JOURNAL LA LIFESCI

VOL. 07, ISSUE 02 (166-181), 2026
DOI: 10.37899/journallalifesci.v7i2.3269

The Importance of Sago Forest for Local Food Security and Climate Change Management on Small Island

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Article Info

Article history:
Received 23 April 2026
Received in revised from 8 June 2026
Accepted 23 June 2026

Keywords:
Food Security
Climate Change
Forest Sago
Sago Starch
Sago Biomass

Abstract

Small Island worldwide are highly vulnerable to local food security and climate change. Therefore, appropriate spatial planning is needed to prevent the massive conversion of forest to non-forest areas, including sago, mangrove, and other natural forest on these small Island. This study used a method comprising a variety of activities, including field surveys, drone mapping, and interviews with sago owners and processors. The results showed that Ihamahu Village, on the small island of Saparua (Eastern Indonesia), had a sago forest area of 82.08 hectares with an average potential wet starch production of 450 kg per tree and a dry sago starch yield of 443 tons. This production enables local communities to process sago for household use and sell to the Saparua wholesale market. As sago has traditionally been a local food, the community continues to conserve forest in the region. In other words, sago potential has become a primary source of food security for local communities. With the ongoing conservation, the forest ecosystem is increasingly protected. The biomass content, especially of Mature Felling sago trees, was 30.33 tons per hectare, and this biomass would be even greater with the inclusion of Non-Mature Felling sago trees. This indicates that the sago forest ecosystem is capable of absorbing Greenhouse gas (GHG) emissions, thereby playing a significant role in mitigating climate change.

Introduction

The issue of local food security in small Island is closely related to the survival of communities living under conditions of limited resources and high vulnerability (Putri et al., 2025). Dependence on food from other regions or countries has been shown to create economic and nutritional fragility, while the local potential of small Island is often underutilized (Amato et al., 2025; Levianto et al., 2026; Atzori et al., 2024). These vulnerabilities include high geographic and climatic exposure, economic fragility due to import dependence, dual nutritional and public health crises, preservation of local culture and knowledge, weaknesses in the implementation of small island spatial planning, and endangered biodiversity. Small Island has unique but fragile geographic characteristics, as land resources are often limited, infertile, and highly vulnerable to the impacts of climate change, including sea level rise, tropical cyclones, and prolonged drought. Many island regions rely significantly on food imports. Inflation and globalization can even weaken domestic food availability in the long term, making local food prices uncompetitive or disrupting supplies due to global price fluctuations. In this context, local food security functions as an "*economic buffer*" that protects communities from shocks in global food prices and currency exchange rates. Furthermore, the shift in consumption patterns from traditional local to processed and imported food has triggered a "*double burden of malnutrition*" in archipelagic regions. When communities rely solely on external food supplies, natural disasters that paralyze maritime transportation routes can immediately trigger a food crisis. Local food, when considered, is not only a physical matter, but also a cultural identity. It embodies local wisdom in food cultivation, including agricultural rituals in various archipelagic regions that reflect the harmony between humans, nature, and the Creator (Hartati & Ramdiana, 2026; Amalia & Rosyida, 2026; Yusuf, 2026).

Small Island is disproportionately vulnerable to the impacts of climate change. This is generally due to geographic factors as well as economic, social, and ecological limitations (Damore et al., 2026; Tohit et al., 2026; Zittis et al., 2025). Most small Island are only a few meters above sea level, increasing vulnerability to sea level rise and coastal inundation. Even small rises can lead to land loss, population displacement, and damage to critical infrastructure (Deo et al., 2025). Limited land area also constrains the availability of fertile agricultural land, freshwater resources, and biodiversity. Saltwater intrusion from sea level rise and storm surges rapidly contaminates scarce freshwater reserves, threatening food security and clean water (UNDP., 2026). The countries most affected by climate change are Small Island Developing States (SIDS), located in the Caribbean, Pacific, Atlantic, Indian Ocean, and South China Sea (AIS).

From a spatial planning perspective, small island management requires careful and thorough consideration of geographical conditions and intrinsic value. Coastal areas often contain mangrove forest, while sago and tropical forest is found in the middle of small Island. These ecosystems are not arbitrarily designed for land conversion into residential areas and other infrastructure development. Mangrove plays a crucial role in coastal protection from the onslaught of waves that can reduce sea abrasion and protect endemic animals (Santoso et al., 2025; Mugilan et al., 2024; Harefa et al., 2025; Mugilan et al., 2024). Meanwhile, sago forest contribute to local food, water conservation, and play a major role in controlling climate change. Numerous studies have examined sago forest from various aspects, including the distribution of sago forest in Indonesia (Dasnarebo Santoso B. Abbas B., 2022; Ismayuni & Sasmita, 2025; Saputra, 2022), comparative morphology and ecological distribution of molat sago species (Sarie, 2023), different factors that influence sago production (Tamtama et al, 2024), and sago commodity economic development strategy (Syarbiah, 2022; Tana, 2023). Other studies have also examined sago as a food security and local economic source (Tegor., 2025), sago plantations based on local wisdom in managing and realizing sustainable sago farming (Dahliani, 2024), community preference level for managing sago (Odorlina, 2018), and use of sago waste for renewable energy (Huwae, 2025; Numberi, 2022; Rahmadani, 2019).

Studies on sago forest from the aspect of food security and biomass content that plays a role in handling climate change, especially on small Island, remain relatively limited (Mardiatmoko et al., 2025; Armanto et al., 2025). This study aims to determine the importance of sago forest for local food security and handling climate change on small Island. Identifying the most appropriate adaptation strategy is important for the sustainability of natural resources and the inhabitants of small Island. Efforts are also needed to preserve various types of mangrove, sago, and other mixed forest because the existence is very vulnerable. This attempt is important to optimally use local food sources found on small Island including sago, tubers (*cassava, taro*), vegetables (*moringa, cabbage*), fruits (*mangosteen, durian, langsat, rambutan*), and fresh fish with a more balanced and healthier nutritional profile. The loss of local food security would not only threaten livelihood but also lead to erosion of cultural practices, the disappearance of agronomic knowledge, and weaken social ties built through the food-sharing system commonly found in island communities.

Methods

Materials

This study was conducted in Ihamahu Village, Saparua Island, Central Maluku Regency, Eastern Indonesia, as shown in Figure 1. The study location was selected because it has sago forest resources that are important for local food security and climate change mitigation on a small island.

Source: https://id.wikipedia.org/wiki/Berkas:Ambon_and_Lease_Islands_(Uliasers)_en.png

Figure 1. Study Site

The field study started with a survey of the sago forest area to determine the extent of sago forest in Ihamahu Village. Drone footage was then taken at an altitude of approximately 100-150 m above the sago canopy. The drone footage showed the extent of the sago forest, the distribution of trees, the composition of species, and the extent of degradation. Based on the drone footage, several field checks were conducted using the geographic coordinates provided by the drone and GPS to ensure accurate location determination. This was followed by soil profiling of the sago forest to determine the type of habitat where the trees grew. Interviews were conducted with the community members who cut the sago to obtain information on the starch produced from the felled trees, including the yield.

The tools used include the DJI Phantom 4 Pro V2.0, GPS, Abney level, hoe, shovel, tape measure, soil drill, plastic bags, Munsell, pH paper, label paper, and stationery. Meanwhile, the materials used include hydrochloric acid (HCl 10%) and hydrogen peroxide (H_2O_2 10%). HCl was used to test for the presence of lime and estimate the relative content from the intensity of the foam by applying a few drops to the surface of the observed soil. H_2O_2 was used to qualitatively estimate the organic matter content in the soil. The field work map used as an initial guide is the Saparua Island Land Unit map, Scale: 1:50,000.

Study design

Land Area Measurement

The calculation and measurement of sago land area were conducted using drones and corrected with field data. To obtain data and information on land characteristics, a survey method was used with a synthetic approach and two observation types, namely boring and minipit. In addition, observations of sago plant distribution were also conducted by tracking changes in hydrological conditions. The characteristics observed include sago species, potential Mature Felling trees (MT) per hectare, and potential wet starch production per tree (kg).

General soil observations included external and internal characteristics, as well as hydrological observations, namely inundation conditions and groundwater depth. External character observations included coordinates, elevation above sea level, terrain shape, slope, drainage, parent material, land use, and land cover. Internal character observations included soil morphology, namely color, texture, structure, consistency, pores, roots, pH, organic matter, and layer boundaries. Additionally, observations were made of existing vegetation growing alongside the sago plants. To determine the number of trees ready for felling (MT) per hectare, calculations were carried out in observation blocks measuring 50 x 50 m. Meanwhile, to determine the production of wet starch per tree (kg), interviews were conducted with sago processing farmers.

Sago Forest Mapping with Drones

Sago forest mapping was conducted with a DJI drone, type: Phantom 4 Pro V2.0. The mapping activities include planning, implementation, and data processing as follows:

Planning (Pre-Field)

The mapping objectives were to determine the extent of sago forest in Ihamahu Village and Tuhaha, estimate sago forest density, forest conversion, and estimate the potential for sago within the "*Cooked Cutting*" (MT) or "Not Yet Cut" (BMT) phases. Secondary data, including administrative maps, were collected, and Satellite imagery (Google Earth) was analyzed to understand topography, area size, and surrounding conditions. Hardware Selection includes a Drone application with waypoint navigation features and Sensor Determination (RGB (*Visible*) or Multispectral / Near-Infrared (NIR) Camera). Supporting Equipment includes spare batteries, a generator/solar panels for charging, a laptop, handheld GPS for GCP surveys. Flight missions were planned based on Area of Interest (AoI) with parameters such as Ground Sampling Distance (GSD), Resolution, Side Overlap (70-80%), Front Overlap (75-85%), and flight altitude carefully determined.

Sago Forest Data Acquisition in The Field

Sago forest data were collected in the field by determining survey ground control points, selecting flight time and conditions, determining flight procedures, including pre-flight check, take-off, and mission plan determination. In this case, the drone would fly automatically according to the waypoint. Flight progress was continuously monitored, and battery replacement was carried out efficiently to ensure uninterrupted data collection. Upon completion, the drone was safely landed, and initial quality control of the acquired data was conducted on-site.

Post-Data Acquisition in The Field

All photos were transferred from the drone to a computer and organized in separate folders for each mission flight. Photogrammetry Processing was conducted with Agisoft Metashape Professional Software. The resulting outputs were analyzed and interpreted to generate maps of sago forest extent, areas of forest conversion, and other relevant spatial information, which were subsequently compiled into a formal report.

Field Survey Implementation

The field survey implementation includes planning, implementation, and reporting, as follows:

Field survey planning

Based on the results of drone mapping, a survey route plan was then created. Materials and equipment for the field survey were prepared, such as GPS, machetes, paint, compasses, soil drills, phibands, and measuring ropes.

Field Implementation

Field work involved following the predefined survey routes, creating 50 x 50 m measurement plots, and calculating sago density, the number of Mature Felling (MF) and non-Mature Felling (non-MF) sago trees, recording the position of each measurement plot using GPS, recording all activities carried out in the measurement plot, determining the soil type in the surveyed sago forest, as well as taking soil samples for physical and chemical analysis. Direct interviews with sago landowners who harvest the sago trees and process the sago into dried starch.

Reporting

All ground survey results in the field were synchronized with drone map outcomes to determine the potential for mature sago (MF) and non-MF. The final activity was to estimate the potential for dry sago starch and the biomass using the formula:

PDS = (SLA x MF x SPT): 2 ……………………………………………………………… (1)

Where:

PDS = Potential Dry Starch

SLA = Sago Land Area

MF = Mature Felling or Ready to Harvest

SPT = Starch Production per Tree

MFSB = TMF x AMFB (1,263.91) ………………..…………………………………….(2)

Where:

MFSB = Mature Felling Sago Biomass per Ha

TMF = Total Mature Felling

AMFB = Average Mature Felling Biomass per tree

The AMFB was obtained from similar studies conducted in Tulehu Village, where sago production is similar to that in Ihamahu Village, located on a different island but within the same regency. The method used was destructive sampling (Mardiatmoko, 2025).

Data Analysis

The collected data were analyzed descriptively. Spatial data from drone mapping and land cover interpretation were used to determine sago forest area and land cover change from 2015 to 2025. Field observation data were used to describe geomorphology, physiography, topography, soil characteristics, hydrology, vegetation association, sago types, and Mature Felling tree density. Interview data were used to estimate starch production per tree. The results were then presented in descriptive form, tables, and maps to show the relationship between sago forest potential, local food security, and climate change mitigation.

Results and Discussion

Geomorphology, Physiography, and Topography

Geomorphologically, the study area is classified as an alluvial landform unit, generally found on the left and right sides of rivers with slopes ranging from 0 to 3%. These alluvial plains are periodically inundated by nearby river overflows or surface runoff. The geomorphological processes that occur are generally transportation and deposition of material from the upper layers.

The physiography of the study area consists of plains and hills with slopes of 0 to 3%, ranging from slightly concave to flat. Sago palms are mostly found growing and developing in the plains. In hilly areas, sago palms are found sporadically at the foot of slopes or along natural drainage channels.

Table 1. Geomorphological, Physiographic, and Topographic Characteristics of the Study Area

Aspect	**Result**
Geomorphological unit	Alluvial landform unit
Location of alluvial plains	Left and right sides of rivers
Slope	0–3%
Landform condition	Slightly concave to flat
Main geomorphological process	Transportation and deposition of material from upper layers
Main sago distribution	Plains with slopes of 0–3%
Sago distribution in hilly areas	Sporadically found at the foot of slopes or along natural drainage channels

The results indicate that the study area has physical land characteristics that are suitable for sago growth, especially in flat alluvial plains with low slopes. The presence of sago palms in hilly areas is more limited and generally associated with natural drainage channels.

Climate

Ihamahu Village is part of Central Maluku Regency, which is classified as a humid-perhumid tropical climate region. The main climatic characteristic of this region is rainfall, followed by temperature variability, which is largely determined by altitude above sea level. Most areas of Ihamahu Village receive high rainfall, with an average of more than 2,200 mm/year.

Rainfall data analysis shows that conditions in Central Maluku Regency vary from slightly wet to very wet. Based on the climate classification, Central Maluku Regency has three agroclimatic zones, namely B1, C1, and D1. The study location is included in zone D1.

Table 2. Climate Characteristics of Central Maluku Regency and the Study Area

Climate Aspect	Result
General climate type	Humid-perhumid tropical climate
Average rainfall in most areas of Ihamahu Village	> 2,200 mm/year
Slightly wet areas	2,000–2,500 mm/year; Wahai and Kobisonta areas
Wet areas	2,500–3,000 mm/year; Amahai, Awaiya, Waipia, Banda Naira, and Hila areas

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Very wet areas	> 3,000 mm/year; Tehoru and Saparua areas
Agroclimatic zones in Central Maluku Regency	B1, C1, and D1
Agroclimatic zone of the study location	D1

The climatic condition of Ihamahu Village supports the development of sago palms because the area receives relatively high rainfall. This condition is important for maintaining soil moisture and hydrological balance in the sago forest ecosystem.

Parent Material and Soil

According to the 1:250,000 scale Masohi Geological Map (Maluku), the parent material on Saparua Island consists of limestone, volcanic andesite, coral sand deposits, volcanic andesite interpolated with limestone, crystalline limestone, acidic andesite intercolated with limestone, andesite beach sand, andesite sand deposits, coastal sedimentary areas, and alluvial material (*silt, sand, gravel, and mud*). The Ihamahu Village region is dominated by alluvial parent material in the form of sand, silt, and gravel deposits. Based on the soil classification units identified in the field, two types of soil were identified, namely alluvial (*Udifluvents*) and gleisol (*Indoaquepts*). Alluvial soils have a layered texture from the top layer to the bottom, which indicates alternating deposition in the area. The Gleisol soil type found in the study area showed hydromorphic characteristics in the first layer, at a depth of 0-50 cm. This phenomenon occurs due to alternating wet (*waterlogged*) and dry conditions, resulting in oxidation and reduction processes.

Hydrology

In the Ihamahu region, there is one river, namely the Tawelasunyo River, whose flow pattern is dendritic and trellis. This river has water year-round, although the discharge decreases slightly during the dry season and increases during the rainy season, potentially causing flooding and inundation. Based on field observations and identification, the hydrological conditions at the study site were found to be relatively good, with inundation lasting less than three months during the rainy season and depths of less than 50 cm.

Vegetation Association

The vegetation association referred to in this case refers to other types of vegetation found growing alongside sago palms. Some of the vegetation associated with sago plants (*Metroxylon* sp) include mangosteen (*Garcinia mangostana* L.), bamboo (*Bambuso ideae*), tongkat langut (*Aralia spinosa*), lenggua (*Pterocarpus falcatus*), galoba (*Hornstedtia allieacea*), samama (*Anthocephalus macrophyllus*), new wood (*Osbornia actodonta*), and marsegu wood (*Nauclea orientalis* L). Others include titi tree (*Gmelina moluccana*), forest nutmeg (*Myristica fragrans* Houtt), mat pandan leaves (*Pandanus tectorius*), ganemo (*Gnetum gnemon* L), ferns (*Polypodiophyta)*, macaques (*Mangifera foetida* Lour), biroro (*Crossandra infundibuliformis*), gomu (*Artocarpus communis*), sirih hutan (*Piper decumanum*), Mayang (*Arenga pinnata*), ferns (*Pityrograma colomelanus*), and kora-kora (*Curea ligolatifolia*).

Sago Potential

Sago Types

Based on the presence of spines, sago is divided into two main types, namely thorny and spineless. These two main types are further divided into five types, including thorny (*M. rumphy* Martius), Ihur (*M. sylvestre* Martius), Makanaru (*M. longispinum* Martius), Rotanthorned (*M. microcanthum* Martius), and the spineless type, Molat sago (*M. sagus* Rottball). In addition to these five types of sago, new varieties may also be discovered due to cross-pollination. Observations and identification of sago species in Ihamahu Village showed four types, namely tuni (*M. rumphy* Martius), ihur (*M. sylvestre* Martius), molat (*M. sagus* Rottball), and rattan thorn (*M. microcanthum* Martius). The tuni sago is the most abundant variety, while the other three species are found in small amounts, sporadically intermixed with the tuni sago.

Sago Land Area

Image interpretation results indicate a slight decrease in sago cover during the 2015-2025 period. The analysis showed that the sago area in 2015 was 82.50 ha. By 2025, this area had reduced to 82.08 ha, representing a decrease of 0.42 ha, or approximately 0.51 percent per year.

Mature Felling Trees (MF)

Mature Felling trees are sago palms that have reached maturity, with optimum starch content in the trunks, and are ready for felling or harvesting. MF for sago palms consists of Mature Felling maputi, heart, antler, and betel fruit stages. Sago palms harvested either before or after the harvesting period have low starch content. Therefore, to obtain optimal starch content, it is best to harvest sago palms during the harvesting period.

The number of MF trees per hectare depends significantly on land conditions and farmer activities. In sago forest, the number of MF trees is lower than in cultivated conditions. Flooding conditions also influence the number of MF trees. Land with permanent flooding conditions has fewer MF trees than land that is never flooded or periodically flooded.

Table 3. Mature Felling Trees in Ihamahu Village

Indicator	**Result**
Number of MF trees based on field condition	20–22 trees/ha
Estimated MF trees when additional stages are considered	24–28 trees/ha
Average MF trees used in calculation	24 trees/ha

The number of MF trees in Ihamahu Village ranges from 20 to 22 per hectare, which is considered quite good. When additional stages such as wela and maputi are considered, the number of MF trees can be assumed to range between 24 and 28 trees/ha. Therefore, the average Mature Felling trees in Ihamahu Village is 24 trees/ha.

Starch Production per Tree (kg)

The starch content of sago palm stems is influenced not only by environmental conditions, but also by stem diameter or circumference and the height of the leaf-free stem. Sago palm starch content in dry land or never-flooded areas is higher than in flooded land, which typically contains more water at the base of the stem. In Ihamahu Village, the range of sago palm stem circumference is 150–180 cm, with a leaf-free stem height of 10–16 m and an average of 13 m.

Interviews with several farmers showed that processing five sago palm trees yields 72 plastic sacks, with an average production of 14.4 sacks per tree, rounded up to 15 sacks. Assuming one plastic sack weighs 25 kg, one sago palm produces 375 kg of wet starch per tree. Other interview results also showed that sago trees with a trunk circumference of 180 cm and a leaf-free trunk height of 10 m produce 15 sacks of starch, equivalent to 375 kg/tree. Meanwhile, sago trees with a trunk circumference of 180 cm and a leaf-free trunk height of 15 m produce an estimated 21 sacks, equivalent to 525 kg/tree. The summary of starch production per tree is presented in Table 4.

Table 4. Starch Production per Sago Palm Tree in Ihamahu Village

Indicator	Value
Stem circumference	150–180 cm
Leaf-free stem height	10–16 m
Average leaf-free stem height	13 m
Production from five sago palm trees	72 plastic sacks
Average production per tree	14.4 sacks, rounded to 15 sacks
Weight per plastic sack	25 kg
Wet starch production from trees with 180 cm circumference and 10 m leaf-free trunk height	375 kg/tree
Wet starch production from trees with 180 cm circumference and 15 m leaf-free trunk height	525 kg/tree
Average wet starch production	450 kg/tree

Table 4 shows that wet starch production per sago palm tree in Ihamahu Village ranges from 375 kg/tree to 525 kg/tree, with an average of 450 kg/tree. This finding indicates that stem circumference and leaf-free stem height are important factors influencing starch yield. The average production of 450 kg/tree was then used as the basis for calculating the potential dry starch production of the sago forest in Ihamahu Village.

Potential for Dry Starch and Sago Biomass

The potential for dry starch and sago biomass in Ihamahu Village was calculated based on the sago land area, the average number of Mature Felling trees, average wet starch production per tree, and average Mature Felling sago biomass per tree. The potential dry starch was calculated using the formula $PDS = SLA \times MF \times SPT \div 2$. Based on this formula, the potential dry starch was calculated as follows: $82.08 \times 24 \times 450$ kg $\div 2 = 443.232$ kg or 443 tons. Meanwhile, the sago biomass potential per hectare was calculated as follows: $24 \times 1{,}263.91$ kg $= 30{,}333.84$ kg or 30.33 tons/ha. The results are presented in Table 5.

Table 5. Potential Dry Starch and Sago Biomass in Ihamahu Village

Indicator	Value
Sago land area	82.08 ha
Average Mature Felling trees	24 trees/ha
Average wet starch production	450 kg/tree
Potential dry starch	443.232 kg or 443 tons
Average Mature Felling sago biomass per tree	1,263.91 kg
Sago biomass potential per hectare	30,333.84 kg or 30.33 tons/ha

Table 5 shows that the sago forest in Ihamahu Village has a potential dry starch production of 443 tons. This value indicates that sago has an important role as a local food resource that can support household consumption and provide surplus production for local markets. In addition, the biomass potential of Mature Felling sago trees reaches 30.33 tons/ha. This finding shows that sago forest also has ecological value, particularly in supporting climate change mitigation through biomass storage and the potential absorption of greenhouse gas emissions.

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

oil Hydrology in Sago Forest

Rainfall in Ihamahu Village on Saparua Island and surrounding areas, which are part of Central Maluku Regency, varies from slightly wet areas with rainfall of 2,000–2,500 mm/year, wet areas with rainfall of 2,500–3,000 mm/year, to very wet areas with rainfall of more than 3,000 mm/year. Laimeheriwa (2014) stated that climatologically, there are two rainfall patterns in the region, namely local and monsoon patterns. The local rainfall pattern is unimodal, but it is opposite to the monsoon pattern generally found in Indonesia. In this pattern, the rainy season generally occurs from October to March. Meanwhile, the monsoon rainfall pattern is also unimodal, with the rainy season lasting for six months from November to April and the dry season occurring from May to October.

In the Ihamahu region, there is a river called the Tawelasunyo River, which has a dendritic and trellis-like flow pattern. Soil hydrology is an important factor because it strongly determines the conditions for sago growth and production. According to Louhanapessy (1994), sago growth is closely related to water availability, inundation duration, and water depth. The hydrological classification for sago growth conditions is presented in Table 6.

Table 6. Hydrological Classification for Sago Growth Conditions

Hydrological Condition	**Inundation Period**	**Rainy Season Water Depth**	**Dry Season Water Depth**
Good hydrology	< 3 months	≤ 50 cm	> 100 cm
Fairly good hydrology	3–6 months	≤ 50 cm	> 100 cm
Moderate hydrology	6–9 months	≤ 50 cm	50–100 cm
Fairly poor hydrology	> 9 months	> 50 cm	0–50 cm
Poor hydrology	12 months	> 80 cm	> 10 cm

Table 6 shows that sago can grow under various hydrological conditions, ranging from good to poor hydrology. However, optimal conditions are generally associated with shorter inundation periods and controlled water depth during the rainy season. In addition to hydrology, other factors affecting sago growth include competition from rapidly growing grasses and herbs, as well as interference from forest trees under dry land conditions.

Changes in Sago Forest Area from 2015 to 2025 in Ihamahu Village

Over time, forest area typically shrinks in various regions due to the conversion for office infrastructure expansion, residential development, and agricultural plantations. Sago forest has also experienced a similar trend. Among the total changes in Ihamahu Village, 1.52 hectares of sago forest have been converted to mixed plantations. Some sago land has been converted to mixed plantations, while others have been retained. The condition of sago cover shows variation, with some areas appearing dense, indicating a high density of sago plants and similar species. Meanwhile, other areas are mixed with other vegetation such as coconut, clove, and nutmeg. This mixture is caused by both natural and human activities. Information on changes in sago land cover between 2015 and 2025 in Ihamahu Village is presented in Table 7.

Table 7. Distribution of Sago Land Cover Changes in Ihamahu Village, 2015-2025

No.	**Land Cover**	**Area - Year**				**Change in Area Size**		**Remarks**
		2015		**2025**				
		Ha	**%**	**Ha**	**%**	**Ha**	**%**	

1.	Natural forest	388.6	32.6	202.9	17.0	-185.7	49.9	There is a decrease
2.	Mixed Garden	704.1	59.1	890.0	74.7	185.9	49.9	There is an increase
3.	Mangrove Forest	7.2	0.6	7.2	0.6	0	0	There is a constant
4.	Settlement	8.4	0.7	8.7	0.7	0.3	0.1	There is an increase.
5.	Sago Forest	82.5	6.9	82.1	6.9	- 0.4	0.1	There is a decrease

Source: Primary Data (2025)

Table 7 shows the dynamics of the sago ecosystem, where some areas remain stable, while others interact with other plants. On the other hand, there has been a very small change in land cover, with settlements occurring at 0.3 ha. This figure is relatively small because settlements in Ihamahu Village have not grown significantly over the past 10 years, with only additions from residents producing crops and constructing goti houses (sago starch production facilities). Meanwhile, there has also been a very small decrease in sago forest area, at 0.4 ha (0.1%) over the past 10 years. These results indicate that local people remain safe in consuming sago as a local food in Ihamahu Village, particularly on Saparua Island. This allows the local community to absorb sago starch, and excess production is sold to neighboring villages or to the main market in Saparua. Mangrove forest tend to remain unchanged, demonstrating the local community strong concern in protecting against coastal erosion and mitigating climate change. Natural forest areas have shrunk and been converted into mixed plantations, increasing from 704.1 hectares in 2015 to 890.0 hectares in 2025, representing a rise of 185.9 hectares.

The dynamics of land use change are presumably influenced by community activities and land use to support economic activities. Spatially, this indicates that sago remains relatively stable and maintained within the Ihamahu Village landscape despite community activities and local economic needs. Delineation results indicate that communities have not completely abandoned sago, despite pressure to convert to mixed plantations. Some sago lands have been converted to mixed plantations to support crop diversification and meet economic needs. This stability also indicates the inherent importance of sago in the village (Figure 2).

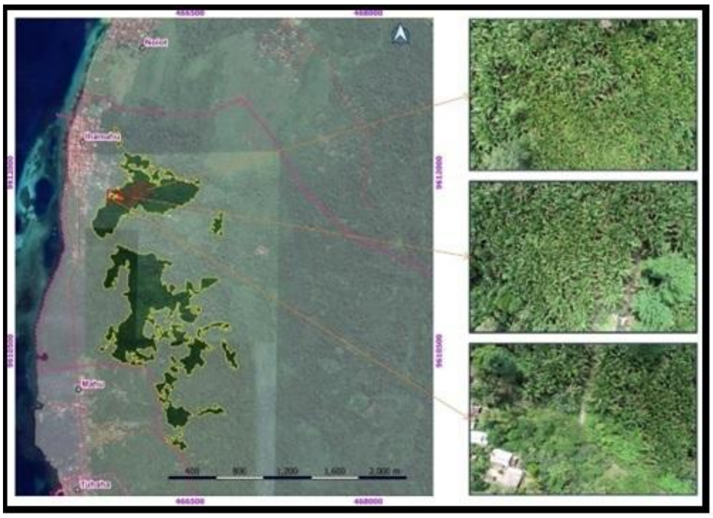

Figure 2. Map of Sago Land Distribution in Ihamahu

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

The results showed that not all residents of Ihamahu Village use sago directly. Only a few process it usually in a goti house, which serves as the center of traditional sago-related activities. The goti house is part of local tradition and identity. In sago processing practices, the community pays attention to the cleanliness of the water in the area, as it plays a crucial role in sago trunk extraction. After sago processing is complete, the remaining pulp is not discarded carelessly but is instead piled and allowed to rot. This pulp then serves as natural compost, allowing the sago to maintain land cover. Furthermore, some residents have built access roads to the sago forest area. The roads are constructed without damaging the cover or the surrounding ecosystem, thereby preserving the sago. The processing practices in the goti house demonstrate that sago still has a social and cultural function maintained by the community. Changes in sago forest land in Ihamahu Village are presented in Figure 3.

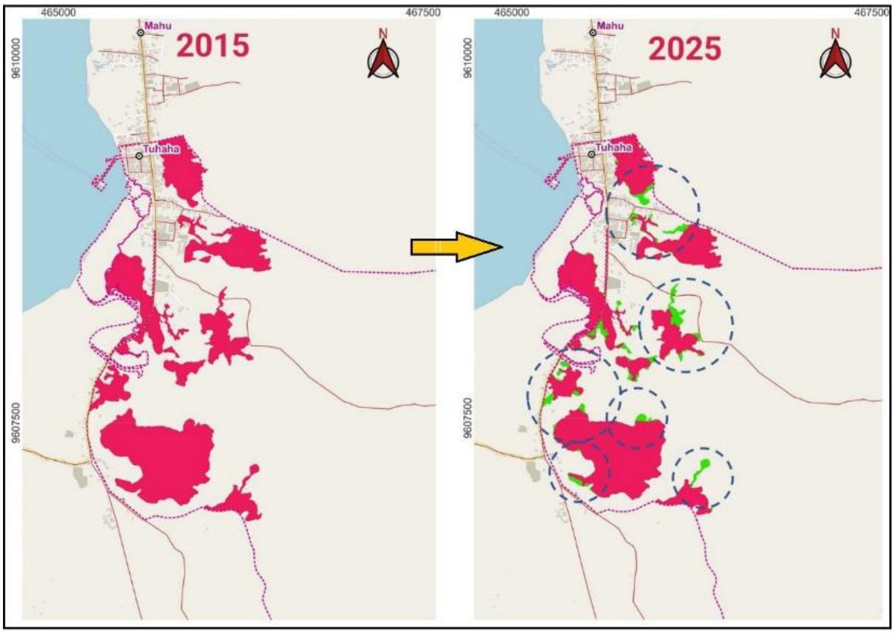

Fig.3. Map of Sago Forest Land Changes in Ihamahu Village 2015-2025

Dry Starch Potential and Sago Biomass

Dry starch potential and biomass vary significantly across regions, particularly in Indonesia, due to the type of sago variety, harvest age, and growing location, including soil conditions and waterlogging (Irawan et al., 2024; Irawan et al., 2024; Moeljono et al., 2025). The most prominent difference is the weight of the sago trunk or pith. The larger the diameter of the sago, the heavier the trunk and the larger the pith. The dry starch potential of sago per tree in Ihamahu Village was estimated at 450 kg. According to Yamamoto et al. (2010), the average starch yield in Sulawesi (Central Indonesia) for the Molat sago variety is 425 kg, Tuni 305 kg, and rattan 142 kg. This difference is due to the variation in sago types and trunk (pith) weight. Starch yield is strongly correlated with trunk diameter (r=0.908) and trunk height (r=0.905), which determine the total amount of pith available for extraction. Regional comparisons further illustrate this variability, for example, in Riau (Western Indonesia), especially in peatland areas, one tree typically produces 150–250 kg of dry starch. In Sulawesi (Central Indonesia), some cultivars, such as Sigenti, produce up to 429 kg, but the average in some areas is around 245.9 kg. Meanwhile, in Papua – Sentani (Eastern Indonesia), production ranges from 54 kg to 313 kg, averaging around 194.9 kg of wet starch.

Sago biomass plays a significant role in controlling climate change because the forest are capable of absorbing large amounts of Greenhouse gas (GHG) emissions (Sudomo et al., 2023; Nugroho et al., 2022; Mardiatmoko et al., 2025) In Ihamahu Village, Saparua small island (Eastern Indonesia), the sago biomass is estimated at 30.33 tons per hectare. Sago biomass smaller than 30.33 tons per hectare is difficult to find in other sago forest areas. This is because the figure of 30.33 tons per hectare is considered low for sago biomass productivity, and biomass is rarely the primary focus of scientific publications, which tend to report maximum potential or average yields. These biomass values are typically used for specific conditions, such as marginal land, immature plants (<3-4 years old), or wild varieties with low productivity, or flooded and highly saline soils. Furthermore, sago biomass and productivity are influenced by at least five main factors, including sea level (Irawan & Kusmiyati, 2024), soil and microbial conditions (Pendi, 2025), forest structure and habitat (Fetriyuna & Purwestri, 2025), genetic factors and sago varieties (Abbas, 2021), and plant physiology (Pendi, 2025). These main factors are interrelated, ranging from environmental conditions to the genetic factors of the plant. Groundwater level is one of the most critical determinants, especially for sago growth on peatlands. At the optimal level, the groundwater level at a depth of 6.8 cm from the soil surface provides the best stem diameter and biomass, while at the critical level, when the groundwater level is deeper than 28.5 cm, there is a significant decrease in stem biomass. This indicates that sago requires consistently wet, but not flooded, conditions for optimal stem growth after stem formation.

Soil conditions and microbial communities indicate that well-trunked sago palms actually benefit from slightly lower nutrient concentrations in the soil. This minimizes ionic antagonism in the roots, resulting in more efficient nutrient uptake. Conversely, ionic imbalance in the soil around non-trunked trees impairs photosynthetic efficiency. Soil microbes show that the presence of certain microbial communities, such as Desulfobacterota and Nitrospirota (*especially Thermodesulfovibrio*), is positively correlated with large-trunked sago palms. These microbes play a role in improving nitrogen and sulfur cycling while also reducing heavy metal stress, ultimately supporting biomass growth. Forest structure, habitat, and environment indicate that the potential biomass and dry starch production of sago (490.3–571.8 kg/tree) vary greatly due to differences in forest structure and composition, as well as habitat and environment. Plant physiology and genetic expression indicate that sago palms have the ability to form large trunks, hence, large trunks will determine the amount of biomass.

Conclusion

This study shows that the sago forest in Ihamahu Village, Saparua Island, plays an important role in supporting local food security and climate change mitigation on a small island. The sago forest area was estimated at 82.08 hectares, with an average wet starch production potential of 450 kg per tree. Based on the calculation of sago land area, Mature Felling trees, and starch production per tree, the potential dry starch production reached 443 tons. This production capacity indicates that sago remains an important local food resource for household consumption and provides surplus production that can be sold to the main market in Saparua.

The findings also indicate that sago forest conservation is closely related to local community practices and traditional food systems. Because sago has long been part of local food culture, the community continues to maintain the forest ecosystem to support family needs and local livelihoods. In addition to its contribution to food security, the sago forest also has ecological value. The biomass potential of Mature Felling sago trees reached 30.33 tons per hectare, and this value would be higher if Non-Mature Felling sago trees were included. These results suggest that sago forest contributes to biomass storage and has potential in supporting

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

greenhouse gas mitigation. Therefore, protecting sago forests on small islands is important not only for sustaining local food systems but also for maintaining ecosystem stability and strengthening climate change adaptation and mitigation efforts.

Acknowledgments

The authors are grateful to the Director of the Walang Perempuan Foundation and the local community of Ihamahu Village for funding the study activities and assisting in the smooth running of Saparua small Island.

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