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Morphological, Morphometric, and Distribution Pattern Characteristics of Optimal Harvest Phase Sago in Forest Area Based on Drone Imagery

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ABSTRACT

The development of remote sensing systems is considered an important innovation in supporting the optimization of today's food crop production, especially the development of sensor technology that can capture detailed variations in plant information. On the other hand, Sago is one of the food crops that is considered to have the potential for development to improve the community's economy and increase global food security. The main objective of this study is to extract the morphological characteristics, morphometry, and distribution patterns of sago in the optimal harvest phase in non-cultivated areas. Very high-resolution Drone imagery was produced through recording with a flight height of 50 meters above the ground using the DJI Mavic 3 Pro. Samples of sago stand coordinates in the optimal harvest phase were collected through field observations. The characteristics of each sample were extracted through a visual interpretation approach and the nearest neighbor analysis technique. The results showed that the morphological and morphometric characteristics of sago stands in the optimal harvest phase can be assessed from Drone Imagery. Each sample shows the same pattern with the shape of trees, leaflets, and canopies that stand out in one clump and have 3-6 young leaflets. The average morphometric parameters of the optimal harvest phase showed low correlation and were randomly distributed with very sparse distances between stands (around 7 trees/ha).

INTRODUCTION

Sago is a starch-producing plant that has become one of the main foods in several regions of Indonesia, such as Papua (Sidiq et al., 2021), Sulawesi (Dewayani et al., 2022), Maluku (Kundre, 2023), and Riau (Swastiwi, Febriyandi, et al., 2023). Sago has a relatively long life cycle which can reach more than 15 years (Yamamoto et al., 2010). Sago can produce starch along with the increase of the height of the stem and the decrease of number of starch in the final stage of flower formation to the death stage (F.-S. Jong, 1995), so the harvest time will affect the number of starch production that can be produced (Chua et al., 2022). Generally, sago reaches its optimal harvest period at the age of between 7 years (Suwarda et al., 2024) to 14 years (Irawan et al., 2024). At the optimal harvest phase, sago can produce dry starch to 1 ton/tree (Djoefrie et al., 2024). However, the age of the sago plant cannot be used as a benchmark to determine the harvest time, because it is difficult to calculate with certainty (Yamamoto et al., 2020), especially in sago forest areas (Karim, 2021). However, sago stands at the optimal harvest phase and can be identified visually through the characteristics of its morphology or morphometric, such as stem size, number of leaflets, leaf shape, and the presence of flowers (Masluki, 2022). These characteristics are important to understand to help determine the right harvest time and optimize production in sago forest areas (non-cultivation).

The characteristics of morphology and productivity of sago at the optimal harvest phase have been documented well through field observation methods from several previous studies. For example, research (Sari, 2024) reported that the phase between the final stage of stem formation to the initial stage of flower emergence has higher starch production than the previous stage. Similar results were also shown in the research by (Yamamoto et al., 2020) that this phase has a starch production between 225-465 kg/tree, while the previous phase had an average starch production under 100 kg/tree. This indicates that the phase between the final stage of stem formation to the initial stage of flower emergence is the optimal harvest time. From a morphological aspect, the research by (Dewayani et al., 2024a) explains that the phase of optimal sago harvest is characterized by the appearance of the most prominent tree height in one clump, having 3-4 leaflets at the top and the flowers are not blooming yet. (Girsang, 2018) added that the lower leaflet of the top tends to turn yellow and the width of the upper leaflet becomes small. Furthermore, the research by (Masluki et al., 2024) comparing the morphometric characteristics of the optimal harvest phase of six sago accessions in the *Tanah Luwu* Area showed that the stem height ranged from 8-15 meters and the stem diameter was > 40 cm.

Field observation is an irreplaceable method in terms of accuracy in monitoring plant growth characteristics. However, in its implementation, it requires high time, cost, and resources (Wang & Gamon, 2019), especially in large observation areas. In addition, the field observation method has high subjectivity and is often only carried out in easily accessible locations (Pandey & Pandey, 2021). The sago forest area which has characteristics of quite high vegetation density (Masluki, 2022) and is difficult to explore (Nurlette et al., 2021), makes the monitoring of the optimal sago harvest phase based on field observations difficult to conduct comprehensively. In fact, determining the right harvest time is very important to get sago starch in maximum quantity and good quality (Sari, 2024). Moreover, sago trees will die after passing the harvest age (Maherawati, Iman Suswanto, 2023), causing a lot of sago production potential to be wasted (Sidiq et al., 2021).

On the other hand, the utilization of remote sensing systems has experienced rapid development, especially in terms of the imagery spatial resolution resulted, such as the use of Drone technology. Drone technology has become an important tool in today's crop monitoring (Perz & Wronowski, 2019; Radoglou-Grammatikis et al., 2020; Singh et al., 2020; Velusamy et al., 2021). Drone technology can reach large and difficult-to-access areas with high efficiency (Emimi et al., 2023; Gowroju & Santhosh Ramchander, 2023). Drone technology can produce imagery with very high resolution (Seifert et al., 2019), making it effective in identifying objects visually (Hamylton et al., 2020). According to the research by (Deur et al., 2021; Ye et al., 2023), very high-resolution imagery can be transformed into thematic plant information, such as leaf color, leaf shape, canopy shape, and plant height, so it can be concluded that the characteristics of morphology and morphometric of sago stands at the optimal harvest phase can be extracted from Drone imagery. However, this has not been explored well. In addition, the results of visual object identification from imagery are prone to misinterpretation (Viljanen et al., 2018). Therefore, the results of this study can be a meaningful reference in the use of drone images for monitoring the harvest phase and optimizing sago management in non-cultivation areas. The main objective of this study is to explore the characteristics of morphology, morphometry, and distribution patterns of sago stands in the optimal harvest phase in sago forest areas based on drone image data.

MATERIALS AND METHODS

This research was conducted through several important stages including field data acquisition, drone photo processing, morphological and morphometric characteristic assessment, and analysis of optimal harvest phase (OHP) distribution patterns. The entire research process is described through a research flowchart shown in Figure 1.

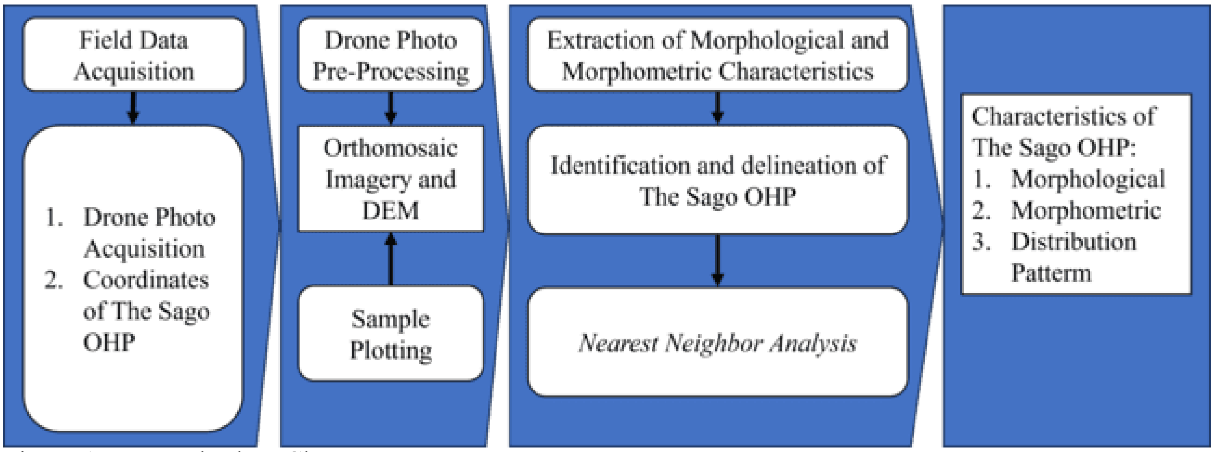

Figure 1. Research Flow Chart

1. Field Data Acquisition

Field data collection includes drone photo recording activities and field observations of sago stands. Drone photo acquisition for analysis needs in this study was carried out in Wailawi Village with a recording area of approximately 8,85 ha (Figure 2). Wailawi Village is one of the centers of sago forest areas in South Sulawesi Province, located in the North Malangke Sub-District, North Luwu District (Masluki et al., 2024; Osozawa, 1990). Photo recording was conducted by using a DJI Mavic 3 Pro Drone flown during the day, between 11 and 12.30. This period is the optimal time for recording Drone photos (Awais et al., 2021). To produce very high-resolution imagery, the recording was set at a flight height of 50 meters above ground level, front overlap of 90%, side overlap of 70%, and camera tilt of 70o. The high image resolution can provide more detailed object recording (Geng et al., 2020), so it allows to extract the detailed information from HPS stands.

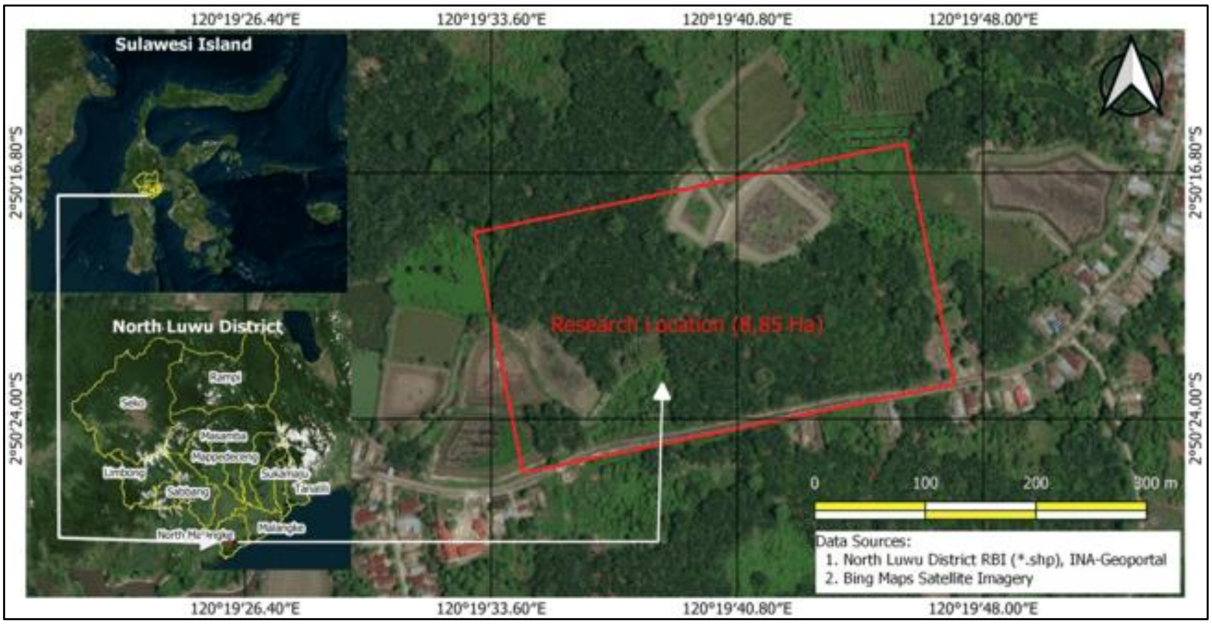

Figure 2: Research Location Map

Field observations are intended to obtain sample stand coordinate points of sago OHP in the drone photo recording area. The selection of Sago OHP samples was based on its morphological characteristics. The research (Osozawa, 1990), divided the growth phase of sago in Luwu Utara Regency into seven categories (Figure 3), namely the vegetative phase (*ana* and *ma'babakung*), generative or productive phase (*pettu sese*, *ma'baru*, *bulu bongko* and *ma'tanru jonga*) and senescence phase (*ma'bua belu* and ma'bua). Meanwhile, the research (Sari, 2024) showed that the *bulu bongko* and *ma'tanru jonga* categories had higher starch production than other categories. Thus, the selection of OHP samples was only focused on these two categories.

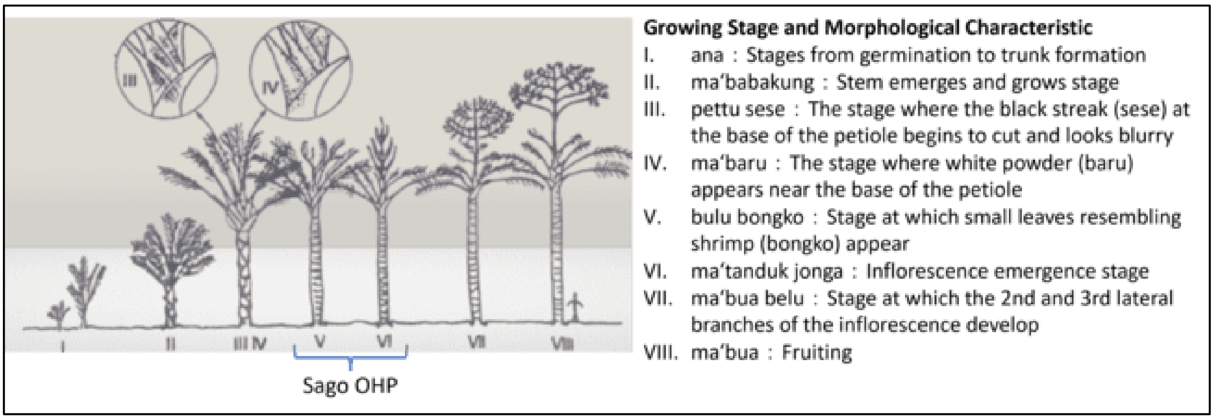

Figure 3. Sago growth stages in North Luwu District (Osozawa, 1990).

2. Drone Photo Processing

Drone photo recording results processing was carried out to obtain orthomosaic imagery using Agisoft Metashape v2.1.1 software. This process includes several critical procedures aimed at ensuring the integrity and accuracy of the resulting data. The first step is photo alignment, where corresponding points between different images are identified and adjusted to build a representative point cloud of the three-dimensional structure of the study area. At this alignment stage, a quality evaluation is performed to detect and correct photos that have alignment problems, such as misalignment or distortion. This adjustment aims to optimize the quality of the orthophoto image that will be produced (Lastilla et al., 2021). Further processing includes building point cloud, building mesh, generating texture and building tiled model, building orthomosaic, and building dem. In this stage, the resulting ortho-mosaic imagery, DTM (digital terrain model) data, and DSM (Digital Surface Model) data as data for assessing the characteristics of Sago OHP.

3. Assessment of Morphological and Morphometric Characteristics

The assessment of the characteristics of OHP sago stands, begins with plotting the coordinates of sago stand samples from field surveys into orthomosaic imagery. The results of the sample plotting are used as a reference in extracting the morphological and morphometric characteristics of OHP sago stands. The morphological characteristics of OHP sago such as leaf tone and color, leaf sheath shape, tree height, canopy shape, and flower presence are assessed qualitatively based on visual characteristics in the image. Conclusions are drawn based on aspects of similarity in the characteristics of each stand sample.

Morphometric characteristics of sago OHP were assessed from the number of leaflets, tree height, and canopy diameter. The number of OHP sago leaflets was calculated manually based on the interpretation of the orthomosaic imagery. The number of Sago OHP leaflets was divided into two categories, namely master leaflets and young leaflets. Tree height was calculated from the ground to the base of the shoot (Figure 4) using normalized DSM data (nDSM) using Equation 1 (Oh et al., 2022). The canopy diameter was estimated through the circle boundary delineated from the outermost boundary of the canopy of each sago OHP stand. The canopy diameter was calculated using the circumference formula (p) of a circle (Equation 2) with a phi value (π) of 3.14 (Rogerson, 2019).

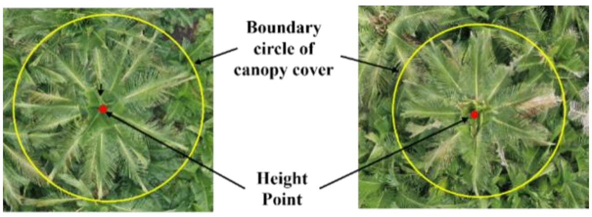

Figure 4. Technical illustration of canopy diameter, and tree height measuring.

$$\text{nDSM}=\text{DSM}-\text{DTM} \qquad (1)$$

$$\text{Diameter Kanopi}= p/\pi \qquad (2)$$

4. Analysis of Optimal Harvest Phase Distribution Patterns

The distribution pattern of OHP sago stands was analyzed through the construction of the

Nearest Neighbor Index (NNI). NNI is a value that describes the spatial distribution of objects in space by comparing the average distance of each nearest object in observation with the average distance of the expected object (Liu & Lee, 2023). NNI was analyzed using the Average Nearest Neighbor (A-NN) tool found in the ArcGIS v1.8 application. The A-NN tool will produce one of three possible conclusions of the distribution pattern (clustered, randomly scattered) based on three statistical tests, namely nearest neighbor ratio, z-score, and p-value (Ghodousi et al., 2020).

RESULTS AND DISCUSSION

Field Data Acquisition and Drone Photo Processing

The collection of photos obtained from the results of recording with a drone was then processed by using Agisoft Metashape software. This process involves the alignment quality evaluation process to ensure the accuracy of position and to correct distorted photos. There are 10 photos that experienced misalignment removed from this process. After that, the point cloud was compacted and further processed to form a mesh, to add texture, and to build a cohesive segmented model. From this processing process, it is obtained orthomosaic imagery with 1 cm spatial resolution (Figure 5a) and DSM Data with 4 cm spatial resolution (Figure 5b).

From the results of field observations, 20 coordinate points were obtained for sago OHP samples. The OHP category includes 18 stands with the *bulu bongko* stage and 2 samples with the *ma'tanru* joga stage. Each sample is plotted into an orthomosaic imagery (Figure 6).

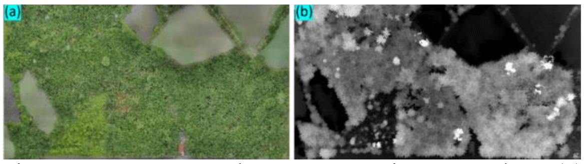

Figure 5. Drone Photo Processing Results. (a) orthomosaic imagery; (b) nDSM.

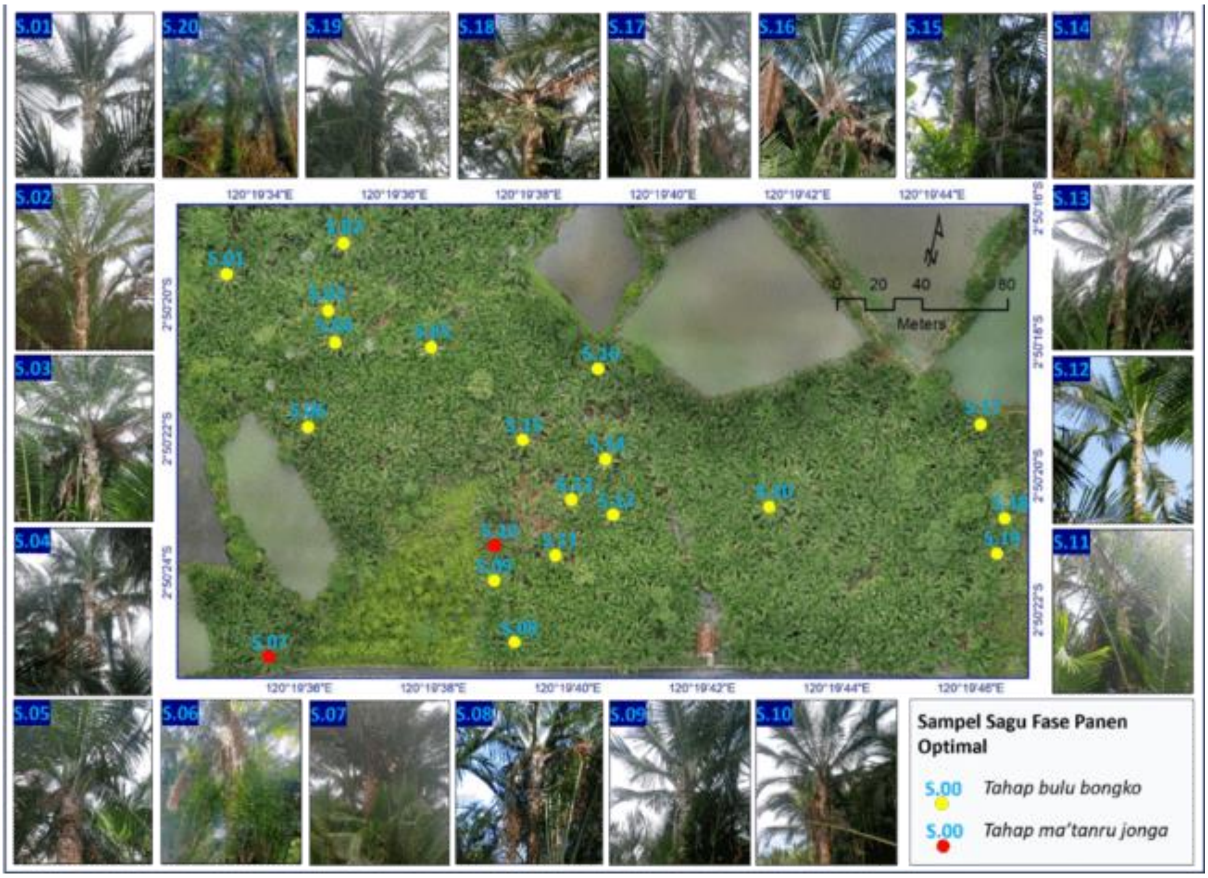

Figure 6. Distribution of Sago OHP Samples from Field Observations

The Morphological Characteristics

Morphological characteristics are key parameters in determining the OHP of sago. Morphological characteristics from the stem to the tip of the sago have a close correlation with the quantity and quality of starch that can be produced at harvest time (Yamamoto, Yanagidate, et al., 2020), so understanding the morphological characteristics of OHP sago has a high significance for increasing sago production and productivity. With the advancement of remote sensing technology, the use of very high-resolution imagery from drone recordings offers a different perspective in monitoring the sago harvest phase, especially its ability to visualize objects in detail that are difficult to reach through field observations. This approach offers a more efficient way to identify sago OHPs. Based on the plotting results on the orthomosaic imagery (Figure 7), each sago stands sample OHP is visually compared to understand the pattern of morphological characteristics. As shown in Figure 9, each sample shows a pattern of similarity in morphological characteristics, especially in terms of leaf shape, canopy shape, and tree height. These morphological characteristics are detailed in Table 1.

As shown in Figure 7, each sample has a leaf shape, canopy cover, and tree height that stand out compared to other phases in a clump. In terms of leaf shape, OHP has a clear difference in the shape of old leaflets and young leaflets in terms of shape, size, and number. According to the research by (Yamamoto et al., 2020) the number of sago leaflets will increase from the initial stage of stem formation to the initial stage of flower emergence. The lower leaflet will stretch horizontally and gradually fall off (Yater et al., 2019). After the final stage of stem formation (*bulu bongko* stage) to the initial stage of flower emergence (*ma'tanru jonga* stage), the length of the leaflet formed will gradually shorten (Yamamoto et al., 2022a). This condition makes the boundary between the young leaflet at the top and the old leaflet at the bottom visible in very high-resolution imagery. The upper leaflets are shorter in size with a more upright shape, while the lower leaflets are longer and stretch horizontally. This also makes the OHP canopy structure have a tiered model, a shape resembling a decagram star to an icosagram, and a wider canopy cover area than other sago stands in one clump.

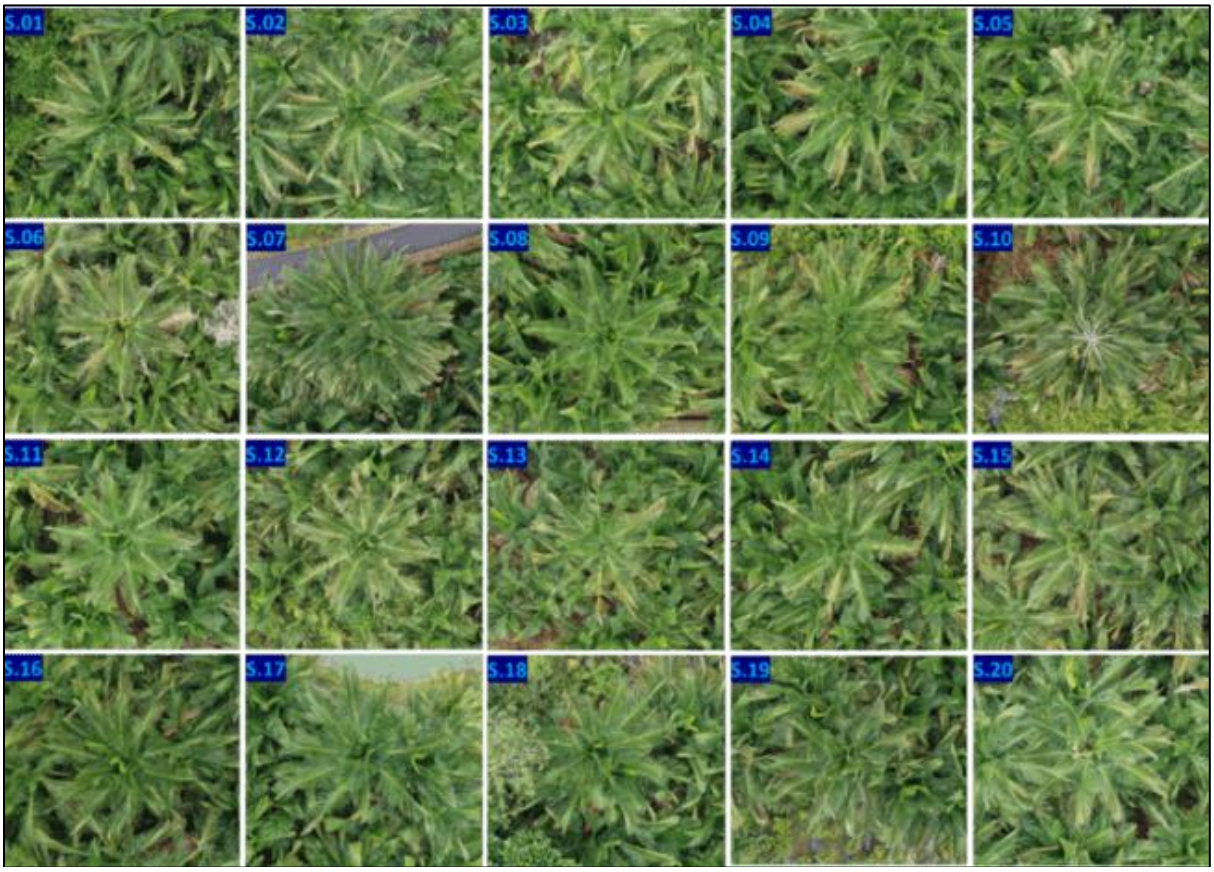

Figure 7. Visual Appearance of Sago OHP Sample from Cropped Drone Image

Table 1. Morphological Characteristics of Sago OHP basic visual interpretation from Orthomosaic imagery

Morphological Aspects	Characteristics
Leaflet Shape	The leaflet on the lower part (old leaflet) appears longer and stretches horizontally, while the upper leaflet (young leaflet) are shorter in size and more upright in shape.
Canopy Shape	The canopy shape looks like a decagram to an icosagram star shape with a wider size compared to other sago stands in one clump.
Tree Height	On average, it has the tallest tree in a clump, so it looks the most prominent.
Flower Shape	Does not have any blooming flowers or fruit yet
Leaflet Tone	The leaf color is brighter compared to sago which has not yet reached harvest age.
Leaflet Color	The leaflets are generally light green (between 2-3 on the rice leaf color chart by the International Rice Research Institute*)* and the signs of aging on the leaf edges (yellow-brown) are more intense.

Sago OHP is the phase where starch production in sago stems reaches its peak (Timisela et al., 2022). In this phase, the formation of the stem will stop until the stage of flower emergence (Hussain et al., 2022), then the sago tree will gradually wither and die (Jariyapong et al., 2021). This indicates that the OHP is the period of sago growth that will reach the maximum tree height. This is also depicted in Figure 8 (the result of the cut orthomosaic image), the OHP which includes the growth stage of *bulu bongko* and *ma'tanru jonga*, as well as the aging phase (*ma'bua belu* stage), has a tree height that appears more prominent in one clump.

From the aspect of leaflet tone and color, the average sample (S.01-S.20) tends to have a brighter leaf tone compared to the early stage of sago growth (the *ana* stage and *ma'babakung*). This is because OHP has taller trees and many leaflets that spread out (flatter canopy shape) so that the reflection of sunlight from the leaf surface captured by the drone camera optics is greater (less scattering and shadow effects) compared to the younger phase which has more upright leaflet (Li et al., 2021). Meanwhile, in terms of leaf color, the average Sago OHP sample has a light green leaf color (score 2-3 from the rice leaf color chart by the International Rice Research Institute) with yellow to brownish colors at the tips of old leaflet tending to be more intensive (signs of aging). The characteristics of the tone and color of OHP leaflet are not distinctive, because they have a high similarity to the pre-harvest phase. As shown in Figure 9, the characteristics of the tone and color of the leaflet of the optimal pane phase (*bulu bongko*) and the pre-harvest phase (*pettu sese* and *ma'baru*) do not have significant differences, so it can lead to misinterpretation.

The presence of sago flowers is one of the important parameters for assessing OHP sago. According to the research results by (Yamamoto et al., 2022b), it is stated that the initial period of the emergence of sago flowers is the growth stage of sago, where starch in the stem will be formed optimally. The presence of sago flowers is the easiest morphological parameter of OHP sago to identify in drone imagery. As shown in Figure 10, sago flowers have a gray-to-white color that contrasts with the color of sago leaflet (green). The difference in color makes the sago flowers stand out in drone imagery. In addition, the presence of sago flowers that are still in the form of petals and flower stalks (S.07 and S.10) is smaller than the shape of flowers that have bloomed (SI and S.II), so that it can be clearly distinguished between OHP and the old phase (SI and S.II). Based on the results of the visual interpretation of the morphological characteristics of OHP sago, it strengthens the use of very high-resolution imagery (drone imagery) for monitoring sago growth in non-cultivation areas.

Figure 8. The visual appearance of tree height from the *bulu bongko* stage to the final phase of sago life from the results of plotting observation samples (S.16, S.08, S.07, and S.10) and the results of Drone Imagery interpretation (S.I, S.II, S.III, and S.IV). (S.16) early *bulu bongko* stage, (S.08) late *bulu bongko* stage, (S.07) early *ma'tanru jonga* stage, (S.10) late *ma'tanru jonga* stage, (S.I) early *ma'bua belu* stage, (S.II) late *ma'bua belu* stage, (S.III) appearance of sago stands that have withered due to aging, (S.IV) appearance of dead sago trees

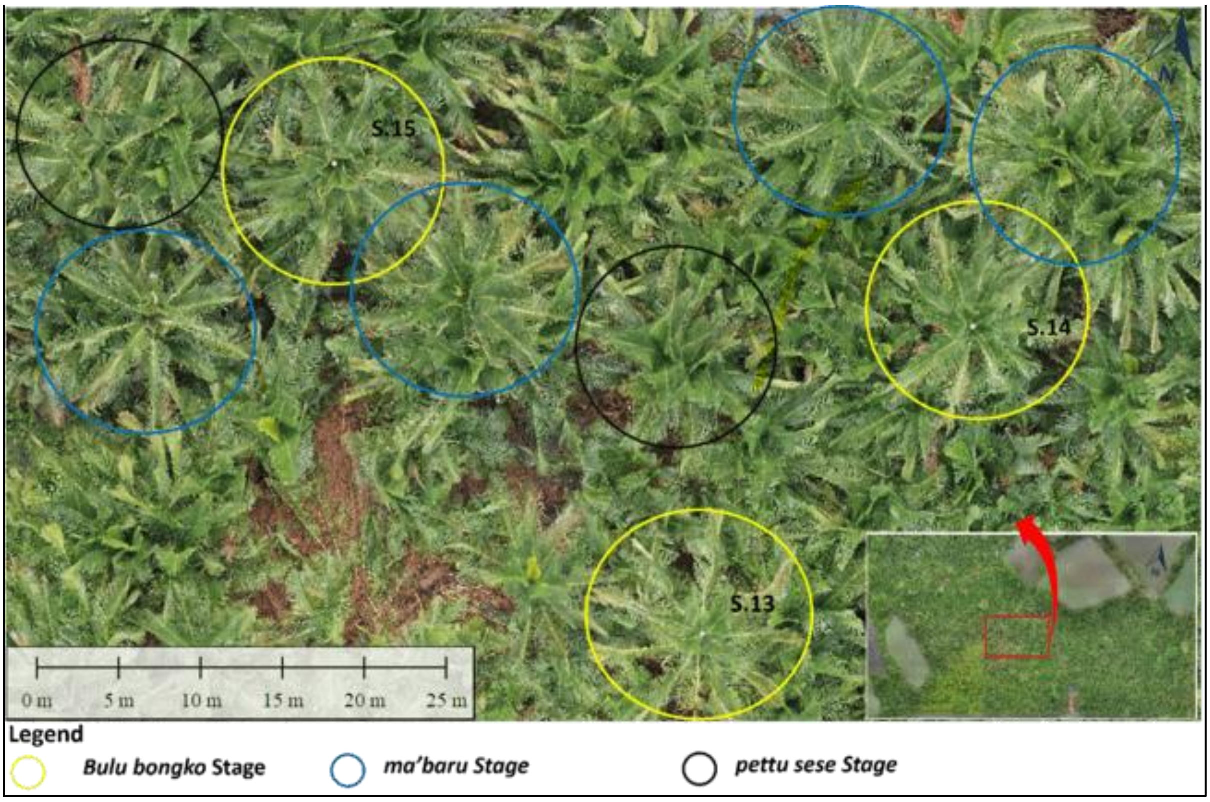

Figure 9. The appearance of tones and colors of the leaflet in the optimal harvest phase (*bulu bongko*) and pre-harvest phase (*pettu sese* and *ma'baru*) in the orthomosaic imagery

The Morphometric Characteristics

The data generated from the drone photo processing results are in the form of orthomosaic imagery with standard RGB channels (red, green, blue) and nDSM data. The morphometric characteristics of sago OHP that can be measured directly from the data are tree height, number of leaflets and canopy size (Table 2). Although its use is not limited to this information, it requires more complicated analysis and tends to take longer. For example, to calculate the leaf area index (dos Santos et al., 2020; Hasan et al., 2019; Raj et al., 2021), measuring the diameter (Raj et al., 2021) and others. On the other hand, information on tree height, number of leaflets, and canopy width have a close relationship to the stem diameter (Sari et al., 2020), while the stem diameter is positively correlated with the amount of starch production (Masluki et al., 2024). The same thing is also emphasized by (FathnoerA et al., 2020) that the optimal tree height, number of leaflets, and canopy width, then starch production will be maximized. It can be concluded that the characteristics of tree height, number of leaflets, and canopy size of sago stands can be the basis for assessment for selecting sago to be harvested.

Table 2. Morphometric Characteristics of Sago OHP Samples based on Drone Imagery data

Samples	Growth Stages	Tree Hight (m)	Number of Old Leaflet	Number of Young Leaflet	Canopy Diameter (m)	Canopy Boundary Area (m^2)
S.01	*bulu bongko*	16,99	19	3	16,84	221,98
S.02	*bulu bongko*	20,65	16	3	17,05	227,58
S.03	*bulu bongko*	16,50	13	3	15,31	183,48
S.04	*bulu bongko*	19,09	15	6	15,53	188,85
S.05	*bulu bongko*	18,19	14	3	13,62	145,22
S.06	*bulu bongko*	18,03	18	6	12,68	125,92
S.07	*ma'tanru joga*	19,37	No Data	6	17,74	246,28
S.08	*bulu bongko*	15,61	17	6	14,93	174,36
S.09	*bulu bongko*	17,13	18	6	14,00	153,44
S.10	*ma'tanru joga*	18,22	20	3	14,64	167,75
S.11	*bulu bongko*	14,98	20	3	12,49	122,11
S.12	*bulu bongko*	16,79	20	4	12,98	131,93
S.13	*bulu bongko*	17,88	15	3	14,25	158,97
S.14	*bulu bongko*	14,40	16	3	13,98	152,95
S.15	*bulu bongko*	15,42	15	6	14,49	164,34
S.16	*bulu bongko*	18,18	14	4	15,22	181,39
S.17	*bulu bongko*	16,12	13	3	14,73	169,71
S.18	*bulu bongko*	16,11	17	4	12,38	119,99
S.19	*bulu bongko*	16,70	19	3	14,07	154,89
S.20	*bulu bongko*	14,33	14	4	14,32	160,50

Table 3. Results of the Spearman Correlation Test between Tree Height Parameter, Number of Leaves, and Canopy Diameter at the level of trust 95%

Morphometric Parameters	Tree Hight	Number of Old Leaflets	Number of Young Leaflets	Canopy Diameter
Tree Hight	1			
Number of Old Leaflets	-0,011055617	1		
Number of Young Leaflets	-0,001843901	0,017839786	1	
Canopy Diameter	0,424477128	-0,29308773	-0,124011423	1

Based on the results of the extraction of OHP morphological characteristics from orthomosaic imagery and nDSM data in the study area (Table 3), show varying values. Variations in tree height range from 14.33 meters to 20.65 meters, the number of old leaflets ranges from 13 to 20 leaflets, the number of young leaflet ranges from 3 to 6 and the canopy diameter ranges from 12.38 meters to 17.74. Meanwhile, from the results of the correlation test at a 95% trust level for the four parameters (Table 3), only the tree height parameter with canopy diameter has a positive correlation with the moderate category, while the others have a less significant relationship. This illustrates that even in one area, the morphometric characteristics of sago OHP in forest areas have high variations. Variations in these morphological characteristics have also been reported by previous studies. For example, the research by (Timisela et al., 2022) states that the height of sago trees can reach 25 meters and begin to produce starch at a height of 6-18 meters. The research by (Dewayani et al., 2024b) stated that the number of young OHP leaflets ranges from 3-4 leaflets. Meanwhile, the research by (Yamamoto et al., 2021) which compared four sago OHP varieties in Kairatu Village, Seram Islands showed that the average tree height characteristics were 21 meters, and the average total number of leaflets was 24.1 and the average of canopy diameter was 18.4. This difference is normal, considering that the morphometric characteristics of sago growth are greatly influenced by environmental factors (soil fertility level, groundwater availability, and vegetation density) and sago varieties/accessions (Manar et al., 2023; Masluki et al., 2024; Yamamoto et al., 2022b).

Despite the variation in the morphometric characteristics of sago OHP, the results of this study prove that the use of very high-resolution imagery can be used for the assessment of sago OHP morphometry in non-cultivation areas. The same thing is also shown by the results of research by (Nasiri et al., 2021; Vacca & Vecchi, 2024; Yurtseven et al., 2019) who used drone imagery to measure tree height and canopy diameter in forest areas with an accuracy level above 85%.

Distribution Pattern Characteristics of Optimal Harvest Phase

Land cover classification using orthomosaic images in the research area is divided into six classes, namely sago land, shrubs, ponds, vacant land, buildings, and roads (Figure 10). From this classification, the area of sago land identified reached 5.24 hectares from a total observation area of 8.85 hectares (Table 4).

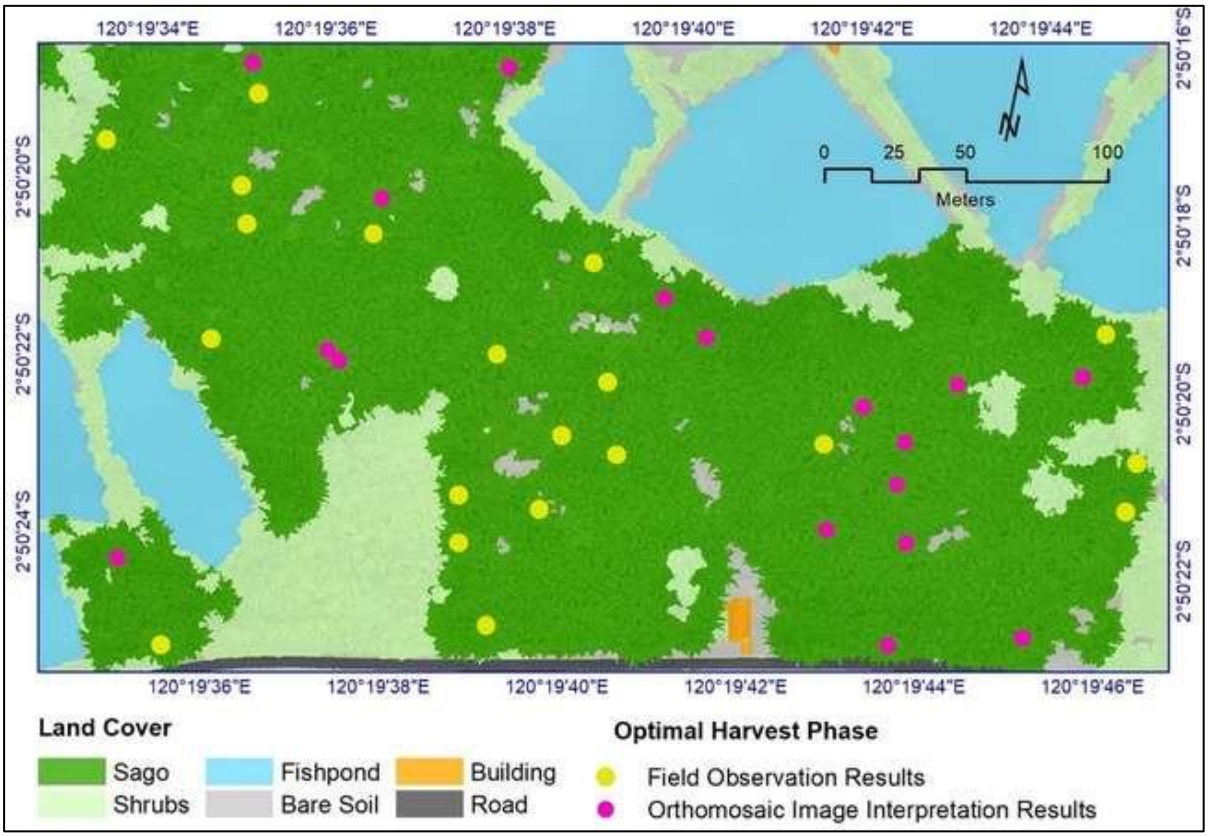

Figure 10. Characteristics of land cover and distribution of optimal harvest phase sago in research area.

Table 4. Land cover classification in the research area

Land Cover Types	Area (ha)	Amount of Optimal Sago Harvest	Density (tree/ha)
(a)	(b)	(c)	(c/b)
Sago	5,24	37	7
Building	0,02		
Fishpond	1,75		
Bare Soil	0,28		
Road	0,10		
Shrubs	1,47		
Total	8,85		

The sago population in non-cultivation areas (sago forest) is the result of natural growth (Tampubolon et al., 2021) and has uncontrolled seedling growth (Lewaherilla et al., 2023), so it has a density high stands (F. S. Jong, 2018) and is difficult to explore (Sidiq et al., 2022). This is also confirmed by the results of this study. As shown in Figure 10, wherein the sago area there is only a little empty land and other vegetation species (shrubs). However, the high density of sago stands is not comparable to the number of sago OHP. Based on the results of field observations and orthomosaic imagery interpretation, only 37 sago OHP trees were found in total, or around 7 trees/ha (Table 4).

According to the research (Gusmayanti et al., 2008) from the ma'bbakung stage to the *bulu bongko* stage takes about 6 months. Meanwhile, the results of research by (Sari, 2024), show that the average dry starch production at the bongko hair stage is 239 kg/tree. If the average production is multiplied by the number of OHP stands per hectare (7 trees/ha), then the potential for dry starch production at the research location is only around 1.67 tons/ha or around 3.35 tons/ha/year. The estimated production amount is still very far from the production potential reported by (Djoefrie et al., 2024), which is 40 tons/ha/year.

The low estimated productivity of sago at the research location can be caused by several factors, such as pest attacks (Rozziansha et al., 2021) and human intervention. The observation location is close to residential areas, some of whom work as sago farmers. This allowed for intensive sago harvesting activities before this research was conducted so the number of sago OHP recorded in the image has decreased significantly. In addition, from the results of visual interpretation of orthomosaic imagery, several sago stands were found to have characteristics of dying (on average, leaflets turned yellow to brown, and young leaflets were brown to white) before reaching the fruiting stage (as shown in Figure 11). However, to conclude the factors that influence the lack of sago OHP stands, further research is still needed.

Furthermore, the results of the analysis of the distribution pattern of Sago OHP stands using the A-NN method showed that the distribution pattern of Sago stands was random with a nearest neighbor ratio value of 0.965005 (Figure 11). The Z-score was 0.354252 and the p-value 0.723150 indicates that this distribution pattern is not statistically significant, either as a clustered or dispersed pattern. This means that sago OHP does not have a specific pattern and tends to grow in a random pattern. This random pattern is commonly found in non-cultivation plant areas that do not receive spacing and planting pattern interventions.

Figure 11. Sago sample showing characteristics of death before the fertilization stage (result of orthomosaic imagery cropping)

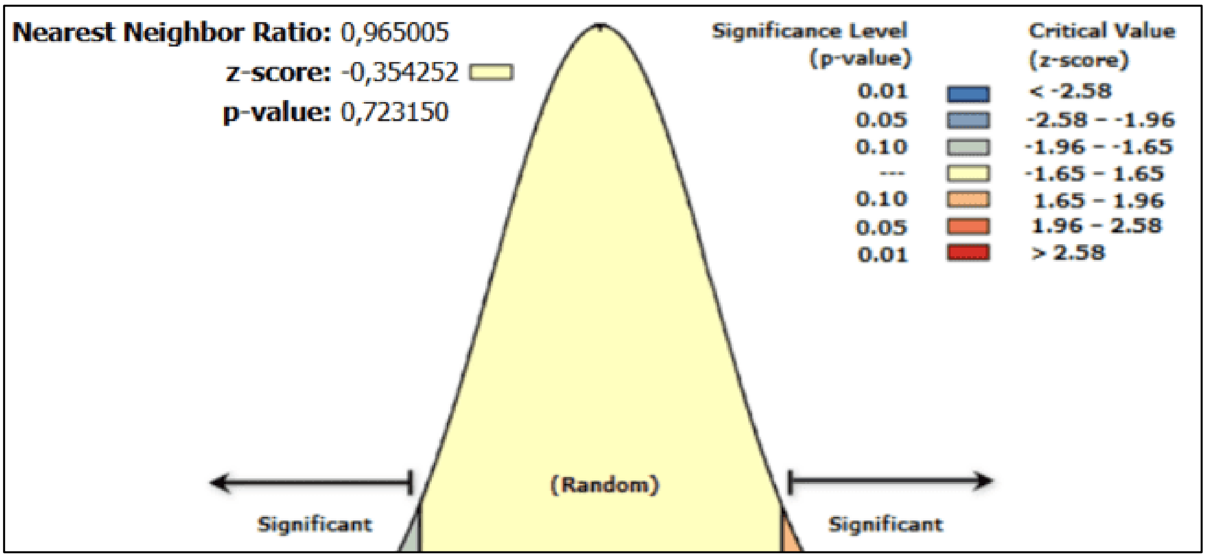

Figure 11. Results of A-NN Analysis of Sago OHP Distribution Patterns

The random pattern of OHP stand development distribution indicates high competition between individuals for resource needs, such as water, soil nutrients, and sunlight (Karim, 2021). This condition is supported by the characteristics of sago's relatively fast reproduction and aggressive growth characteristics (Chua et al., 2022). However, it still allows for the growth of various types of invasive plants (F. S. Jong, 2018). As seen in Figure 10, there are other types of vegetation (shrubs) that grow in the sago area. This condition causes competition not only between individuals but also between species. The high level of competition limits the optimal growth of sago stands and the highest starch production potential that can be achieved, namely 1 ton/tree (Bintoro et al., 2018). In addition, Figure 10 also shows a tendency for human intervention (fishpond, building, and road) which causes the area of sago forest land to decrease. In line with research by (Rampisela et al., 2018), the area of sago land has decreased from year to year due to land conversion activities. This shows that the low productivity of sago in non-cultivated areas (Ishak et al., 2021) can not only be caused by natural factors, but also by factors of sago area management that are not supportive. Therefore, appropriate management policies and strategies need to be pursued in the future to increase the productivity and sustainability of sago production in non-cultivation areas. Considering that optimizing sago production in non-cultivation areas can not only provide a positive contribution to the economy of local communities that depend on sago commodities (Konuma, 2018), but can also increase food security Murod et al., 2019; Swastiwi, Febby Febriyandi, et al., 2023) and the national economy (Wonohardjo et al., 2019; Yusuf et al., 2022).

CONCLUSION

The use of drone technology can support the effectiveness and efficiency of monitoring sago growth in non-cultivation areas. The results of this study prove that the important parameters of morphological and morphometric aspects for the assessment of sago OHP can be identified in orthomosaic imagery and nDSM data through the simplest method (visual interpretation). The average sago OHP sample shows the appearance of the morphology of the tree height which is prominent in one clump with the shape of old leaflets that are elongated and drooping horizontally, the shape of young leaflet is shortened and upright and the shape of the canopy resembles a decagram star to an icosagram that forms a clear two-layer pattern (layer of old and young leaflet) and a wider canopy size in one clump. The morphological characteristics of Sago OHP that appear in the orthomosaic imagery have a high similarity to the development stages of other sago, especially the shape and color of the leaflet at the *ma'baru* stage, so they are prone to misidentification.

From the morphometric aspect, the average OHP sample showed high variation in characteristics. From the results of the correlation test of four morphometric parameters of Sago OHP, the average showed a low correlation. However, each Sago OHP sample showed homogeneous characteristics of the number of young leaflets (3-6 leaflets). Therefore, future research can combine morphological and morphometric parameters to build a more accurate analysis method for identifying Sago OHP.

The distribution of Sago OHP in the observation area shows a random distribution pattern with a very sparse distance between OHP stands, which is only around 7 trees/ha with an estimated productivity of around 3.35 tons/ha/year. This estimated productivity is very low compared to the potential production of cultivated sago which can reach 40 tons/ha/year. The low production estimate may be due to methodological limitations in this study. Therefore, further research is still needed with the use of more accurate methodologies, such as improving data quality (imagery and DEM) and the use of modern analysis techniques (deep learning and artificial intelligence). In addition, it is necessary to pay attention to the selection of observation locations by considering aspects of the intensity of harvesting by the community, so that a comparison of the results of the Sago OHP distribution analysis in the sago forest area is obtained.

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