches, and the Attims model is characterized by continuous growth with lateral flowering that does not affect shoot construction. These architectural models are distinguished by perpendicular branches suitable for resting or sleeping (Widiastuti et al. 2017).

Orangutans are arboreal mammals that highly rely on trees, particularly for nesting. They select a new tree for nesting and resting each day, considering specific characteristics and types of trees. Orangutans strategically place their nests to maintain a clear view of the surrounding forest. Trees with dense horizontal branches and a compact crown with uniformly spread leaves (a ball crown) are commonly preferred, as these features facilitate nest building. This preference is related to the tree's architectural model (Nowak 1999; Muin 2007; Nasution et al. 2018). Understanding the architectural models of orangutan nest trees is crucial to identify trends in the prevalence of specific models and their association with nest characteristics. Such knowledge can serve as a guideline for selecting tree species in habitat restoration initiatives, especially in creating distinct forest block corridors as part of orangutan conservation efforts.

METHODS

Study Area

The Leuser Ecosystem Area (KEL) is a critical natural environment characterized by its unique flora and fauna, forming a balanced ecosystem essential for maintaining biodiversity. This ecosystem supports several Critically Endangered species, including the Sumatran Orangutan *Pongo abelii*, Sumatran Rhinoceros *Dicerorhinus sumatranus*, Sumatran Tiger *Panthera tigris sumatrae*, and Sumatran Elephant *Elephas maximus sumatranus*. A notable protected area within the Leuser Ecosystem is the Soraya Research Station, which is recognized for its importance as an orangutan habitat. According to Mariana et al. (2020), the quality of orangutan habitat is primarily determined by the availability of food and nesting trees. In 2016, the Leuser Conservation Forum (FKL), in collaboration with the Aceh Forestry Environmental Service (DLHK), undertook the management of the Soraya Research Station (SRS), situated in a tropical environment with an annual rainfall of 2,450 mm. The temperature in this location ranges between 25–30 °C, with humidity averaging 98% in the morning and 95% in the afternoon. The SRS region has a hilly topography and is located at an elevation of 75–350 m. This research station area is classed as lowland tropical rainforest. Dipterocarpaceae, such as *Shorea* spp. and 'keruing' (Bahasa: Dipterocarp trees), *Dipterocarpus* spp., dominate the vegetation of the SRS. Other plant families that dominate at this location include Euphorbiaceae, Meliaceae, Lauraceae, Moraceae, and Anacardiaceae (Iqbar 2015).

Sampling Procedure

This study was conducted at the SRS from November to December 2020 using the principle of purposive sampling and an observation approach in the form of a nest survey on the path/trail. Strip transects with plots were used for observations and data gathering. The transect length was 100 m, with a single plot running the length and a width of 20 m at 10 observation locations (stations), for a total observation area of 2 ha (Figure 1).

Nest Survey

Nest surveys are conducted by strolling slowly down the trail, paying attention to the canopy at a 180° viewing angle, as well as direct surveys at the locations of nest trees discovered and recorded at the SRS (Atmoko & Rifqi 2012). The discovery of orangutan nest trees serves as the foundation for establishing observation locations. The nest tree is any tree that has an orangutan nest in a condition that allows for observation and collection, such as when practically all of the leaves have fallen or the structure of the twigs is evident.

Nest Tree Profile

Orangutan nest tree profile data, including tree type, diameter, total tree height, free branch height, and canopy area were observed with recordings featuring both common and scientific names, along with essential characteristics for identification. The diameter at breast height (DBH) was used to estimate the diameter of the tree, i.e., approximately 110–120 cm or 30 cm from the top of the buttress. A rangefinder was used to determine the total height of the tree as well as the free height of its branches. The crown area was calculated by measuring the distance between the outermost diagonal line and the tree canopy.

Nest Profile

Height of the nest was measured with a rangefinder, as was the position of nest and canopy of orangutan nest on tree. Orangutan nest position category included (Atmoko & Rifqi 2012):

a. Position 1, nest is at base of main branch of tree.
b. Position 2, nest is in middle or end of a tree branch.
c. Position 3, nest is at top of tree.
d. Position 4, nest is between two or more trees.
e. Position 0, nest is on the ground.

Type of orangutan nest canopy category (Atmoko & Rifqi 2012):

a. Opened canopies,
b. Semi-opened canopies, and
c. Closed canopies.

Vegetation Analysis

Vegetation analysis is an approach to quantify the composition, diversity, and richness of plant community with some parameters described as follow:

a. Density and Frequency (Rahman 2010):

$$\text{Density} = \frac{\text{Total number of individuals of the species in all sampling units}}{\text{Total number of sampling units studies}}$$

$$\text{Frequency} = \frac{\text{Number of sampling units in which species occur}}{\text{Total number of sampling units employed for the study}}$$

$$\text{Relative Density} = \frac{\text{Total number of individuals of the species in all sampling units}}{\text{Total number of all species}} \times 100\ \%$$

$$\text{Relative Frequency} = \frac{\text{Number of occurrences of the species}}{\text{Total number of occurrences in all sampling units}} \times 100\ \%$$

b. Species diversity index (H') analysed using Shannon-Wiener formula:

$$H' = -\Sigma P_i \ln P_i \ (P_i = n_i/N)$$

Where:

P_i = Proportion number of individuals to number of individuals all species,

ln = Natural logarithm.

Criteria for diversity index (Magurran 1988):

a. H'>3, species diversity is high
b. 1<H'≤3, species diversity is medium
c. H'<1, species diversity is low

c. Margalef species richness index (D_{mg}) analyzed using the formula:

$$D_{mg} = (S-1)/\ln N$$

Where, S = Number of species observed,

N = Total number of individuals of all species.

Criteria for richness index (Magurran 1988):

a. D_{mg} ≤3.5, richness index is low
b. 3.5< D_{mg} <5, richness index is medium
c. D_{mg} ≥5, richness index is high

Preference Test

The analysis employs the Neu approach, which is based on the frequency of habitat utilization in certain proportions. The assumption is that preference for nest tree type is exactly related to the frequency of nest presence in that tree type. Table 1 includes preference index criteria for data processing to generate preferences for nest tree architectural models (Neu et al. 1974; Bibby et al. 1998; Muin 2007):

a. w <1, not too likely
b. w ≥1, likely

Correlations test

The Statistical Package for the Social Science (SPSS) software was used to conduct quantitative data analysis to investigate the link between nest tree architectural model preferences and nest characteristic data in the form of nest profiles and nest tree profiles (Cantrell et al. 2016). Pearson correlation testing was performed on the assumption of correlation coefficient value (r), correlation coefficient criteria (Sarwono 2009), specifically:

a. r = 0, uncorrelated
b. 0 > r > 0.25, very week
c. 0.25 > r > 0.5, enough
d. 0.5 > r > 0.75, strong
e. 0.75 > r > 0.99, very strong
f. r = 1, perfect

RESULTS AND DISCUSSION

Orangutan Nest Survey

During the observation at the Soraya Research Station, a total of 59 orangutan nests were identified in 47 distinct trees. Numerous individual nest trees contained more than one orangutan nest.

Distribution of trees encountered along the transects is illustrated in Figure 2. The density of individual trees is a crucial factor in the preference test. The highest number of individual trees was observed at an altitude of 90 m with gentle to steep slope conditions. The vegetation in this area is quite dense, with tree heights ranging from 7–33 m and canopy widths varying from 1–19 m. Due to its proximity to a river, the canopy is partially open. Factors such as height, slope, canopy, and proximity to a river significantly affect orangutan nest establishment (Rijksen 1987; Muin 2007; Prayogo et al. 2016).

Nest Architecture Model

Nests were discovered in 31 of the 103 tree species that were studied (Table 2). Nine of the sixteen tree architectural models that were seen included the kind of tree that contained the nest.The Attims model had the most types (20) among the various nest tree types (six), while the Stone model had nine types with several nest tree variations (Figure 3). The Stone model was observed in all surveyed locations within the lowland rainforests, while the Cook, Fagerlind, and Prevost models were challenging to locate in some observation areas. Seven architectural models where no orangutan nests were discovered are listed in Appendix 8, including Leeuwenberg, Aubreville, Massart, Nozeran, Rauh, Champagnat, and Troll. The number of nest tree species is more influenced by tree attributes such as trunk diameter, tree height, canopy area, and tree architectural model rather than the number of tree species. The architectural models of discovered nest trees feature robust trunks, multiple branches, and are compactly arranged. These features support their suitability as orangutan nest trees. Architectural models of trees without nests exhibit weaker trunks with few poorly organized branches, making them unsuitable as orangutan nest trees due to their inability to support the orangutan's weight. The main factor influencing the selection of nest trees is the stem character, with orangutan nests being predominantly located in large, sturdy trees (Rijksen 1978; Muin 2007; Putro et al. 2019; Mardiana et al. 2020).

The number of tree species suitable for nesting is influenced more by specific tree attributes—such as trunk diameter, tree height, canopy area, and tree

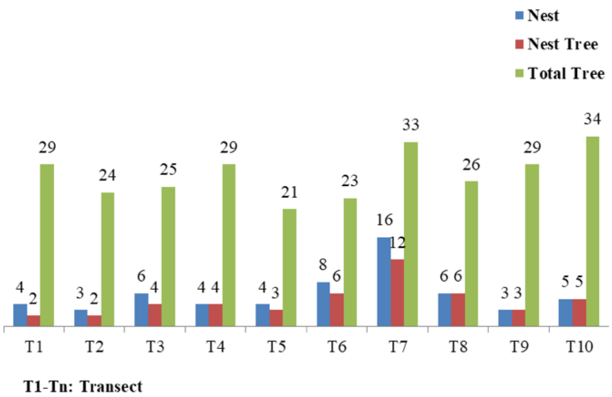

Figure 1. Profile of orangutan nests at Soraya Research Station.

Table 1. Summary of nest tree data in preferences index formula.

Nest Tree	P	N	u	e	W	b
1						
2						
...						
k	Pk	Nk	uk	ek	wk	bp
Total	1000	Σn	1000	Σe	Σw	1000

p—individual proportion of tree architecture models | n—frequency of nest's presence | u—proportion of nests presence (n/Σn) | e—expected value (p × Σn) | w—preference index (u/p).

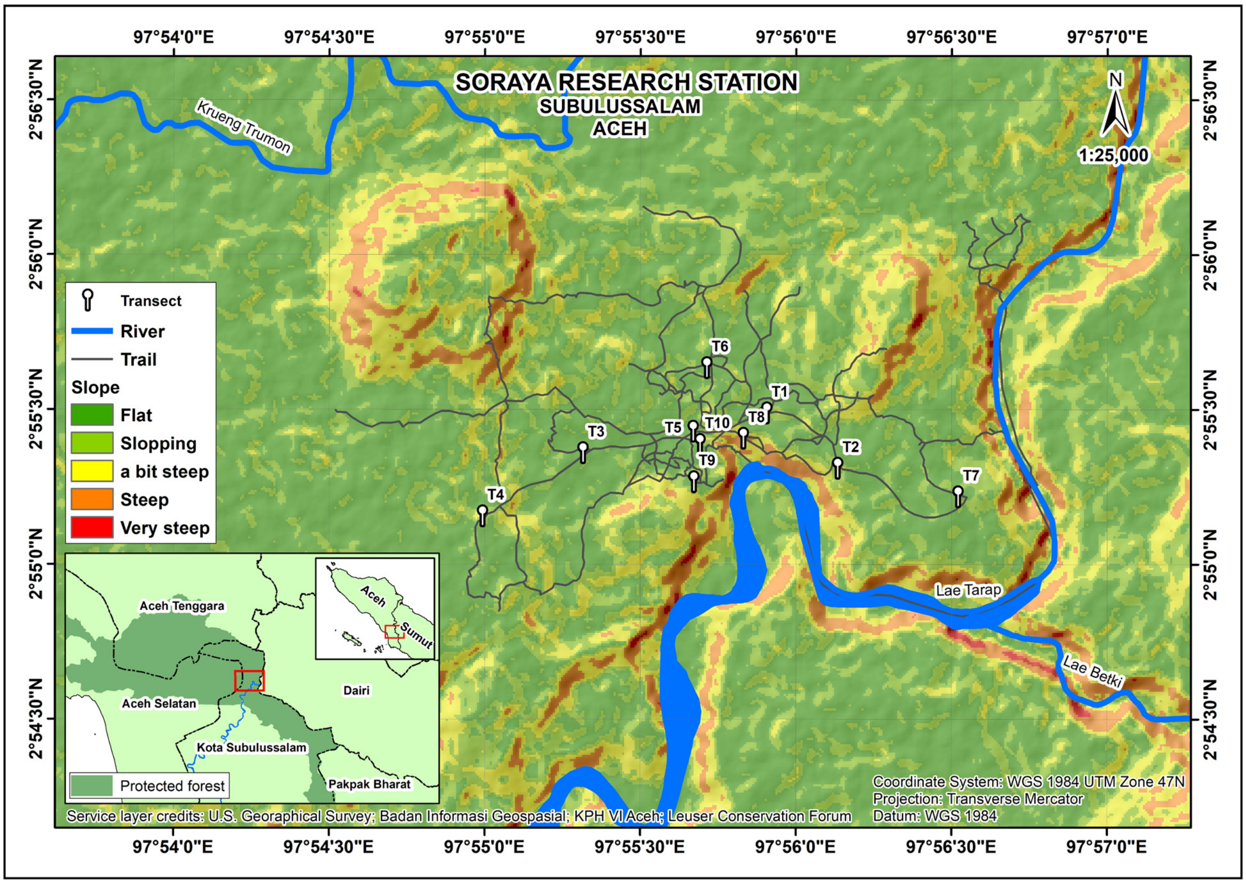

Figure 2. Map of Soraya Research Station showing sampling point of nest survey.

architectural model—rather than merely the number of tree species available. Trees exhibiting the appropriate nest architectural model typically feature strong trunks, numerous well-organized branches, and close compactness, making them well-suited as orangutan nest trees. Conversely, trees lacking these nest features present weaker trunks and fewer, disorganized branches, rendering them unsuitable as orangutan nest trees due to their inability to support the orangutan's weight. Consequently, the main factor in nest tree selection is the tree's physical structure, with orangutan nests most frequently found in larger, sturdier trees (Rijksen 1987; Prayogo et al. 2016).

Vegetation composition and ecology

The assessment of 103 identified species revealed 10 species with the highest RD and RF values (Table 3). Of these, nests are found in eight species. *Shorea multiflora* (Burck) Symington boasted the highest RD value (10.57%), while *Streblus elongatus* (Miq.) Corner, *Shorea leprosula* Miq., and *Palaquium rostratum* (Miq.) Burck exhibited the highest RF value (3.33%). These four tree species are frequently used by orangutans for nesting purposes. The region exhibits a rich diversity of tree species (*H'*) with a Shannon-Wiener diversity index of 4. Moreover, the richness of tree species in the region is substantial with a Margaleff Index (D_{mg}) of 15.96. As a critical element of the orangutan habitat, vegetation plays a significant role. The diversity and richness of plant species impact various aspects of orangutan survival, including feeding, migration, and nesting behaviors. A habitat containing a wide array of food and nest trees improves significantly with the high diversity and richness of plant species. Conducting a vegetation analysis helps understand the composition of the vegetation in a given area. It helps differentiate land cover types and habitat variations based on the most relevant plant species (Rahman 2010; Kuswanda 2014b; Regina et al. 2020).

Preference Test

The findings from the preference test suggest that three tree architectural models are highly favored (Figure 4). Orangutans exhibit a tendency to construct nests based on various factors such as tree height, diameter,

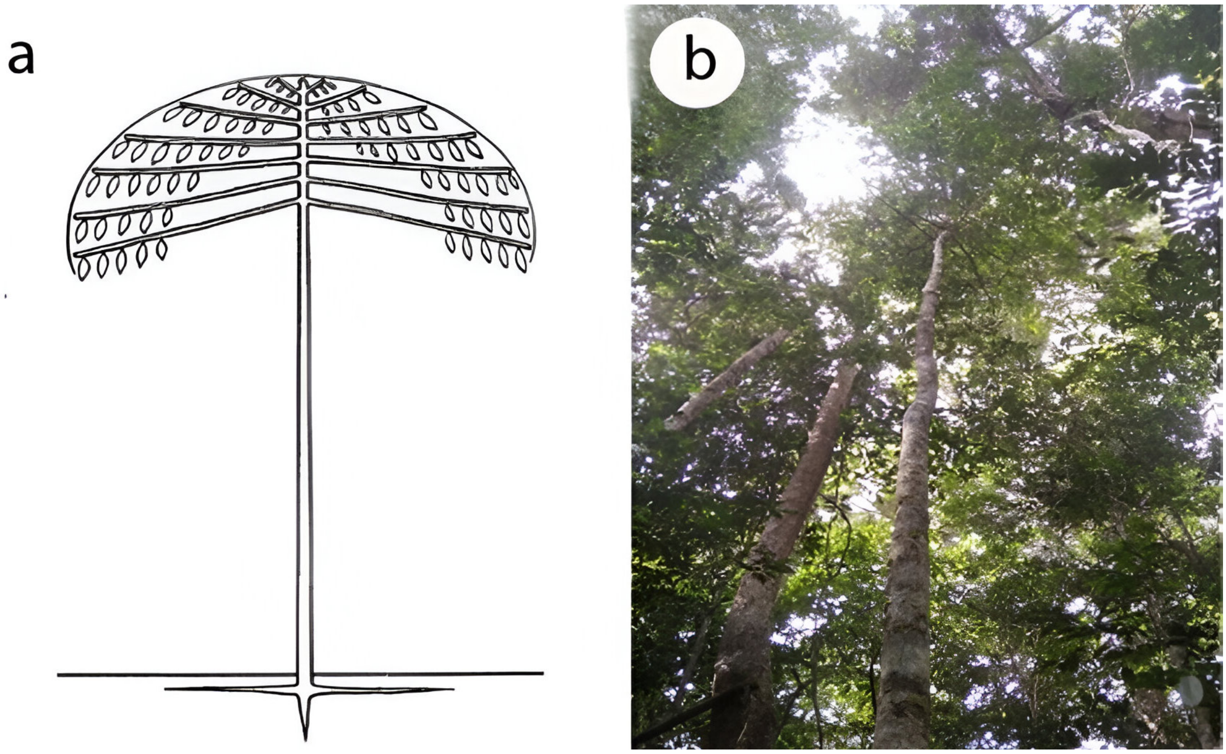

Image 1. a—Illustration of Cook architectural model (Halle et al. 1978) | b—*Monocarpia maingayi* (Hook.f. & Thomson) I.M. Turner. © Anugrah Gilang Permana Lubis.

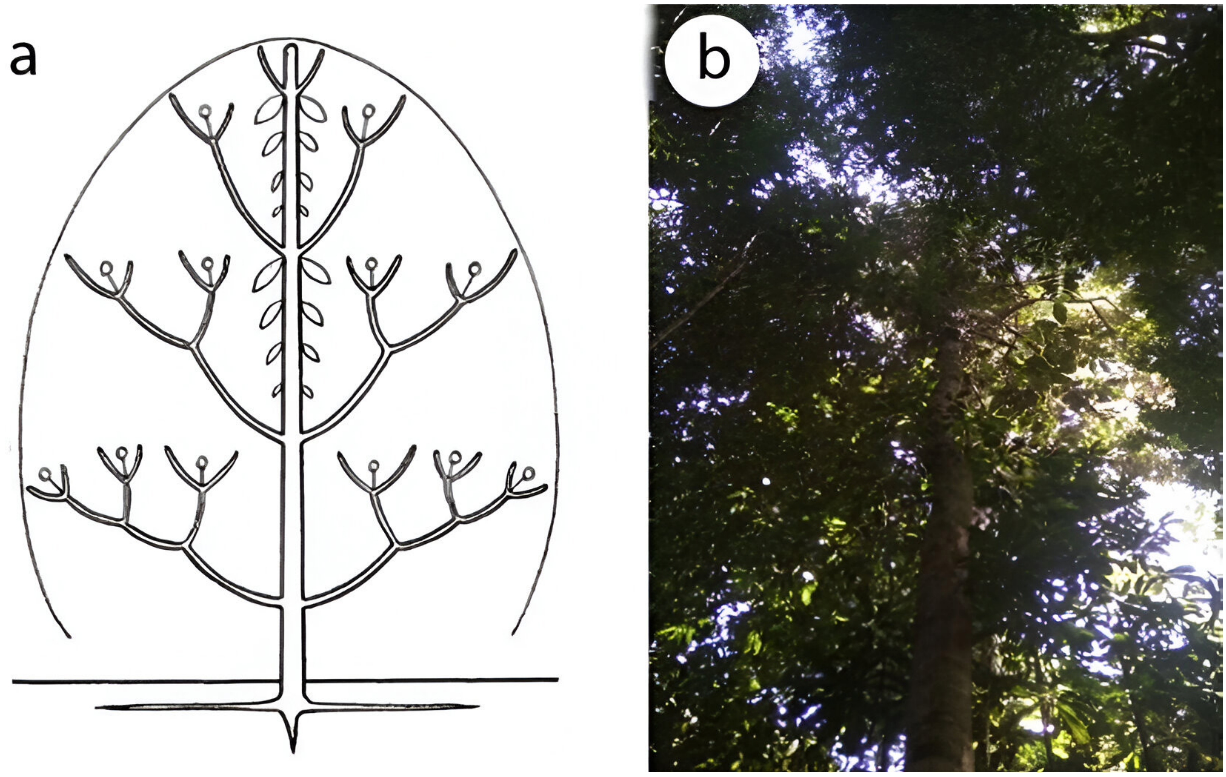

Image 2. a—Illustration of the Scarrone architectural model (Halle et al. 1978) | b—*Lithocarpus javensis* Blume. © Anugrah Gilang Permana Lubis.

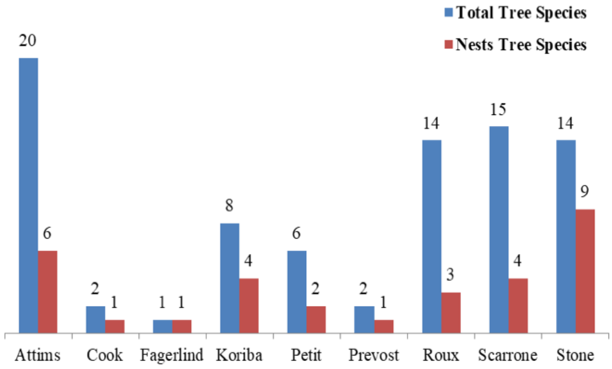

Figure 3. Number of species with nest each architecture models.

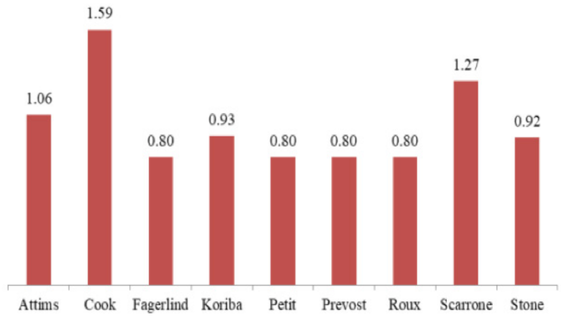

Figure 4. Diagram of preference test result.

crown size, and crown shape, nest height, nest position, and nest canopy. These aspects have a direct bearing on the appearance of the nest. The branch shape and tree size are key characteristics of tree architecture (Muin 2007; Nababan et al. 2021).

The Cook tree model represents a branching structure with a central trunk and multiple branches (Image 1). This type of architecture results from continuous branching originating from the main stem, showing either spiral or crossing (decussate) phyllotaxis. The phyllomorphic branching structure resembles compound leaves and is a subset of plagiotropic branching that includes non-modular or equivalent monopodial or sympodial branches. In this model, branches are closely spaced and leaves are evenly distributed, giving rise to a robust architectural design (Halle et al. 1978).

Scarrone is a branching tree architectural form (Polyaxial) with a vegetative axis divided into trunks and branches (Image 2). Growth takes the form of rhythmic ramification from orthotropic monopodial stems. Sympodial branching consists of non-equivalent orthotropic branches. This model has a strong architectural style and several branches (Halle et al. 1978).

Table 2. Distribution of species across tree architecture models that orangutan nest exist in Soraya Research Station.

Tree architecture models	Species
Attims	*Aglaia* sp.
	Dacryodes costata (A.W.Benn.) H.J. Lam.
	Palaquium rostratum (Miq.) Burck
	Payena lucida A.DC.
	Shorea glauca King
	Shorea multiflora (Burck) Symington
Cook	*Monocarpia maingayi* (Hook.f. & Thomson) I.M.Turner
Fagerlind	*Cyathocalyx sumatranus* Scheff.
Koriba	*Aglaia korthalsii* Miq.
	Aglaia speciosa Blume
	Aporosa antennifera (Airy Shaw) Airy Shaw.
	Streblus elongatus (Miq.) Corner
Petit	*Diospyros pyrrhocarpa* Miq.
	Durio oxleyanus Griff.
Prevost	*Knema cinerea* (Poir.) Warb.
Roux	*Garcinia celebica* L.
	Shorea leprosula Miq.
	Syzygium spp.1
Scarrone	*Barringtonia scortechinii* King
	Lithocarpus javensis Blume
	Mangifera foetida Lour.
	Xanthophyllum vitellinum (Blume) D.Dietr.
Stone	*Aporosa lunata* (Miq.) Kurz
	Diospyros bangkana Bakh.
	Garcinia dioica Blume
	Gluta renghas L.
	Lithocarpus sp.
	Lithocarpus wrayi (King) A.Camus
	Mischocarpus sundaicus Blume
	Rinorea sclerocarpa (Burgersd.) Melch.
	Syzygium spp.2
Total	
nine models	31 Species

Attims is a tree architectural model that belongs to the branching tree (Polyaxial) category, with a vegetative axis that is separated into trunk and branches (Image 3). Continuous ramification from orthotropic monopodial stems drives growth. Monopodial branching is equivalent to orthotropic growth direction. The branches are grouped tightly together with the same size, and the leaves are evenly distributed with many twigs, resulting

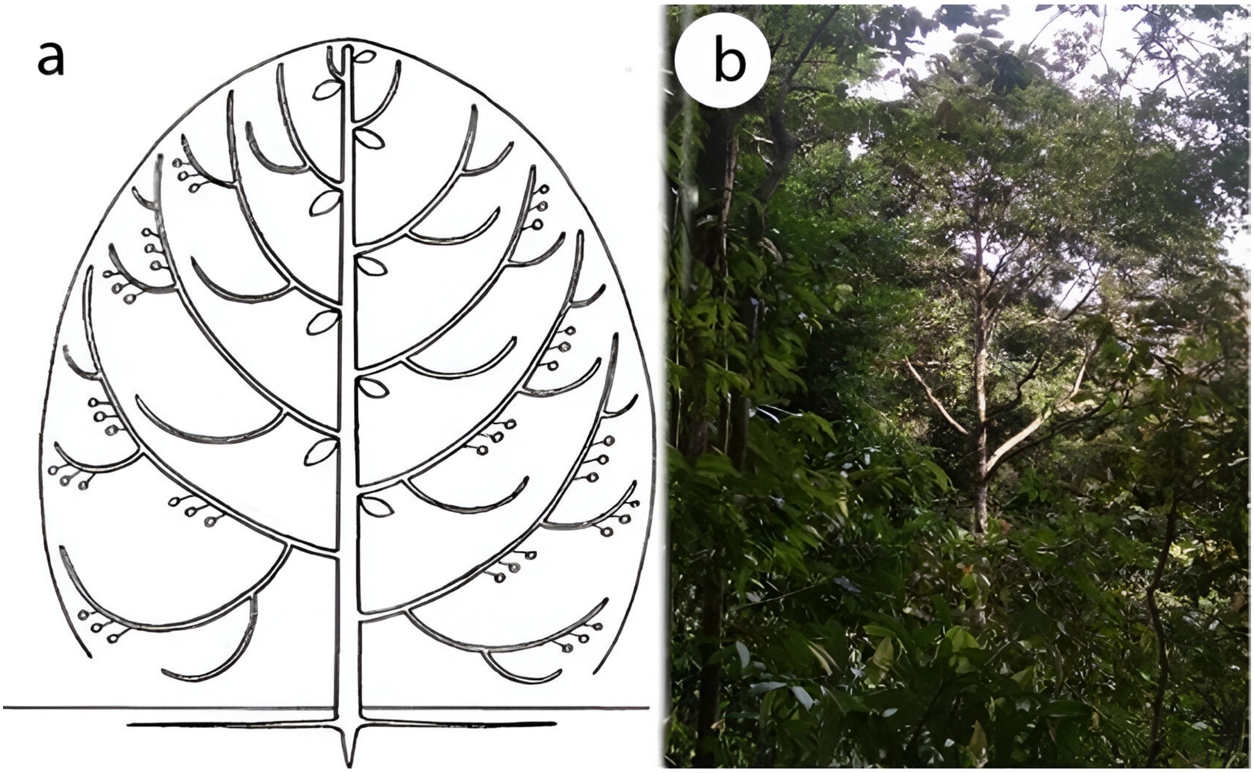

Image 3. a—Illustration of the Attims architectural model (Halle et al. 1978) | b—*Parashorea lucida* Kurz. © Anugrah Gilang Permana Lubis.

Table 3. Major tree species utilized by orangutan and its ecological indices in Soraya Research Station.

	Species	Models	RF (%)	RD (%)	H	D_{mg}
1	*Shorea multiflora* (Burck) Symington	Attims	2.59	10.57	4	15.96
2	*Streblus elongatus* (Miq.) Corner	Koriba	3.33	7.89		
3	*Artocarpus kemando* Miq. *	Champagnat	2.96	5.37		
4	*Shorea leprosula* Miq.	Roux	3.33	4.7		
5	*Palaquium rostratum* (Miq.) Burck	Attims	3.33	3.86		
6	*Barringtonia scortechinii* King	Scarrone	2.96	2.35		
7	*Gluta renghas* L.	Stone	2.22	3.02		
8	*Syzygium* sp. 1	Roux	2.59	1.51		
9	*Monocarpia maingayi* (Hook.f. & Thomson) I.M.Turner	Cook	2.22	1.85		
10	*Macaranga pruinosa* (Miq.) Müll. Arg. *	Rauh	1.85	2.18		

*—non-nest tree

in a solid architecture (Halle et al. 1978).

Three tree architectural models—Cook, Scarrone, and Attims—demonstrate a structure with trunks and branches. While Scarrone displays a sympodial growth form, both Cook and Attims exhibit monopodial growth. These models are characterized by robust branches and a closely spaced design, enabling the trunk, branches, and twigs to support the orangutan's weight. Cook's architectural design features a circular crown with horizontal branches, whereas Attims and Scarrone present a ball-shaped crown with vertical branches.

Correlation test

In terms of the correlation test, the preference index for the nest tree architecture model displays a sufficient, yet statistically insignificant correlation with parameters

Table 4. Pearson's correlation coefficient (r) of related parameters.

Parameter	Correlation coefficient (Pearson correlation)							
	w	PS	KS	TS	TPS	TBC	LT	LB
w	1	0.108	0.161	0.348	0.350	0.305	0.264	0.289
PS	0.108	1	0.954**	0.794*	0.930**	0.409	0.819**	0.616
KS	0.161	0.954**	1	0.658	0.909**	0.306	0.752*	0.659
TS	0.348	0.794*	0.658	1	0.779*	0.665	0.710*	0.419
TPS	0.350	0.930**	0.909**	0.779*	1	0.339	0.899**	0.695*
TBC	0.305	0.409	0.306	0.665	0.339	1	0.358	-0.079
LT	0.264	0.819**	0.752*	0.710*	0.899**	0.358	1	0.780*
LB	0.289	0.616	0.659	0.419	0.695*	-0.079	0.780*	1

w—preference index | PS—nest position | KS—nest canopy | TS—nest height | TPS—nest tree height | TBC—free branch height | LT—canopy area | LB—basal area | **—significant at the 0.01 level | *—significant at the 0.05 level.

tested. The factors correlating in descending order are nest tree height, nest height, branch free height, basal area, and crown area (Table 4). On the other hand, there is a weak correlation between nest position and nest canopy. A moderate to extremely strong and significant association exists between nest profile parameters and the nest tree profile. The primary aim of this investigation was to explore the relationship between nest tree selection and the preference index value for the nest tree profile.

The architectural structure of trees, encompassing branching forms and crown shapes, significantly influences orangutan nesting preferences, as evidenced by the adequate correlation between the preference index and nest features. These elements, including the nest site, canopy, and height, play pivotal roles in defining the nest qualities (Muin 2007). Nest profile and nest tree profile stand as influential determinants of orangutan nesting behavior. The correlation test findings strongly demonstrate a positive and substantial association between the nest profile and the nest tree profile. The height of the nest correlates directly with the height of the nest tree, while the position of the nest is governed by the dimensions of the nest tree, such as basal area and crown area (Khoetiem et al. 2014). Moreover, the tree's architectural model, particularly characterized by a canopy shielding the orangutan's nest, affects the selection of nest trees. Previous research has suggested that orangutan nests are more commonly found in trees with a canopy structure and area sufficiently large to shelter the nest or canopy (Nasution et al. 2018).

CONCLUSION

The preference index value was determined by calculating the proportion of the frequency of orangutan nests across eight architectural models of trees observed during the study. Among these models, the Cook, Scarrone, and Attims architectures emerged as the most preferred for nesting activities. This preference is supported by the correlation coefficient results, which indicate a significant relationship between orangutan nesting behaviors and specific tree architecture models. These findings highlight the importance of these models in shaping habitat components critical for the conservation of orangutans.

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