



Population Dynamics of *Asplenium nidus* as a Bed Bioindicator (*Paradisaea minor jobiensis* Rothschild, 1897) in the Period 2018–2024 in Barawai, Yapen Island, Papua, Indonesia

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Abstract

Asplenium nidus is an epiphytic fern recognized as an ecological bioindicator associated with the nesting habitat of the lesser bird-of-paradise (*Paradisaea minor jobiensis* Rothschild, 1897). This study analyzed population dynamics of *A. nidus* between 2018 and 2024 and examined its relationship with host tree species as an indicator of forest ecosystem health in the Imbowiari Barawai Forest, Yapen Island, Papua, Indonesia. Field observations were conducted using a transect-plot method, and data were analyzed using diversity indices, descriptive statistics, and morphometric comparisons. In 2018, 63 individuals of *A. nidus* were recorded on 49 host tree species, with high host diversity ($H' = 3.77$). In 2024, 79 individuals were recorded on only nine host species, resulting in moderate diversity ($H' = 1.79$). Five host species, *Canarium hirsutum*, *Pimeleodendron amboinicum*, *Intsia bijuga*, *Ficus sp.*, and *Myristica longipes*, consistently supported *A. nidus* populations in both periods. Morphometric characteristics showed no significant differences among sampling sites. These findings indicate that *A. nidus* can serve as a useful bioindicator of habitat conditions and provide baseline information for long-term ecological monitoring, habitat assessment, and conservation of bird-of-paradise nesting habitats in Papua and support sustainable forest management practices.

Keywords: population, *Asplenium nidus*, bioindicator, *Paradisaea minor jobiensis*, Barawai Yapen Papua

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Introduction

The Yapen Islands in Papua are a biodiversity-rich region, with tropical forests supporting a wide range of plant and animal species (Raunsay, 2022). The Imbowiari Barawai forest is part of this area, which contains ecosystems important for the survival of local flora and fauna species, including birds-of-paradise *Paradisaea minor jobiensis* and epiphytes such as *Asplenium nidus* (Raunsay, 2014; Raunsay et al., 2022). In the context of tropical forest ecosystems, epiphytic species play a crucial role in maintaining ecosystem balance, both as air humidity regulators and as habitats for various organisms (Nawawi et al., 2014; Darma et al., 2018).

A. nidus, or bird's nest spike, is known as an epiphyte that is sensitive to environmental changes (Fitrah et al., 2014). This species depends on stable environmental conditions, especially in terms of humidity, temperature, and air quality (Mansur et al., 2004). Therefore, *A. nidus* is often used as a bioindicator to assess the health of forest ecosystems. In a healthy ecosystem, *A. nidus* populations will thrive, whereas

in degraded areas, they will decline.

In this study, *A. nidus* was used to monitor the dynamics of the Imbowiari Barawai forest ecosystem, particularly as a marker of environmental degradation caused by human activities or climate change in the period 2018 to 2024. Monitoring *A. nidus* populations is relevant because its sensitivity to environmental change can provide early insights into changes in habitat quality but is also important as a means for lesser yellow birds-of-paradise to lay their nests.

P. m. jobiensis, also known as the little yellow bird of paradise, is a bird species that symbolizes Papua's biodiversity. This bird has certain habitat preferences, including favoring areas rich in epiphytes, such as *A. nidus*, to build or lay their nests (Raunsay, 2022). Nests made in epiphyte-infested environments suggest that these environments still maintain favorable microclimatic conditions for the survival of various species.

The presence of *A. nidus* around Cenderawasih nests is an indicator that the ecosystem is still in good condition

(Raunsay, 2014). A decrease in the number of epiphytes may provide an early signal of a decline in habitat quality that may impact populations of *P. m. jobiensis* and other species.

The period 2018–2024 is a crucial timeframe for monitoring changes in forest ecosystems in Yapen, especially in the Imbowiari Barawai area. During this period, various environmental changes, both due to human activities such as deforestation, land use change, and climate change impacts, are expected to affect *A. nidus* populations. The population dynamics of this epiphyte not only reflect changes at the vegetation level but also changes at the ecosystem level as a whole (Nawawi et al., 2023).

This study aims to analyze changes in *A. nidus* populations as a key bioindicator and see how these fluctuations correlate with the presence of *P. m. jobiensis*. Data collected over the period 2018–2024 will provide a comprehensive picture of the environmental conditions in this forest area and the relevance of the role of epiphytes in supporting biodiversity.

Methods

This research was conducted in the Imbowiari forest area, Barawai village, Yapen Islands Regency, Papua Province, in August 2024. The tools and materials used in this research are a camera, GPS, binoculars, roll meter, 70% alcohol, and herbarium equipment. The population in this study includes all host species and *A. nidus* found in the Imbowiari Barawai forest area, while the samples are hosts and *A. nidus* species found in the transect observation plot.

Data collection on *A. nidus* as a bioindicator of bird of paradise *P. m. jobiensis* nests using the modified transect method to analyze *A. nidus* distribution and height on hosts. The research data collection procedure is as follows: a) exploratory field surveys began in the Imbowiari forest area with observations of *A. nidus* and its hosts; b) establish 3 transect lines, where each transect consists of 15 plots measuring 20 m × 20 m (Figure 1); and c) data collection on the number of *A. nidus* included host tree height and host tree herbarium samples.

Data on the vertical distribution of *A. nidus* were analyzed descriptively, qualitatively, and quantitatively. A simple regression analysis was conducted to test the extent of the relationship between the number of *A. nidus* as the dependent variable and host tree height as the independent variable. The simple linear regression equation model is shown in Equation [1] (Astuti & Sulistiyowati, 2017).

$$Y = a + bX \quad [1]$$

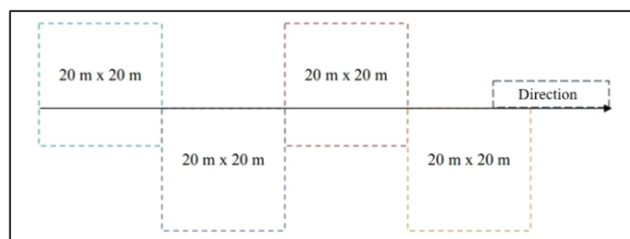


Figure 1 Design of sampling transects with transect method and plot method that intersect contour lines.

note: Y = dependent variable (*A. nidus*), X = independent variable (host tree height), a = constant, and b = regression coefficient (slope). The values of a and b can be calculated using Equation [2] and Equation [3].

$$a = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \quad [2]$$

$$b = \frac{(\sum y)(\sum x) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \quad [3]$$

The temporal design of this study only covers two observation periods, namely 2018 and 2024, with an interval of six years. Such data collection patterns are not sufficient to accurately describe the population dynamics of *A. nidus* because natural populations can experience annual fluctuations due to climatic variations and seasonal ecological disturbances. Thus, the results of this study represent more a comparison of conditions between the two observation times rather than a long-term trend. To gain a more comprehensive understanding of population dynamics, monitoring should be done periodically every year or every two years with seasonal replication. This approach will help detect more pronounced temporal variations and support the scientific interpretation of population changes.

The number of plots used in this study, which is 45 plots from three transects, is still relatively limited to represent the entire Barawai forest ecosystem. Small sample sizes can degrade statistical power, making it possible to detect only large changes while missing more subtle ecological variations. This condition has the potential to cause the interpretation of the results to be less representative of the actual population conditions. To improve the validity and accuracy of ecological inferences, a greater number of plots and a distribution of transects covering different habitat types are required. Proportional addition of plots in each ecosystem zone will provide more accurate picture of the *A. nidus* population. Therefore, further research needs to expand the scope of the sample to reach the ideal tropical forest monitoring standard, which is around 100–200 plots.

The placement of the research plot mostly follows a path that is easily accessible to the researcher, thus giving rise to the potential for spatial bias towards areas that have been disturbed by human activities. This condition can cause the results of observations to reflect more of the forest edges or degraded locations than the natural conditions of the ecosystem. Such spatial biases reduce the ability of research to represent the overall community structure in the Barawai forest area. Therefore, further research needs to apply a stratified random sampling design with predetermined GPS coordinates to ensure randomness and representation. This strategy will help reduce distortions due to site selection and improve the reliability of the ecological data collected. Thus, the results of the research will be more objective and reflect the condition of the forest as a whole.

The data collection process in 2018 and 2024 was not explained in detail, whether it was carried out by the same team or using identical recording methods. Differences in observers, field experience, and recording techniques can give rise to variations in results that do not reflect real ecological changes. This condition raises the potential for observer bias that reduces the consistency and reliability of

data between years. To minimize this risk, follow-up research should involve joint training for all observers and use standardized observation protocols. Photo documentation, identification sheets, and voucher specimens also need to be included for result verification. This step is important so that data differences truly reflect population dynamics, not human error.

Table 1 Structure and composition of *Asplenium nidus* in 2018

Family	Latin name	Total
Apocynaceae	<i>Lepinopsister natensis</i> Valetton.	1
Apocynaceae	<i>Cerbera manghas</i>	2
Anacardiaceae	<i>Mangifera</i> sp. L.	1
Arecaceae	<i>Areca microcarpa</i> L.	1
Arecaceae	<i>Arenga microcarpa</i> Becc.	1
Arecaceae	<i>Areca macrocalyc</i> L.	1
Anonaceae	<i>Monnon congregatum</i>	1
Anacardiaceae	<i>Mangifera</i> sp. L.	1
Burseraceae	<i>Canarium hirsutum</i> Willd.	2
Combretaceae	<i>Terminalia complanata</i> K. Schum	1
Elaeocarpaceae	<i>Elaeocarpus</i> sp.	1
Elaeocarpaceae	<i>Elaeocarpus sphaericus</i> K. Schum	1
Euphorbiaceae	<i>Pimeleodendron amboinicum</i> Hassk.	5
Euphorbiaceae	<i>Pothostemon javensis</i> Blume.	1
Fabaceae	<i>Intsia palembanica</i> Miq.	3
Fabaceae	<i>Intsia bijuga</i> Colebr.	1
Hernandiaceae	<i>Hernandia peltata</i> Meisn	1
Icacinaeae	<i>Medusanthera</i> sp.	1
Icacinaeae	<i>Gonocaryum litorale</i> Miq.	1
Icacinaeae	<i>Medusanthera laxiflora</i> Miers.	3
Icacinaeae	<i>Pometia pinnata</i> J.R. Forst.	1
Lauraceae	<i>Litsea odolifera</i> Valetton.	1
Lauraceae	<i>Litsea tuberculata</i> Boerl.	1
Lauraceae	<i>Litsea glutinosa</i> Lour.	1
Lauraceae	<i>Litsea</i> sp. Lam.	2
Melastomataceae	<i>Memecylon</i> sp. L.	1
Meliaceae	<i>Aglaia culculata</i> Roxb.	1
Moraceae	<i>Parinari papuana</i> Becc.	1
Moraceae	<i>Ficus</i> sp. L.	1
Moraceae	<i>Ficus annulata</i> Blume.	1
Myristicaceae	<i>Myristica longipes</i> Warb.	1
Myristicaceae	<i>Horsfieldia irya</i> Willd.	1
Myristicaceae	<i>Knema</i> sp. Lour.	1
Myristicaceae	<i>Knema tomentella</i> (Miq.) Warb.	1
Myristicaceae	<i>Myristica subalulata</i> Miq.	3
Myristicaceae	<i>Myristica</i> sp. Gronov	1
Maesaceae	<i>Maesa</i> sp. Forssk.	1
Nyctaginaceae	<i>Pisonia</i> sp. L.	2
Pittospraceae	<i>Pittosporum</i> sp. Banks ex sol.	1
Phyllantaceae	<i>Ptychosperma macarthurii</i>	1
Rubiaceae	<i>Psychotria</i> sp. Danbula.	1
Rubiaceae	<i>Nauclea</i> sp. L.	1
Rubiaceae	<i>Neonauclea papuana</i> Blume.	1
Sapindaceae	<i>Pometia acuminata</i> Hookf.	1
Sapotaceae	<i>Palaquim</i> sp. Blanco.	1
Sapotaceae	<i>Pouteria</i> sp. Aubl.	1
Saxifragaceae	<i>Fagraea racemosa</i>	1
Theaceae	<i>Gordonia</i> sp. Ellis.	1
Tiliaceae	<i>Althoffia</i> sp. L.	1

Results

Structure and composition of *A. nidus* as a nest bioindicator of *P. m. jobiensis* in 2018 Research data on *A. nidus* in Imbowiari forest as a bioindicator of *P. m. jobiensis* bird nests showed that 63 individuals were distributed on 49 hosts as shown in Table 1. This data shows that there is a tendency for 1 *A. nidus* individual to be on 1 host, although some of them have more. Some host species that have more than 1 individual of *A. nidus* are *Cerbera manghas*, *Canarium hirsutum* Willd., *Litsea* sp., *Pisonia* sp. L., each (2 individuals); *Intsia palembanica* Miq., *Medusanthera laxiflora* Miers., *Myristica subalulata* Miq. each (3 individuals); *Pimeleodendron amboinicum* Hassk with 5 individuals.

Structure and composition of *A. nidus* as a bioindicator of *P. m. jobiensis* in 2024 Analysis of the structure and composition of *A. nidus* was conducted at the five bird-of-paradise spots of the lesser yellow. This research is important to analyze the presence of *A. nidus* as a nest bioindicator. This is in line with research conducted by Raunsay (2014), Raunsay (2020), Raunsay et al. (2022), which states the role of *A. nidus* in the Imbowiari Barawai forest area as a bioindicator of *P. m. jobiensis* bird nests. The results of research in the Imbowiari forest area of Barawai Village show that overall there are 9 hosts species of *A. nidus* were recorded Table 2, where for the first spot consists of 3 types of hosts, the second spot 12 types, the third spot 4 types, the fourth spot 4 types, and the fifth spot 2 types. Of the five spots distributed, *A. nidus* in each spot with a total of 79 individuals, where the first spot is 9 individuals, second 23 individuals, third 10 individuals, fourth 27 individuals and fifth 10 individuals as shown in Table 2. The total number of *A. nidus* individuals found this time is much higher than the previous record of 63 individuals. Raunsay et al. (2022) observation data at these sites show the diversity of host tree species and the number of individuals or entities observed at each spot.

A. nidus, found in a forest area, primarily serves as a suitable host for this organism. Field research results show that the current condition of Imbowiari forest has a fairly high density. This is indicated by the thicker litter and forest floor and the large tree canopy and diameter and height of trees that are different from the previous few years. The dependence and tendency between *A. nidus* and host trees are of course

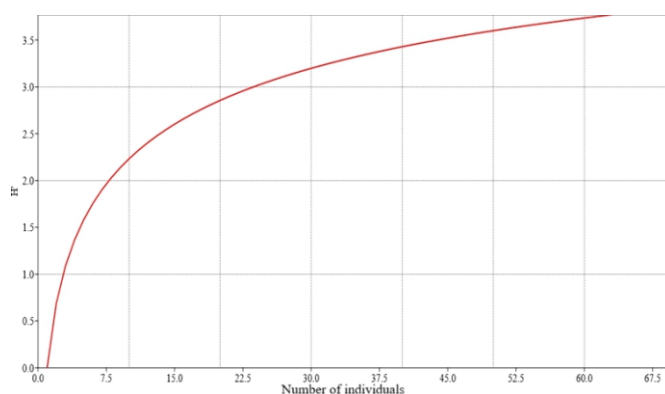


Figure 2 Diversity graph of *Asplenium nidus* in 2018.

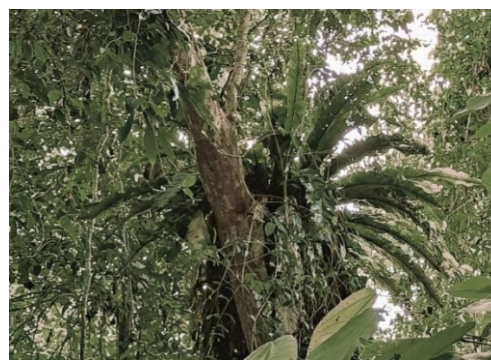


Figure 3 *Asplenium nidus* in Barawai Imbowiari forest.

Table 2 Distribution of *Asplenium nidus* in Barawai Village forest

Spot	Point	Host tree (Substrate)	Total
1	1	<i>Intsia bijuga</i> (Colebr.) Kuntze	3
	2	<i>Intsia bijuga</i> (Colebr.) Kuntze	2
	3	<i>Myristica longipes</i> Warb.	4
		Subtotal	9
2	1	<i>Pometia acumminata</i> Hookf.	3
	2	<i>Canarium hirsutum</i> Willd.	1
	3	<i>Alpinia malaccensis</i>	5
	4	<i>Gnetum gnemon</i> Linn.	2
	5	<i>Tristania microsperma</i> Ridl	1
	6	<i>Intsia bijuga</i> (Colebr.) Kuntze	2
	7	<i>Myristica longipes</i> Warb.	1
	8	<i>Intsia bijuga</i> (Colebr.) Kuntze	2
	9	<i>Pimeleodendron amboinicum</i> Hassk.	1
	10	<i>Myristica longipes</i> Warb.	1
	11	<i>Intsia bijuga</i> (Colebr.) Kuntze	2
	12	<i>Gnetum gnemon</i> Linn.	1
		Subtotal	23
3	1	<i>Pimeleodendron amboinicum</i> Hassk.	1
	2	<i>Alpinia malaccensis</i>	1
	3	<i>Tristania microsperma</i> Ridl	1
	4	<i>Canarium hirsutum</i> Willd.	1
	5	<i>Pometia acumminata</i> Hookf.	3
	6	<i>Myristica longipes</i> Warb.	3
		Subtotal	10
4	1	<i>Intsia bijuga</i> (Colebr.) Kuntze	8
	2	<i>Ficus</i> sp.	5
	3	<i>Intsia bijuga</i> (Colebr.) Kuntze	3
	4	<i>Ficus</i> sp.	7
	5	<i>Myristica longipes</i> Warb.	4
		Subtotal	27
5	1	<i>Intsia bijuga</i> (Colebr.) Kuntze	5
	2	<i>Ficus</i> sp.	5
		Subtotal	10
Total			79

also caused by air humidity or environmental conditions. This factor supports the germination process of *A. nidus* spores. Humidity is closely related to temperature, where air humidity will become low with decreasing temperature. Imaniar et al. (2017) stated that ferns that grow in the tropics

generally require a temperature range of 21–27 °C for growth. The appropriate temperature causes the number and distribution of many fern species in tropical forest areas.

A. nidus is highly dependent on host trees with their characteristics. Host tree characteristics can influence the number of *A. nidus* individuals.

The number of individuals found on a tree indicates that physical factors such as trunk texture and rough bark are suitable host sites (Sukarsa et al., 2011; Sirami, 2015). The large number of individuals found on a tree indicates that the physical factors of the tree, such as trunk texture and rough bark, are suitable places for them to serve as hosts (Sukarsa et al., 2011; Sirami, 2015).

According to Sukarsa et al. (2011), in general, epiphytic ferns like rough, grooved trunks and gaps to make it easier to stick their fibrous roots, making the ferns (*A. nidus*) grow more vigorously compared to host trees that have rather smooth skin. This plant also likes tall tree trunks (Hartini, 2006). According to Sukarsa et al. (2011), 86% of epiphytic spikes grow on host trees with rigid bark because they are more able and stable to withstand the weight of epiphytic spikes. Nawawi et al. (2014) added that, in general, the host tree preferred by epiphytic ferns is a type of host that has a thick, grooved, or stringy skin texture and has a hard skin and is thought to be a factor affecting the association between the host tree (phorophyte) and its epiphytes. Epiphytic ferns in the Bukit Pengelengan, Tapak, and Lesung forest areas generally grow on host trees with rough and old bark (Darma et al., 2018).

The dominance of *A. nidus* with a fairly good distribution on hosts with various tree characters can provide an overview of the diversity of ecosystems in the region, especially in Imbowiari forest as a nest bioindicator for *P. m. jobiensis* birds in their habitat. The diversity of *A. nidus* can be shown in Figure 4.

The results of the analysis show that the diversity of *A. nidus* for each spot is in the low-medium category, where the first and fifth spots are in the low category while the second, third, and fourth spots are in the medium category. Overall, the diversity of *A. nidus* in the Imbowiari forest area in 2024 is in the medium category (1.79), which can be shown in Figure 5.

Host types and number of *A. nidus* still found in 2024

Figure 6 shows that the five hosts of *A. nidus* found since 2018 were still found in 2024. The five hosts include *C. hirsutum*, *P. amboinicum*, *I. bijuga*, *Ficus* sp., and *M.*

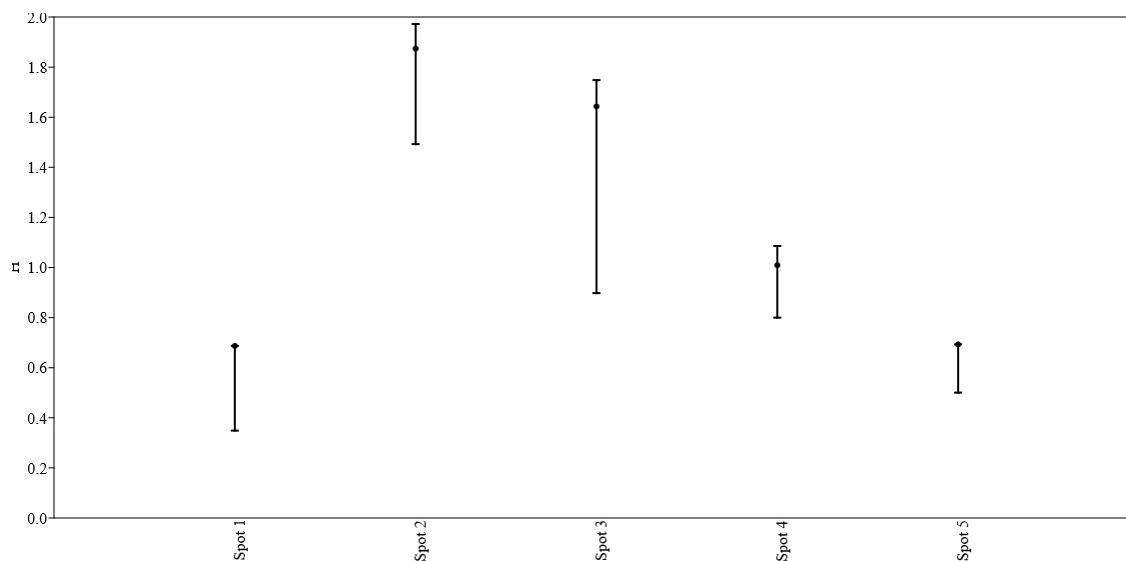


Figure 4 Diversity graph of *Asplenium nidus* for each spot.

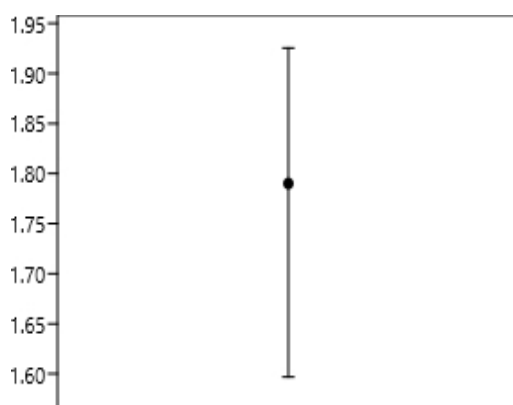


Figure 5 Diversity of *Asplenium nidus* in Barawai Imbowiari forest in 2024.

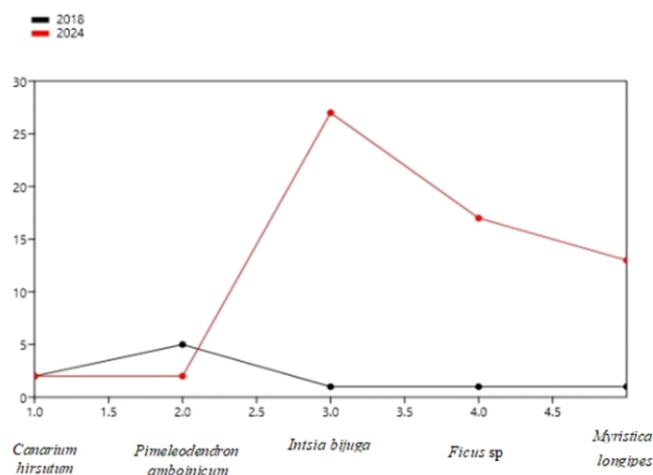


Figure 6 Host types still found in 2024 and number of *Asplenium nidus* in Barawai Imbowiari forest in 2024.

longipes. This data can also show that there has been an increase in the number of *A. nidus* individuals within a period of 6 years, from 2018 to 2024. The natural increase in the number of *A. nidus* individuals in the Imbowiari forest area is thought to be influenced by the healthy condition of the forest ecosystem. This is evidenced by the data collection activities: the vegetation conditions are getting denser, the tree canopy is tall and lush.

Population structure of *A. nidus* in Barawai Imbowiari Forest (2018–2024). Vertical and horizontal distribution *A. nidus* as an epiphyte generally grows in tree crowns, which are also often used as nest sites by Lesser Yellow birds-of-paradise. The vertical structure of vegetation may reflect habitat preferences for this species (Proctor, 2012). Taller trees may be more frequently inhabited by *A. nidus*, which also provides an ideal location for the little yellow bird of paradise to build nests.

Population density level In areas with optimal environ-

mental conditions, *A. nidus* can thrive in large numbers, while in areas degraded by human activities or climate change, its population will decline (Chen et al., 2023). Fluctuations in population density from 2018 to 2024 can provide insight into changes in forest environmental conditions (Ainuddin & Najwa, 2009). *A. nidus* populations can vary in density depending on environmental conditions such as availability of sunlight, moisture, and suitable substrate. In Imbowiari forest, *A. nidus* density may be higher in areas undisturbed by human activities.

Population composition of *A. nidus* in Barawai Imbowiari Forest (2018–2024). Genetic variability and concurrent species *A. nidus* populations in the Imbowiari forest may exhibit genetic variation influenced by micro-ecosystem conditions. This variation may affect the ability of *A. nidus* to survive and thrive in different tree strata, particularly those affected by environmental changes.

A. nidus populations may have variations in size, leaf

structure, or even leaf color that can be influenced by environmental factors. The presence of other epiphytic species such as mosses or orchids in the same region can also affect the overall epiphyte community composition.

Growth dynamics. Population change (2018–2024) Observations from 2018 to 2024 may show annual growth patterns influenced by changes in climate, *rainfall*, or levels of habitat degradation. In this period, increases or decreases in *A. nidus* populations may provide a direct indication of the health of the forest ecosystem.

A. nidus reproduces sexually by producing spores that are dispersed primarily by wind. Successful spore germination and gametophyte establishment depend strongly on environmental conditions, particularly moisture, humidity, temperature, and suitable substrates (Chen et al., 2023). The availability of adequate water and substrate in tropical forests such as the Imbowiari Forest is essential for this reproductive cycle (Simbolo, 2007).

The role of *A. nidus* as a bioindicator of *P. m. jobiensis* nests. Habitat conditions that affect nesting *Habitat condition indicator* The presence of *A. nidus* can directly reflect the quality of ideal habitat for lesser yellow birds-of-paradise (Karasawa & Hijii, 2006). *A. nidus* provides a natural substrate for these birds to nest, and its widespread distribution reflects a healthy forest environment relatively free from external disturbances.

Nest availability *A. nidus* provides an ideal physical substrate for the lesser yellow bird of paradise to build a nest. The wide and strong leaf structure allows birds to build stable and secure nests. The presence of this epiphyte on trees can be an important indicator of the presence of lesser yellow bird of paradise nests.

Quality of nesting substrate *A. nidus* is known to have a wide and strong leaf structure, which provides stability to Cenderawasih bird nests. The presence of this epiphyte can be used as a sign that the habitat has good environmental conditions to support nesting activities (Trimanto et al., 2021).

Linkage to environmental factors *A. nidus* populations are often an indicator of moisture, light, and the health of host trees (Taylor & Burns, 2015). If populations decline or disappear, this may indicate ecosystem disturbances that could impact *Paradisaea minor jobiensis* nesting behavior.



Figure 7 *Paradisaea minor jobiensis* and *Asplenium nidus* nests.

Ecosystem health indicators *Effects of pollution and habitat degradation* Changes in *A. nidus* populations during 2018–2024, such as population declines, could be a sign of environmental pressures, such as air pollution, deforestation, or other human activities.

Effects of climate change If *A. nidus* populations decline over the 2018–2024 period, this could be an indicator of environmental pressures, such as air pollution, deforestation, or climate change, which will also impact the birds-of-paradise. As a species that depends on stable forest conditions, birds-of-paradise tend to select nests in areas where epiphytes such as *A. nidus* thrive.

If changes in temperature and rainfall occur, this may affect the health of *A. nidus* (Chen et al., 2023). A significant decrease in humidity or increase in temperature might adversely affect the presence of this epiphyte (Karasawa & Hijii, 2006) and thus affect the lesser yellow bird of paradise that relies on this plant for nest building.

Population dynamics and relationship with *P. m. jobiensis* nests *Population fluctuations* Over the period 2018 to 2024, changes in *A. nidus* populations may be associated with changes in nesting behavior of birds-of-paradise. If there is a decline in *A. nidus* populations in a particular area, this could affect the number of Cenderawasih nests in that area.

Interaction of other species *A. nidus* is not the only epiphyte in Imbowiari forest, and interactions with other epiphyte species may affect the overall composition of the epiphyte community. Competition for growing space on tree trunks and branches will play an important role in determining the distribution of *A. nidus*. The presence of mosses, orchids or other epiphytes can provide a more complete picture of ecosystem health (Komada et al., 2022). The presence of other epiphytic species that compete with or affect the growth of *A. nidus*. Sujalu (2017) may also affect the population dynamics and distribution of lesser yellow bird of paradise nests.

Morphometric characteristics of host trees and *A. nidus* in Barawai Village Forest Morphometric characters of host trees of *A. nidus* in Imbowiari forest of Barawai Village were analyzed based on little yellow bird of paradise spots. The presence of *A. nidus* and its character in Cenderawasih bird spots is important because both have a relationship with the animal's nest. *A. nidus* as a nest bioindicator for birds-of-paradise. The research data shows that there are 5 spots identifying the presence of *A. nidus* and its host which will then be described thoroughly.

Morphometric characteristics of host tree and *A. nidus* in the first spot Table 3 shows the morphological character measurements of *A. nidus* and its host trees as substrates. This data shows that there are 2 types of trees that host *A. nidus*, including *I. bijuga* (Colebr.) Kuntze and *M. argentea* Warb. Of the two species, *I. bijuga* (Colebr.) Kuntze is the dominant species in spot 1 or there are 2 individuals while *M. argentea* Warb. There is 1 individual. Data on morphological character measurements of *A. nidus* and its hosts show that the first *I. bijuga* has 3 individuals and the second is 2 individuals.

While for the host *M. argentea* Warb. has 4 individuals of *A. nidus*.

Measurement data of host morphological characters showed that the average DPI was 47 cm and TPI 34.66 m. While the morphological characters of *A. nidus* show that the average D (34.33 cm), T (86.22 cm), PD (146 cm), LD (24.22 cm), TPT (13.22 m).

Morphometric characteristics of host tree and *A. nidus* in the second spot Table 4 shows that in the second spot there were 12 host individuals with 7 different species including

Pometia pinnata, *C. hirsutum* Willd., *Alpinia malaccensis*, *Gnetum gnemon* Linn., *Tristania microsperma* Ridl, *M. argentea* Warb., *P. amboinicum* Hassk. Of the seven host species, the ones with the most or preferred number of *A. nidus* individuals were *A. malaccensis* (5 individuals) and *P. pinnata* (3 individuals). From the measurement of morphological characters of *A. nidus* and its host, it shows that the average DPI (30.33 cm), TPI (24.08 m), D (41.36 cm), T (91.54 cm), PD (155.77 cm), LD (27.13 cm), TPT (11.68 m). The relationship between *P. pinnata* and *A. malaccensis* with *A. nidus* can be explained in the context of

Table 3 Morphological character measurements of *Asplenium nidus* and the host tree (substrate) in the first spot

Host tree (PI)	DPI (cm)	TPI (m)	Morphological characters					Number of individuals	Total
			D (cm)	T (cm)	PD (cm)	LD (cm)	TPT (m)		
<i>Intsia bijuga</i> (Colebr.) Kuntze	55	39	22	53	155	16	8	1	3
			51	177	106	28	17	1	
			30	170	175	20	25	1	
<i>Intsia bijuga</i> (Colebr.) Kuntze	60	30	26	50	152	28	16	1	2
			50	130	169	30	20	1	
<i>Myristica argentea</i> Warb.	26	35	15	30	139	15	6	1	4
			25	45	155	23	8	1	
			27	46	158	27	9	1	
			63	75	110	31	10	1	
Max.	60	39	63	177	175	31	25	1	4
Min.	26	30	15	30	106	15	6	1	2
Average	47	34.66	34.33	86.22	146.55	24.22	13.22	1	3
SD	14.98	3.68	15.27	53.95	22.74	5.65	6.16	0	0.81

Notes: PI = host tree; D = diameter; T = height; PD = leaf length; LD = leaf width; TPT = plant height from ground level

Table 4 Morphological character measurements of *Asplenium nidus* and the host tree (substrate) in the second spot

Host tree (PI)	DPI (cm)	TPI (m)	Morphological characters					Number of individuals	Total
			D (cm)	T (cm)	PD (cm)	LD (cm)	TPT (m)		
<i>Pometia pinnata</i>	50	10	20	50	150	15	8	1	3
			50	175	100	25	15	1	
			30	170	175	19	18	1	
<i>Canarium hirsutum</i> Willd.	15	20	20	49	148	15	1	1	1
<i>Alpinia malaccensis</i>	60	30	25	50	153	20	8	1	5
			30	100	150	25	10	1	
			20	48	151	24	15	1	
			26	50	152	28	16	1	
<i>Gnetum gnemon</i> Linn.	13	19	50	130	169	30	20	1	2
			15	30	139	15	6	1	
			25	45	155	23	8	1	
<i>Tristania microsperma</i> Ridl	15	5	22	40	158	27	3	1	1
<i>Intsia bijuga</i> (Colebr.) Kuntze	50	45	63	75	110	31	10	1	2
			90	132	140	30	13	1	
<i>Myristica argentea</i> Warb.	25	15	26	65	100	28	10	1	1
<i>Intsia bijuga</i> (Colebr.) Kuntze	35	50	90	180	280	40	20	1	2
			105	250	306	54	25	1	
<i>Pimeleodendron amboinicum</i> Hassk.	20	15	34	67	80	36	10	1	1
<i>Myristica argentea</i> Warb.	25	30	47	90	109	24	10	1	1
<i>Intsia bijuga</i> (Colebr.) Kuntze	46	35	38	80	190	32	10	1	2
			59	106	267	41	13	1	
<i>Gnetum gnemon</i> Linn.	10	15	25	32	45	15	8	1	1
Max.	60	50	105	250	306	54	25	1	5
Min.	10	5	15	30	45	15	1	1	1
Average	30.33	24.08	41.36	91.54	155.77	27.13	11.68	1	1.83
SD	16.50	13.38	25.02	57.28	60.79	9.45	5.61	0	1.14

Notes: PI = host tree; D = diameter; T = height; PD = leaf length; LD = leaf width; TPT = plant height from ground level

tropical forest ecology, especially in relation to the role of these trees as hosts for *A. nidus*, as well as the adaptation of this epiphyte to the various microhabitats provided by the host trees.

Morphometric characteristics of host tree and *A. nidus* in the third spot Table 5 shows that there are 6 types of hosts for *A. nidus*, namely *P. amboinicum* Hassk., *A. malaccensis*, *T. microsperma* Ridl., *C. hirsutum* Willd., *P. pinnata* and *M. argentea* Warb. Of these host species, *P. pinnata* and *M.*

argentea Warb. were the preferred species for *A. nidus* to attach to. The research data showed that on these two there were 3 *A. nidus* individuals on each host species.

Table 6 shows that there are 5 individuals hosts or consist of 3 species, namely *I. bijuga* (Colebr.) Kuntze, *Ficus* sp. and *M. argentea* Warb. Overall, the preferred hosts for *A. nidus* to attach were *Ficus* sp. (12 individuals), *I. bijuga* (11 individuals) and *M. argentea* (4 individuals). This suggests that *Ficus* sp. and *I. bijuga* are suitable species for *A. nidus*.

I. bijuga, known as the merbau tree, is one of the largest

Table 5 Morphological character measurements of *Asplenium nidus* and the host tree (substrate) in the third spot

Host tree (PI)	DPI (cm)	TPI (m)	Morphological characters					Number of individuals	Total
			D (cm)	T (cm)	PD (cm)	LD (cm)	TPT (m)		
<i>Pimeleodendron amboinicum</i> Hassk.	20	15	34	67	80	36	10	1	1
<i>Alpinia malaccensis</i>	45	25	23	50	149	20	15	1	1
<i>Tristania microsperma</i> Ridl.	15	5	22	40	158	27	3	1	1
<i>Canarium hirsutum</i> Willd.	20	30	25	50	149	25	25	1	1
<i>Pometia pinnata</i>	58	23	38	80	190	32	15	1	3
			59	106	267	41	17	1	
			63	75	110	31	20	1	
<i>Myristica argentea</i> Warb.	25	15	26	65	100	28	5	1	3
			47	90	109	24	8	1	
			80	176	200	40	10	1	
Min.	15	5	22	40	80	20	3	1	1
Max.	58	30	80	176	267	41	25	1	3
Average	30.50	18.83	41.70	79.90	151.20	30.40	12.80	1	1.67
SD	15.58	8.17	18.93	37.16	53.40	6.59	6.50	0	0.94

Notes: PI = host tree; D = diameter; T = height; PD = leaf length; LD = leaf width; TPT = plant height from ground level

Table 6 Morphological character measurements of *Asplenium nidus* and the host tree (substrate) in the fourth spot

Host tree (PI)	DPI (cm)	TPI (m)	Morphological characters					Number of individuals	Total
			D (cm)	T (cm)	PD (cm)	LD (cm)	TPT (m)		
<i>Intsia bijuga</i> (Colebr.) Kuntze*	60	40	15	50	150	15	8	1	8
			50	175	100	25	15	1	
			30	170	175	19	18	1	
			45	180	200	40	21	1	
			55	175	100	39	24	1	
			65	240	254	55	30	1	
			39	50	40	30	34	1	
			70	175	100	59	40	1	
<i>Ficus</i> sp.	80	25	38	80	190	32	10	1	5
			59	106	267	41	13	1	
			63	75	110	31	20	1	
			80	132	140	30	23	1	
			90	200	210	60	24	1	
<i>Intsia bijuga</i> (Colebr.) Kuntze	58	23	38	80	190	32	15	1	3
			59	106	267	41	17	1	
			63	75	110	31	20	1	
<i>Ficus</i> sp.	95	20	15	50	150	15	8	1	7
			50	175	100	25	15	1	
			30	170	175	19	18	1	
<i>Myristica argentea</i> Warb.	25	15	26	65	100	28	5	1	4
			47	90	109	24	8	1	
			80	176	200	40	10	1	
			90	180	280	50	12	1	
Min.	25	15	15	50	40	15	5	1	3
Max.	95	40	90	240	280	60	40	1	8
Average	63.60	24.60	52.04	129	161.60	33.98	17.73	1	5.40
SD	23.62	8.40	21.19	56.20	64.14	12.72	8.55	0	1.85

Notes: PI = host tree; D = diameter; T = height; PD = leaf length; LD = leaf width; TPT = plant height from ground level

tropical trees found in coastal and lowland forests. Its large, sturdy trunk and branches provide an ideal surface for epiphytes such as *A. nidus* to attach to. The sturdiness of *I. bijuga* supports physical stability for epiphytes, especially in the face of wind and heavy rain in tropical forests. *A. nidus* often derives nutrients from organic matter trapped in the branches of the host tree. *I. bijuga*, with its extensive canopy and branches, allows the collection of organic matter such as fallen leaves, litter, and dust, which provide nutrients for *A. nidus*. This supports optimal growth for the epiphyte on this host tree.

Morphometric characters of host tree and *A. nidus* in the fifth spot Table 7 shows that there are 2 types of *A. nidus* hosts, namely *I. bijuga* (Colebr.) Kuntze and *Ficus* sp. The research data shows that there are 5 individuals of *A. nidus* on each host. This illustrates that in this spot these two host species have a fairly good influence on the presence of *A. nidus*.

I. bijuga provides an ideal habitat for *A. nidus* due to its wide canopy and limited light under the tree. Epiphytic species like *A. nidus* are often found attached to the branches and trunks of large trees, including *I. bijuga*. Fallen leaves from *I. bijuga* and other organic debris can provide nutrients to *A. nidus* attached to tree branches, helping them get the nutrients they need.

Ficus sp. or fig trees are a genus of trees known for their aerial root systems and adaptability in various types of habitats. *Asplenium nidus* is often found as an epiphyte on *Ficus* sp. The aerial roots of *Ficus* sp. provide physical support for *Asplenium nidus* to attach and grow (Darma & Peneng, 2007). *Ficus* sp. provides ideal environmental conditions for *Asplenium nidus* due to higher humidity under the tree canopy and a more protected environment.

Larger host tree diameters usually provide a larger surface for epiphytes such as *A. nidus* to occupy. Larger host trees also tend to have stronger and more numerous branches, thus providing more space for *A. nidus* to grow and thrive (Janna et al., 2020). This allows these epiphytes to gain more access to sunlight and moisture necessary for optimal photosynthesis and growth.

Trees with larger diameters often create a more stable

microclimate around the area where *A. nidus* attach. Larger canopies tend to keep the surrounding air moist, which is very important for epiphytes as they depend on air moisture for water. A more humid environment around the host tree will support growth better compared to smaller trees, where conditions are drier and temperature fluctuations are more extreme (Janna et al., 2020).

Although *A. nidus* does not obtain nutrients directly from its host tree, the presence of a large tree can provide more organic material, such as fallen and decomposed leaves, which can accumulate in the area where the epiphyte grows. This organic material provides an additional source of nutrients for *A. nidus*, supporting its long-term growth. Larger tree diameters provide better structural stability to support large epiphytes like *A. nidus*. Larger trees tend to be more resistant to strong winds and extreme weather conditions, allowing *A. nidus* to grow undisturbed by tree or branch movement. Trees with smaller diameters may host fewer epiphytes due to limited space and resources. In contrast, trees with larger diameters may host more epiphytic species, including *A. nidus*. Competition for space and resources on larger trees can be more intense, but the larger surface area usually supports more species without reducing the growth of one particular epiphyte. Host tree diameter plays an important role in influencing the growth characteristics of *A. nidus* through various mechanisms, including the provision of greater space, a more humid microclimate, access to additional nutrients, and better structural stability. Trees with larger diameters generally support better epiphyte growth compared to smaller trees.

The relationship between *A. nidus* and its host tree is often described as commensalism. In this relationship, *A. nidus* benefits by attaching to the tree without directly harming or benefiting the host. As an epiphyte, *A. nidus* does not take nutrients from the host tree, but rather utilizes the tree only as a stable growing site, mainly to gain access to light, water from air humidity, and nutrients accumulated around the root system and decomposed foliage. Not all host tree species are suitable for *A. nidus*. Some tree species may provide a more optimal environment for the growth of this epiphyte, such as the rough texture of the tree bark that provides strong attachment points, as well as the ability of

Table 7 Morphological character measurements of *Asplenium nidus* and the host tree (substrate) in the fifth spot

Host tree (PI)	DPI (cm)	TPI (m)	Morphological characters					Numbers of individuals	Total
			D (cm)	T (cm)	PD (cm)	LD (cm)	TPT (m)		
<i>Intsia bijuga</i> (Colebr.) Kuntze	57	25	15	50	150	15	8	1	5
			50	175	100	25	15	1	
			30	170	175	19	18	1	
			45	180	200	40	21	1	
			55	175	100	39	24	1	
<i>Ficus</i> sp.	90	28	38	80	190	32	10	1	5
			59	106	267	41	13	1	
			63	75	110	31	20	1	
			80	132	140	30	23	1	
			90	200	210	60	24	1	
Min.	57	25	15	50	100	15	8	1	5
Max.	90	28	90	200	267	60	24	1	5
Average	73.50	26.50	52.50	134.30	164.20	33.20	17.60	1	5
SD	16.50	1.50	21.23	50.37	51.67	12.15	5.53	0	0

Notes: PI = host tree; D = diameter; T = height; PD = leaf length; LD = leaf width; TPT = plant height from ground level

the tree to retain moisture in its surroundings. For example, older trees with larger diameters and denser canopies usually support better *A. nidus* growth. Some tree species that are more resistant to climate change or drought can also be more stable hosts than more sensitive trees. Different host trees can create a unique microclimate around the *A. nidus* site. For example, trees with dense canopies may retain higher humidity underneath, which is especially important for epiphytes that depend on water obtained from the air. In addition, some tree species may reduce direct exposure to wind and temperature fluctuations, which favors more stable epiphyte growth.

In addition to direct relationships with host trees, *A. nidus* also has indirect relationships with animals, such as birds that utilize these plants as shelter or nests. Species such as *P. m. jobiensis* (little yellow bird of paradise) may have a preference for nests close to epiphytes such as *A. nidus*, which may be more common in certain tree species. Therefore, host tree specificity may also influence the presence of certain fauna that interact with *A. nidus*.

Morphometrics of *A. nidus* in each observation spot Table 8 shows the morphometric comparison of *A. nidus* in each observation spot. Morphometric characters of *A. nidus* include diameter, height, leaf length and leaf width. The data showed that the diameter (D) value varied from 27 cm (Spot 1) to 52.5 cm (Spot 5). The *p*-value (0.6547) indicated that there was no significant difference in diameter among the five spots based on Dunn's Post Hoc test (*p*-value > 0.05), indicated by two asterisks (**). Meanwhile, epiphyte height (T) ranged from 53 cm (Spot 1) to 151.5 cm (Spot 5). The *p*-value (0.07364) indicated that there was no significant difference in height among the five spots based on Dunn's Post Hoc test, although it was close to significance (*p*-value < 0.10). This could be an indication of variation that may be more meaningful in large populations or with other statistical tests. The Leaf Length (PD) character varied from 149 cm (Spot 3) to 162.5 cm (Spot 5). The *p*-value (0.1797) also indicated that there was no significant difference in leaf length between spots, with two asterisks indicating *p*-value > 0.05. Leaf Width (LD) characters ranged from 27.5 cm (Spot 1) to 31.5 cm (Spot 5). The *p*-value (0.3711) indicates that leaf width was also not significantly different among the spots.

The statistical significance of a *p*-value is an important tool in the interpretation of morphometric data. The *p*-value indicates the probability that the observed results occurred by chance if the null hypothesis is true. In the context of morpho-metric data, *p*-value helps in understanding whether the observed differences or relationships between morphometric variables are statistically significant or

simply the result of random variability. A *p*-value of less than 0.05 is considered statistically significant. This means there is less than a 5% chance that the observed difference or relationship is the result of chance. In other words, the results are considered strong enough to support the alternative hypothesis and suggest that there is a real effect or relationship. If the *p*-value is greater than 0.05, the result is considered not statistically significant. This means there is a greater than 5% chance that the observed result may have occurred by chance alone.

The box plot provides a visual comparison of the morphological traits of *A. nidus* from different locations. It uses standard deviations and 95% confidence intervals to give us insight into the variability and reliability of the data. This type of analysis is essential for understanding how environmental factors may affect the characteristics of this fern species in various habitats. Spot 1 has the largest range of *A. nidus* distribution, and shows high data variability in the area, while spots 2 to 5 have a more uniform distribution and are less scattered than spot 1. Overall all spots had relatively symmetrical data distributions, with no significant outliers.

Spot 1 has a larger range of *A. nidus* distribution than the other spots, which also shows high data variability. This could be interpreted as the presence of more variable environmental conditions in Spot 1, such as moisture levels, light intensity, or host tree types, which can support a variety of microhabitats for *A. nidus* to thrive. These conditions often result in broader distribution patterns, with greater fluctuations in population size and density. In contrast, Spots 2 to 5 have a more uniform distribution and are less dispersed, suggesting that these areas may have more homogeneous environmental conditions. Factors such as stable moisture and light availability or less variation in host tree species may lead to a more controlled and uniform distribution of *A. nidus*. The narrower distribution in these areas may reflect more specific microhabitat limitations or a lack of ecological variation favoring *A. nidus* growth. The higher variability in Spot 1 may also reflect external disturbance factors or other ecological dynamics affecting the population, such as competition with other species or adaptation to more diverse environmental conditions.

Figure 8 shows that the closer the data points are to the line, the more similar the data distribution is to a normal distribution. The black dots seen on the graph represent the actual distribution of the sample data. If these points follow the line closely, the data likely follows a normal distribution. The correlation coefficient value for each spot indicates how well the data from each spot follows a normal distribution. A correlation coefficient value close to 1 indicates a very high fit to the normal distribution. The value shown for spot 3 has the best fit to the normal distribution (0.9947), while spot 5

Table 8 Morphometric comparison of *Asplenium nidus* in each spot

Morphometric character (cm)	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	<i>p</i> -value (Dunn's Post Hoc)*
Diameter (D)	27 ± 15.27	30 ± 25.02	36 ± 18.93	50 ± 21.19	52.5 ± 21.23	0.6547**
High (T)	53 ± 53.95	70 ± 57.28	71 ± 37.16	132 ± 56.20	151 ± 50.40	0.0736**
Long leaf (PD)	155 ± 22.74	150.5 ± 60.79	149 ± 53.40	150 ± 64.14	162.5 ± 51.67	0.1797**
Width leaf (LD)	27 ± 5.65	26 ± 9.45	29.5 ± 6.59	31 ± 12.72	31.5 ± 12.15	0.3711**

Notes: (*) Raw *p*-values, sequential Bonferroni significance; (**) no significant difference *p*-value < 0.05.

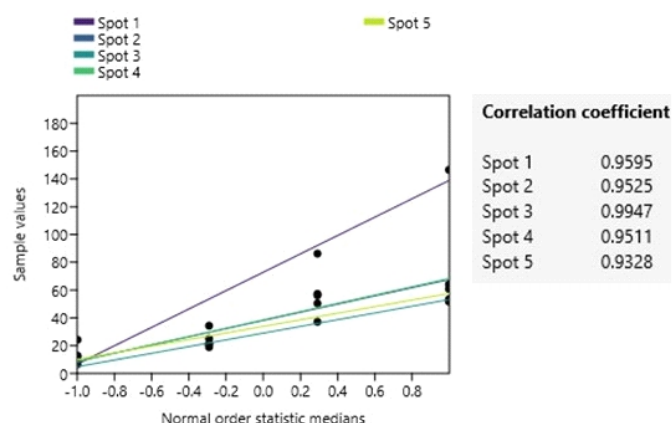


Figure 8 Normal probability plot (graph), showing correlation coefficient values between morphometric characters of each *Asplenium nidus* specimen in each observation spot.

has the lowest fit (0.9328). Spot 3 has a coefficient value of correlation (0.9947), which indicates that the data from this spot almost completely follow a normal distribution. In other words, the variation in the data distribution at spot 3 is minimal, or the data distribution is stable and symmetrical. Spot 5 has the lowest correlation coefficient value (0.9328), which indicates that the data from it deviates more from the normal distribution. This could indicate that the distribution in spot 5 is more variable or there is greater instability than spot 3.

Limitations and future research directions This study has several limitations that need to be considered in interpreting the results and compiling scientific recommendations. The temporal design, which only includes two observation periods (2018 and 2024), has not been able to comprehensively describe the population dynamics of *A. nidus*. The small number of samples and the fact that the transects are not completely random make the statistical analysis and the picture of the whole forest ecosystem less strong. Therefore, the results obtained should be viewed as preliminary findings that require further validation with a wider temporal and spatial scope.

In addition, the lack of measurements of environmental variables such as temperature, humidity, light intensity, and soil pH prevents the results of this study from explaining the factors causing population change. Such environmental data are critical to understanding the interactions between epiphytes and microhabitats that affect the survival of *A. nidus*. The integration of microclimate sensors, soil analysis, and canopy structure measurements will be important steps to strengthen ecological analysis in advanced research. This multidimensional approach can also help identify the environmental variables that have the most influence on the growth and distribution of epiphytes.

Another methodological factor that needs to be improved is the absence of reliability tests between observers and quality control of field data. Differences in recording techniques or observer experience may result in variations in results that do not reflect real ecological changes. Therefore,

subsequent research needs to implement standardized observation protocols, involving training of data collection teams and documenting photos and voucher specimens. These measures will improve the consistency of results between observation periods and reduce the potential for observer bias.

In the future, research on *A. nidus* as a bioindicator of *P. m. jobiensis* nests needs to be carried out more comprehensively through a correlative and longitudinal approach. Simultaneous studies of the distribution of epiphytes and bird's nest density will provide a strong empirical basis for scientifically assessing the function of bioindicators. It is also recommended to use advanced statistical methods such as GLM or multivariate analysis to capture non-linear relationships between ecological variables. By improving the design, measurement, and analysis aspects, further research is expected to produce ecological monitoring models that are more accurate, applicable, and beneficial for the conservation of Papua's tropical forests.

Discussion

Structure and composition of *A. nidus* as a nest bio-indicator of *P. m. jobiensis* in 2018 The calculation results show that the diversity index of *A. nidus* in Imbowiari Barawai forest in 2018 is categorized as high (3.77). The diversity index value describes the state of *A. nidus* in the Imbowiari Barawai forest area. The high level of diversity is thought to be influenced by the status of the Imbowiari Barawai forest area as a protected area or as a habitat for birds-of-paradise so that there are no human activities such as plantations, logging, or other infrastructure development. This is in line with research by Raunsay (2014), showing that the diversity of tree vegetation in the Imbowiari forest area is categorized as high. High species diversity illustrates high productivity, balanced ecosystem conditions, and reciprocal relationships between flora and fauna in it. This is supported by research by Raunsay et al. (2022), which states that the dependence between *Asplenium* sp. and host trees that interact with each other is so that the ecosystem remains balanced. The dependence or presence of *Asplenium* sp. with its host is influenced by the texture of the trunk of a tree species. Based on observations at the research site, it was found that epiphytes are more likely to stick to support plants (hosts) that have thick, grooved, or filamentous skin texture and have durable skin. In accordance with the opinion of Nawawi et al. (2014), the skin of the host plant that has grooves and gaps will cause epiphytes to grow vigorously, while the rather slippery skin of the host plant will make it difficult for epiphytes to attach and grow on the host.

A. nidus with an epiphytic habit is more likely to be on a hard-skinned host plant because it is better able to maintain or attach the epiphytic root bonds attached to the tree bark so that it can maintain the existence of epiphytes on the host plant. In accordance with the opinion of Nawawi et al. (2014), which states that the growth of epiphytic ferns in the forest is very dependent on the support plant (host) for a place of life, not as a food source. Therefore, if the support plant of *A. nidus* has a soft bark texture, the safety of the epiphyte will be threatened, because the support plant (host) is unable to support or maintain the epiphytic roots.

The dependence between *A. nidus* and its host tree is influenced by air humidity because this factor supports the germination process of its spores. Humidity is closely related to temperature; air humidity will be low with decreasing temperature. Imaniar et al. (2017) state that ferns that grow in the tropics generally require a temperature range of 21–27 °C for growth. The appropriate temperature conditions cause the spread of many types of ferns in tropical forest areas. *A. nidus* is influenced by air humidity factors and host plant stratification. Host plant stratification is a factor that affects the number of epiphytic ferns on a tree.

This study did not include baseline or comparative location data from natural forest areas, making it difficult to determine whether the observed changes indicate habitat restoration or degradation. The absence of a reference point makes the interpretation of the results limited to a purely local and temporal context. Comparative data from conservation areas or historical records are needed to identify the direction of change in the *A. nidus* population. Therefore, it is important for advanced research to include reference plots in areas with minimal disturbance as ecological references. With a baseline, population dynamics can be evaluated more objectively and in a broader ecological context. This approach will also strengthen the conservation value of long-term monitoring results.

Structure and composition of *A. nidus* as a bioindicator of *P. m. jobiensis* in 2024 The research data showed the presence of more than one individual of *A. nidus* in each host. *I. bijuga* (Colebr.) Kuntze is a host tree that shows the dominance of the presence of the number of individuals and is almost distributed in each observation spot, wherein in the first spot there are 5 individuals of *A. nidus*, in the second spot 4, in the fourth 11, and in the fifth 5 individuals. This shows that *A. nidus* has a high level of preference for *I. bijuga* as a host. The host species that have one individual of *A. nidus* include *C. hirsutum* Willd., *T. microsperma* Ridl., *M. argentea* Warb., *P. amboinicum* Hassk., *G. gnemon* Linn., and *A. malaccensis*.

The composition and structure of *A. nidus* have varying values or numbers of individuals in each host due to the different characteristics of each tree. Variations in composition and structure in a plant community are strongly influenced by plant phenology, dispersal, and natality. In addition, different fertility and fecundity in each plant species also affect the success of forming new individuals (Arrijani, 2008; Beljai & Worabai, 2018).

The results of this study show another unique thing: *A. nidus* has a vertical distribution on each host even with more than 1 individual. This is in line with research by Mansur et al. (2004), which states that the presence of the number of *A. nidus* individuals is on the trunk or branches of the host tree, where the lowest is 1 individual and the highest is 11 individuals.

Raunsay et al. (2022) say that the number of species and the number of individuals of each species found on a tree indicates that the tree is a suitable place to serve as a host. This is related to the fact that spores of epiphytic plants that fall in a suitable place will be able to germinate and grow to form new epiphytic individuals (Darma et al., 2018). Host

trees favored by epiphytic ferns, especially *A. nidus*, generally have thick, grooved, or filamentous bark texture and have hard bark and are thought to be a factor that affects the association between the host plant (phorophyte) and its epiphytes (Fitrah et al., 2014; Darma et al., 2018).

Moderate species diversity illustrates moderate productivity and balanced ecosystem conditions, where there is a reciprocal relationship between flora and fauna in it. This phenomenon can be seen from the interdependence between *Asplenium* sp. and host trees that interact with each other so that the ecosystem remains balanced. The dependence or presence of *Asplenium* sp. with its host is influenced by the texture of the trunk of a tree species. The number of species and the number of individuals of each species found on a tree indicates that the tree is a suitable place to serve as a host. Epiphytic ferns generally grow on host trees (phorophytes) with rough and old bark.

Host trees for epiphytic ferns are generally old trees with rough bark. This is related to the fact that spores of epiphytic plants that fall in a suitable place will be able to germinate and grow to form new epiphytic individuals (Darma et al., 2018). Nawawi et al. (2014) and Darma et al. (2018), adding, in general, the host tree favored by epiphytic ferns has a thick, grooved, or filamentous skin texture and has a hard skin and is thought to be a factor that affects the association between the host plant (phorophyte) and its epiphytes. The dependence between *A. nidus* and the host tree is influenced by air humidity so that the spores of *A. nidus*. This factor supports the germination process of *A. nidus* spores. Humidity is closely related to temperature, air humidity will become low with decreasing temperature.

Imaniar et al. (2017) state that ferns that grow in the tropics generally require a temperature range of 21–27 °C for growth. So it can be seen that the temperature is in accordance with the growth of ferns (Pteridophyta). The appropriate temperature conditions cause the spread of many types of ferns in tropical forest areas. Imaniar et al. (2017) state that *A. nidus* is influenced by the air humidity factor between *A. nidus* and stratification of host plants; namely, with sufficient air humidity, it helps the process of germination of spores of *A. nidus*, and stratification of host plants is a factor that affects the number of epiphytic ferns on a tree.

Host types and number of *A. nidus* found in 2024 The healthy condition of the Imbowiari forest ecosystem will certainly have a good impact on the presence and abundance of *A. nidus* in increasingly abundant numbers. The abundance of *A. nidus* indicates that the condition or texture of the trunk of each host is the most suitable habitat for attachment. In addition, the condition of trees in a very dense forest ecosystem causes high air humidity, which is very good for the reproduction or breeding of *A. nidus*. Imaniar et al. (2017) stated that air humidity and host plant stratification can affect the number of *A. nidus* in an ecosystem. Host plant stratification is a factor that affects the number of epiphytic ferns on a tree. Raunsay et al. (2022) said that the stratum layer or strata are certainly characterized by the height of the host tree, and this is one of the factors that can affect the number of *A. nidus*. The establishment and development of

vascular epiphytes are strongly influenced by host-tree characteristics that provide both physical support and suitable microhabitats, including bark texture, canopy architecture, humidity, light availability, and organic matter accumulation, all of which determine epiphyte distribution, growth, and ecological functions in tropical forest ecosystems (Zotz & Hietz, 2001; Callaway et al., 2002; Zotz, 2016).

Structure and composition of *A. nidus* in Barawai Imbowiari forest (2018–2024) *A. nidus* tends to be unevenly distributed in Imbowiari forests, especially in areas that are more humid and have adequate substrate on tree branches. Factors such as the availability of water, sunlight, and nutrients on the host tree strongly influence this distribution (Nakamura et al., 2017)

High rainfall, consistent temperatures, and minimal ecosystem disturbances (such as tree felling) will keep *Asplenium nidus* populations stable (Böhnert, et al., 2016). Population declines may occur if there is a reduction in humidity, increase in temperature, or direct disturbance to the host trees (Zuquim et al., 2022).

A. nidus populations may have variations in size, leaf structure, or even leaf color that can be influenced by environmental factors. The presence of other epiphytic species such as mosses or orchids in the same region can also affect the overall epiphyte community composition.

Population dynamics and relationship with *P. m. jobiensis* nests During this period (2018–2024), *A. nidus* populations may experience fluctuations due to natural factors such as climate change and anthropogenic factors such as tree felling or forest fires. Population fluctuations of this epiphyte may reveal information about its impact on the population viability of *P. m. jobiensis* in the area.

A temporal design that uses only two sampling periods (2018 and 2024) within a six-year span has limitations in distinguishing real ecological trends from short-term random fluctuations. Natural populations such as *Asplenium nidus* generally experience several cycles of ups and downs over this period, so the observed differences could potentially be misleading if interpreted as long-term trends. Robust ecological monitoring should be conducted annually or biannually with seasonal replication to capture authentic temporal variations and provide a more reliable interpretation of population changes.

Morphometric characteristics of host trees and *A. nidus* in Barawai Village forest *I. bijuga* (Colebr.) Kuntze is the most preferred host of *A. nidus*. Morphological characters showed that *A. nidus* attached to *I. bijuga* had a more dominant size than those attached to *M. argentea*.

I. bijuga is a hardwood tree that grows large and can live very long. It has a large trunk and rough bark, which makes it a very suitable substrate for the growth of epiphytes such as *A. nidus*. The large size and lifespan of the tree allow *A. nidus* to thrive as it provides ample growing space, as well as a stable structure for attachment. The dense canopy of *I. bijuga* also creates a more humid microclimate underneath, maintaining the air humidity that is so important for *A. nidus* as an epiphyte. This moisture helps *A. nidus* to absorb water

from the air through dew and atmospheric moisture mechanisms. *I. bijuga* trees produce leaf litter that is rich in organic matter. The fallen leaves around the growing area of *A. nidus* provide an additional source of nutrients that the epiphyte needs to survive and thrive. This strengthens the commensalism relationship between the two species.

M. argentea is a well-known tropical forest tree species in Papua, especially in lowland rainforests. Its rough bark and complex surface texture provide an ideal substrate for *A. nidus* to attach. As an epiphytic plant, *A. nidus* depends on the moisture provided by the host tree, and *M. argentea*, with its dense canopy, helps maintain consistent air humidity. As nutmeg-producing trees, *M. argentea* are often found in undisturbed forest areas, which means they tend to support a wide range of epiphytic life. The tree produces a large amount of fallen foliage and forms a fertile layer of soil around the epiphytic area, providing *A. nidus* with a good source of organic matter and moisture to grow. In addition, since *M. argentea* is often part of forests inhabited by a variety of fauna, epiphytes such as *A. nidus* may inadvertently directly benefit from the presence of animals passing by or nesting in these host trees, such as birds or small mammals that can contribute to the spread of their spores.

Both *I. bijuga* and *M. argentea* are trees that provide an ideal environment for *A. nidus* growth. Both species offer a suitable substrate surface for attachment, maintain a favorable moisture microclimate, and provide a source of organic matter from leaf litter that supports the growth of this epiphyte. This relationship suggests a commensalism interaction, where *A. nidus* benefits from its host tree without harming or affecting it directly (Mudiana, 2008).

As an epiphytic host, *P. pinnata*, commonly found in tropical forests of Southeast Asia and the Pacific, is a tree with a large trunk and many branches, providing a large surface for epiphytes such as *A. nidus* to grow. The large and open branch structure of *P. pinnata* allows *A. nidus* to attach and grow well, as it provides enough space for its epiphytic roots to develop. *A. nidus* growing on *P. pinnata* may benefit from the tree's ability to maintain moisture in its canopy area, especially in areas with high rainfall. The lush leaves help regulate the microclimate, providing moisture and shade that favor epiphyte growth (Sujalu, 2017). In this regard, *A. nidus* plays a role in maintaining host tree health by contributing to local nutrient cycling. It can absorb organic particles from its surroundings, maintaining the quality of the microhabitat in the branches and trunk of *P. pinnata*.

A. malaccensis is a tropical herbaceous plant often found in the shade of the forest canopy. Although it does not play a direct role as a major epiphytic host, the presence of *A. malaccensis* on the forest floor has the potential to create favorable microhabitat conditions for *A. nidus*, especially in terms of moisture and shade in areas under the canopy. In areas where *A. malaccensis* and *A. nidus* grow together, *A. malaccensis* can help maintain soil moisture and the surrounding microenvironment, which can increase the habitat carrying capacity for *A. nidus* growth in nearby trees. Although *A. malaccensis* is not a host tree, their interaction may affect the distribution of *A. nidus* in the area.

The relationship between *P. pinnata* and *A. malaccensis* with *A. nidus* shows how these epiphytes can utilize different tree species and microhabitat conditions in tropical forests. *P.*

pinnata provides an ideal physical structure for *A. nidus* to grow as an epiphyte, while *A. malaccensis* can play a role in creating a microenvironment that supports the growth of *A. nidus* around it. This combination reflects the importance of inter-species interactions in supporting the health and stability of forest ecosystems.

P. pinnata is a large tree found in tropical forests of Southeast Asia and the Pacific, with a broad trunk and tall branches that provide a suitable surface area for epiphytes such as *A. nidus*. This wide trunk and branch surface allows *A. nidus* to attach and thrive there. The microhabitat conditions created on top of *P. pinnata* trees, such as maintained humidity and diffused sunlight, strongly favor the growth of *A. nidus* (Raunsay et al., 2022). This epiphytic plant obtains nutrients from organic debris caught in the crevices of tree trunks and branches, as well as moisture from dew and rain (Sujalu, 2017). In this interaction, *A. nidus* can serve as a bioindicator of forest health. The steady growth of this epiphyte on *P. pinnata* trees indicates good environmental conditions, such as sufficient air quality and moisture (Darma et al., 2018).

M. argentea, a nutmeg-producing tree found in the forests of Papua, also serves as a potential host for epiphytes such as *A. nidus*. Although it may be smaller and not as hardy as *P. pinnata*, this tree can provide the moisture that is needed to sustain the epiphyte required by epiphytes. The dense canopy of *M. argentea* helps maintain the microclimate beneath the tree, favoring moisture retention needed by *A. nidus*. *M. argentea* produces nutrient-rich leaf litter, which may contribute to the accumulation of organic matter in areas of the branches and trunk where *A. nidus* attaches. These epiphytes obtain nutrients from decaying organic matter in the microhabitat environment of the tree (Sirami, 2015).

Although both trees can support *A. nidus* growth, there are differences in the microhabitats provided. *P. pinnata* may offer a more open and higher area in the canopy, thus more exposure to sunlight, whereas *M. argentea* tends to provide a more moist and shady environment under its canopy. These conditions may influence the size and shape of *A. nidus* that grows on each tree. The relationship between *A. nidus* and these trees shows how important host tree diversity is for supporting epiphytic populations. With trees such as *P. pinnata* and *M. argentea*, *A. nidus* has various habitat options that support its survival and reproduction in tropical forests.

P. pinnata and *M. argentea* serve as important hosts for *A. nidus* in tropical forests. These two trees provide different microhabitat conditions, but both support the growth of this epiphyte. This interaction reflects the complex ecological relationship between epiphytes and host trees, which together contribute to the balance and biodiversity of forest ecosystems (Darma & Peneng, 2007).

Metamorphic characteristics of host tree and *A. nidus* in the fourth pot *Ficus* sp. (various fig tree species) are trees with complex aerial and trunk root structures, which often support epiphytic life. The distinctive aerial roots of *Ficus* sp. often provide additional surfaces for epiphytes such as *A. nidus* to grow on, thus expanding the area where epiphytes can thrive (Darma & Peneng, 2007). *Ficus* sp. trees can create unique microhabitats in their canopy environment. With dense branches and roots that extend in multiple

directions, *Ficus* sp. provides ideal moisture and shade for *A. nidus*. Additionally, *Ficus* sp. efficiently distributes water around its tree surface through its dispersed root system, benefiting epiphytes. *Ficus* sp. is often considered a keystone tree in ecosystems, as it provides a home for many species, including epiphytes, birds, and insects. As such, the relationship between *Ficus* sp. and *A. nidus* is not only structural but also ecological, in that it is part of a wider web of life on this host tree.

I. bijuga and *Ficus* sp. provide different but complementary host roles for *A. nidus*. *I. bijuga* provides a strong and stable physical structure, while *Ficus* sp. offers microhabitat diversity with numerous aerial branches and roots that expand the epiphytic growth area. These two trees, with their respective ecological characteristics, help support *A. nidus* populations at various sites within tropical forests. *I. bijuga* may support epiphytes in higher and more exposed areas, while *Ficus* sp. provides sites in shadier and damper areas.

The specific ecological relationship between *A. nidus* and its host tree varies widely depending on tree species, microenvironment, and other factors (Paiki et al., 2022). In general, *A. nidus* exhibits a commensalism relationship with its host, but host tree qualities, such as diameter, age, canopy, and litter composition, can affect the growth and development of this epiphyte (Mudiana, 2008). Differences in host tree characteristics may also affect epiphyte interactions with other environmental factors, including competition with other epiphytes and relationships with local fauna.

Variation in the morphological characteristics of *A. nidus* has a major effect on its ecological role in forest ecosystems, especially as epiphytes and environmental bioindicators (Darma & Peneng, 2007). Variation in *A. nidus* morphology affects its ecological roles, such as the ability to store water and nutrients, a stable structure for animal habitat, adaptation to the microenvironment, a role in nutrient cycling, and protection against erosion and soil moisture (Raunsay, 2022). The size of *A. nidus* leaves can vary depending on environmental conditions such as humidity and light availability (Zhang et al., 2009). Larger leaves increase the plant's ability to capture water from dew or rain, as well as absorb nutrients from organic particles that accumulate on their surface (Yatabe et al., 2001). This is important for *A. nidus* living on tree branches without direct access to the soil. With its broad leaves, *A. nidus* helps maintain moisture in the surrounding area, which supports other organisms living in the forest, including microorganisms and invertebrates that utilize the moisture. The plant also serves as a "filter" for nutrients from the air and water, recycling organic matter in the ecosystem.

Variations in the height and diameter of *A. nidus* affect its role as a habitat for a variety of fauna, including birds, insects, and other organisms that utilize these plants as homes or nests. Larger plants provide more space for species such as the little bird of paradise (*P. m. jobiensis*), which uses *A. nidus* as a place to build nests. By providing a stable and secure home in the forest canopy, *A. nidus* plays an important role in maintaining the balance of forest ecosystems (Larrivée & Buddle, 2009). It provides refuge and nesting sites for animals while contributing to the ecological network

that supports the survival of other species.

A. nidus can show morphological variations based on environmental factors such as light availability, temperature, and humidity (Zhang et al., 2009). For example, in areas with dimmer light, these plants may have longer and thinner leaves to increase light absorption, whereas in more open areas, the leaves may be thicker to prevent excessive water loss.

These morphological adaptations allow *A. nidus* to survive in a wide range of microhabitats, from tree canopies to lowland forests. This adaptability also makes it a good bioindicator, as its morphological variation reflects local environmental conditions (Saroh & Krisdianto, 2020). Thus, morphological changes in *A. nidus* can provide clues about the overall health of the forest ecosystem.

Leaf length and width are morphological characteristics that affect the ability of *A. nidus* to capture organic particles and dust falling from the forest canopy. Wider and longer leaves capture more organic material that decomposes around the plant roots (Larrivée & Buddle, 2009). The plant acts as an effective nutrient collector, and as the organic matter trapped on the leaves and in the area around the roots decomposes, *A. nidus* contributes to nutrient cycling in the forest ecosystem. This supports the growth of other organisms and increases the fertility of the microhabitat where it grows.

The roots of *Asplenium nidus* do not penetrate the soil like other land plants but instead attach to the surface of the host tree (Utami et al., 2023). Nonetheless, this root system plays an important role in maintaining soil stability in the host tree and helps prevent erosion, especially in tropical rainforests that often experience heavy rains. Roots *A. nidus* helps bind organic matter and moisture in the area where it grows. This helps maintain local moisture balance and mitigate the impact of erosion around the host tree.

Based on the analysis results presented in this table, there were no significant differences in morphometric characters of *A. nidus* (diameter, height, leaf length, and leaf width) among the five sampling locations (spots) (Dong, 2011). This result indicates that morphometric variation among sites is uniform and there is no significant environmental influence on the growth of *A. nidus* at each of the measured sites.

Research on the morphology and anatomy of *Asplenium* has been conducted, which suggests that differences in leaf size, stomatal structure, and epidermal characteristics can be important indicators for distinguishing *Asplenium* species, including *A. nidus* (Sofiyanti et al., 2021). Variations in leaf size can be influenced by environmental conditions such as humidity and light intensity, and these are often used in research to evaluate plant adaptation to microclimate change (Perrie & Brownsey, 2005; Voronkov & Ivanova, 2021).

Figure 9 shows that all five data sets (Spot 1 to Spot 5) have distributions that are fairly close to a normal distribution, with Spot 3 having the best fit based on its correlation coefficient. If the data points on the box plot follow a straight line, this indicates that the data at that spot is significantly close to a normal distribution.

Non-random plot placement that tends to focus on easily accessible areas has the potential to cause bias towards edge zones or areas that have experienced anthropogenic

disturbance. This condition causes the data collected not to represent the actual forest ecosystem conditions. To ensure adequate spatial representativeness, the sampling design should use stratified random sampling with random GPS coordinate determination on different topographic and vegetation strata. This approach will eliminate location selection bias and increase the ecological validity of the observation results.

The claim that *A. nidus* functions as a “bioindicator” for *P. m. jobiensis* nests has not been supported by empirical correlation data showing a direct relationship between epiphyte abundance and bird nest density. This statement remains assumptive without scientific validation. Validation of the bioindicator concept requires simultaneous surveys of *A. nidus* populations and the number of bird-of-paradise nests at the same location so that the causal relationship can be statistically tested. This approach allows for empirical proof of the role of *A. nidus* as a quantitative indicator of ecosystem health.

The absence of inter-observer reliability tests and standardized observation protocols increases the risk that differences in detected population data between 2018 and 2024 are due to methodological inconsistencies rather than actual ecological changes. Quality control should involve more than one observer, the use of blind counting methods, photographic documentation of each individual, and storage of voucher specimens for future verification. In this way, the results of observations can be guaranteed to be consistent over time and can be replicated by other researchers.

A temporal design that uses only two sampling periods (2018 and 2024) within a six-year span results in limited statistical power, capable of detecting only very large

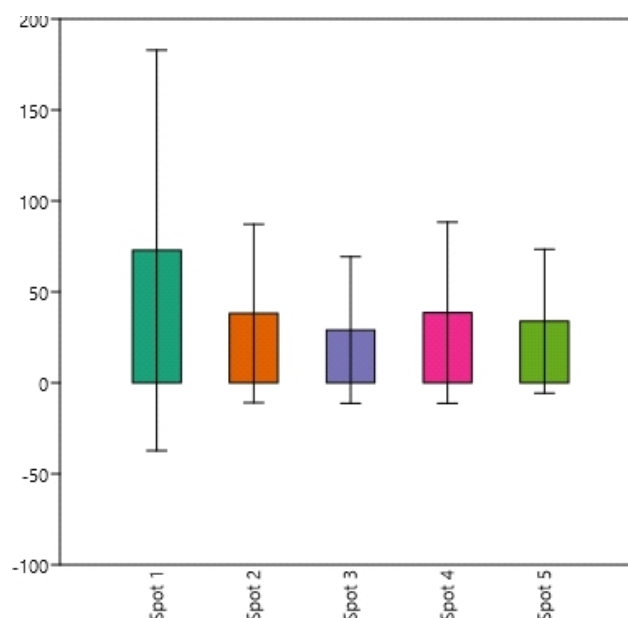


Figure 9 Box plot (plot type: bar chart), whisker type: standard deviation; whisker length: 95% interval. Shows the comparison of morphometric characters based on the mean value (standard deviation) of *Asplenium nidus* specimens in each observation spot (1, 2, 3, 4, 5).

changes and potentially missing subtle but ecologically important variations. Natural populations such as *Asplenium nidus* experience periodic fluctuations over this time frame, so that observed differences may lead to biased interpretations if considered as long-term trends. Credible ecological monitoring should be conducted annually or biennially with seasonal replication in order to capture true temporal variation and produce valid ecosystem-level inferences. Furthermore, the use of only three transects with a total of 45 plots to represent the entire forest ecosystem is considered inadequate, as it results in low statistical power and is unable to describe spatial variation comprehensively. Credible forest ecosystem monitoring standards generally require a minimum of 100–200 plots in order to produce valid and representative ecosystem inferences.

The lack of environmental measurements, including temperature, humidity, light availability, and soil pH, precludes explanation of population changes or prediction of future dynamics, rendering the monitoring ecologically uninformative. Robust ecological monitoring must integrate microclimate sensors, soil analyses, and canopy structure measurements to understand controlling factors.

Monitoring that is limited to adult individuals without taking into account age structure and recruitment rates risks giving rise to misinterpretations of population stability. The total number of individuals that seem stable may include elderly individuals who are no longer reproducing, contributing to what is known as a "living dead population." Monitoring of population viability should include data on size classes, reproductive status (active and dormant spores), mortality rates, and successful recruitment of new individuals. With this approach, the long-term survival of *A. nidus* can be monitored realistically and scientifically.

The use of simple linear regression to analyze complex ecological relationships ignores the non-linear and multifactorial nature of tropical forest ecosystem systems. The relationship between moisture, canopy structure, bark texture, and epiphytic density cannot be explained by just one independent variable. A more appropriate analysis should use multivariate approaches, such as GLM, PCA, or machine learning approaches to capture the true complexity of ecological interactions.

Overall, the monitoring design currently used does not meet the scientific standards of long-term ecosystem monitoring. The approach is more similar to scientific tourism, which collects data without a solid methodological framework and without measurable conservation goals. True ecological monitoring requires a complete overhaul of methodologies with adequate temporal resolution, integration of environmental variables, and the use of multivariate analyses to support science-based conservation decision-making.

The statistical analysis used in this study is still limited to simple linear regression, even though the ecological relationships in forest ecosystems are complex and non-linear. The approach is not fully capable of capturing the multifactor interactions between epiphytic populations, microclimatic conditions, and other environmental factors. The use of more sophisticated statistical models such as GLM or multivariate analysis will provide a more

comprehensive picture. With this method, the pattern of population variation can be understood in the context of the interaction between ecological variables. In addition, the use of advanced statistical techniques will also improve the reliability of the interpretation of the results. Further research is recommended to integrate this approach to make the analysis of population dynamics more accurate and representative.

Conclusion

This study demonstrates that the population of *A. nidus* increased from 63 individuals associated with 49 host species and high diversity in 2018 to 79 individuals associated with nine host species and moderate diversity in 2024. Five host species were consistently recorded in both observation periods, indicating their role as stable and preferred substrates for *A. nidus*. Morphometric analysis showed no significant differences in diameter, height, leaf length, or leaf width among the five sampling locations, reflecting uniform growth patterns across sites. These results indicate relatively homogeneous environmental conditions within the study area and suggest that spatial variation did not significantly influence the growth of *A. nidus*.

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