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Pine resin tapping
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Full Length Research Article

Effect of Landform on the Distribution of *Metroxylon sagu* Habitat in Yapen Islands, Papua Province, Indonesia

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ABSTRACT

Sago palm (*Metroxylon sagu*) plays a vital role in the Papuan indigenous community's social, economic, and cultural life. It is a source of staple food, household income, and embedded cultural values. This research aimed to determine the extent of sago palm habitat spread using spatial data. The classification method and multispectral imaging were used by employing satellite imagery (Landsat 8 and Quick Bird) and field surveys. The sago forest coverage in Yapen islands was 87.73%, located between 9–50 masl, covering 9,456.26 ha. The results revealed that 43.53% of the habitat lies in the inclination of 2–8% (extreme gentle slope), covering 4,692.45 ha. Sago forest was found in a gleysol soil type with precipitation of 3,000-3,100 mm. The sago forest distances of 0–250 m and 251–500 m to the coastline showed that the habitat covers an area of 153.87 ha and 368.19 ha. The preferable area in this category is Raimbawi Subdistrict, followed by Kosiwo Subdistrict, and the less suitable area, or the marginal land, is in Windesi Subdistrict.

1. Introduction

Sago starch is a common carbohydrate source consumed by many indigenous people in Moluccas and Papua. It was reported that a sago palm could produce 150–300 kg (Hasibuan et al. 2018; Konuma 2018; Yamamoto et al. 2020a) and 116.69–372.89 kg of dry starch (Dewi et al. 2016). In terms of productivity, this plant is three to four times more efficient as a food source than rice, corn, and wheat. Compared to cassava, sago productivity is 17 times higher than this tuberous plant (Alcázar-Alay and Meireles 2015; Hussain et al. 2019). Hence, sago can be classified as one of the highest starch-producing plants in the world. So, this high carbohydrate content potential in sago palm can be seen as an alternative to the world's carbohydrate crisis (Haryanto et al. 2020). Currently, sago starch has been used extensively in various food applications and for non-food purposes. In addition, the sago palm has enormous variations based on its morphology and genetics (Yamamoto et al. 2020b; Abbas et al. 2020). So, this sago palm potential can be viewed as one of the assets for local food security. Therefore, the potential can be viewed as one of the assets for local food security. Sago's palm has a significant role in social, economic, and cultural systems in customary Papuan communities, especially for indigenous people living in the areas of the lowland, river, coast, and island (Sidiq et al. 2021). However, there have been changes in sago forest areas due to habitat fragmentation and the over-exploitation of natural resources. The threatened sago palm diversity is due to the failure to protect ecosystem integrity, exploitation, and climate change influence.

In general, sago palm habitat characteristics are found in swampy freshwater, peat, and watershed areas. It can grow in an area with poor water drainage systems ranging from 0–450 m.a.s.l. with rain precipitation of 750–2,500 mm (Azhar et al. 2020; Dimara et al. 2021). The morphological appearance of each sago variety is influenced by its genetic and environmental factors (Dewi et al. 2016; Yater et al. 2019). The difference in environmental conditions in the coastal area has contributed to the growth and productivity of this palm. The Sago forest in Yapen islands is the plant community connecting the coastal ecosystem to the lowland forest ecosystem. Sago forest is vital in maintaining freshwater balance in the coastal area (Ehara 2018). The difference in environmental conditions along the coastal area has contributed to the growth and productivity of sago palms. Environmental pressure can lead to different growth phenomena (Hussain et al. 2019). Assessing the ecological character of the habitat is essential in determining the consistent differential patterns and providing an alternative to recognize sago palm suitability. The use of spatial and empirical data is important; to characterize species ecology requirements, understand the distribution and its biogeography and obstacles, and identify sago palm habitat change (Dimara et al. 2021). The spatial distribution is the quantitative relation to a series of environmental factors. It can be used to understand the sago palm preference and contributing environmental factors to the growth.

Geographic information systems (GIS) and remote sensing (RS) are technologies used to analyze spatial and non-spatial issues and provide the latest maps relating to large areas (Sulistyo 2017; Birhane et al. 2019; Sidiq 2021). The information on forest area coverage, climate parameters, soil, and hydrology can be used to create an environmental spatial model of the sago palm growing habitat. This spatial data can monitor eco-environmental parameters like rain precipitation, soil types, geomorphology, land use and coverage, elevation, inclination, vegetation condition, and growth (Lei et al. 2021; Adhyaksa et al. 2017). Habitat suitability through biophysical characteristics and environmental elements is essential to managing sustainability. This spatial model is one of the schemes to map and predict sago palms based on influencing-environment variables (Avtar et al. 2013).

Sago is one of the local food sources used by the people of the Yapen Islands. The fulfillment of local food is expected to meet regional food needs, especially for people in rural areas. Currently, most of the sago starch is harvested from plants in natural forests. However, the characteristics of the land in this area provide a type of sago habitat that is only distributed in a few places. In addition, sago plants in natural forests are currently not being managed intensively. Therefore, it requires good planning and management. For intensive sago management planning, it is necessary to identify the distribution of sago habitat in the Yapen Islands area. Therefore, this research aimed to identify the area where sago palm grows. It also provides relevant information on identifying the different habitats using spatial data.

2. Materials and Methods

2.1. Study Area

The research was conducted between January–October 2021 in sago forests located in Yapen Islands Regency, Papua Province, Indonesia. These forests are found in 11 subdistricts, namely

Angkaisera, Kosiwo, Poom, Raimbawi, Ampimoi Bay, Windesi, Wonawa, West Yapen, South Yapen, East Yapen, and North Yapen, Papua Province, Indonesia. Yapen Islands are located between 1°26’42.73”–2°0’14.05“S and 135°4’37.28”–137°3’34.85“E (**Fig. 1**).

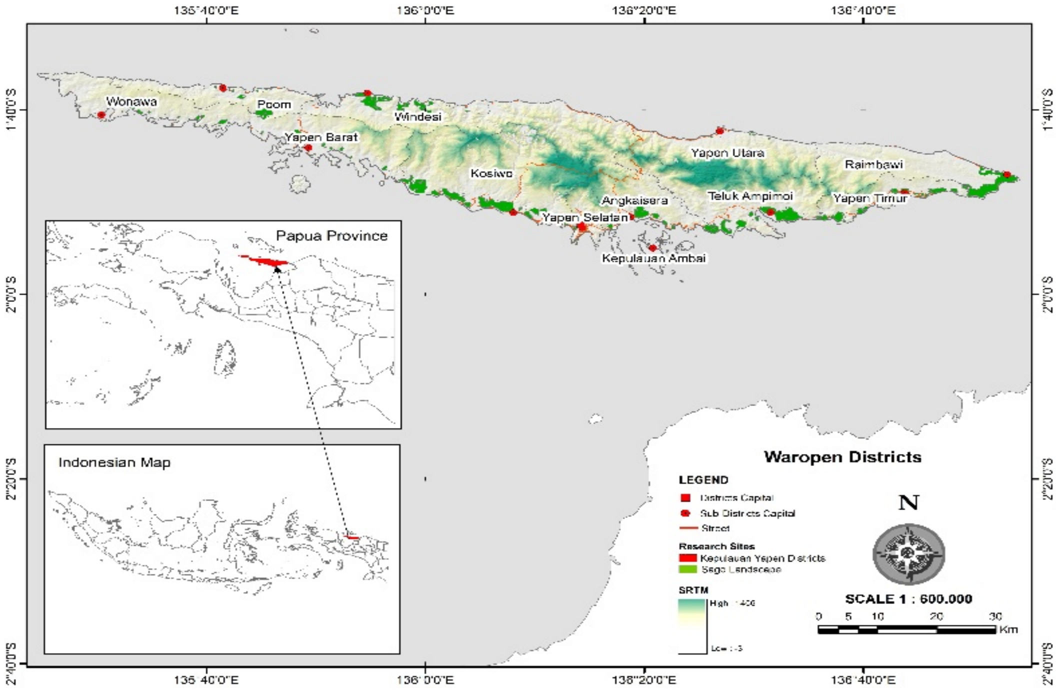

Fig. 1. Location of sago forest in Yapen Islands, Papua, Indonesia.

2.2. Research Procedure

Information on sago forest coverage was obtained from image interpretation of Landsat 8 (2021) and Quickbird (2012), which have radiometric and geometric corrections (USGS 2017). Satellite imagery processing was conducted through several stages: pre-processing images, selecting the best band combination, interpreting the visual image, creating class markers, analyzing separability, classifying the image, and testing the accuracy. Furthermore, the image was processed using Envi 5.3 (Research System, Inc (RSI), USA) to generate composite and land cover classification. The maximum likelihood supervised classification method was used (Ahmad 2012; Fichera et al. 2012). The method was based on the consideration that the maximum similarity algorithm is more accurate than other classification techniques. The initial step was the selection of sample locations in the selected area (training area) concerning the appearance of the terrain, spectral values, and object colors in the composite image and assisted by land use maps and field data. Sampling was attempted to truly represent all features in the image and was nearly homogeneous for one class.

To obtain the outputs and two land coverage classes of sago and non-sago forest. Subsequently, sago forest spatial data was analyzed using ArcGIS 10.8 (Environment Science and Research Institute, USA) to describe the palm area characteristics. This research used spatial distribution techniques to understand the sago palm’s environment requirements and biogeography aspects. It also used a comparison method to evaluate land durability by matching and comparing the characteristics to the class requirements of the sago palm. This spatial analysis used several calculations and logical evaluation to determine the potential link or patterns with geographical elements (Kindu et al. 2013).

The descriptive method defined sago palm habitat suitability using a quantitative approach from thematic spatial data integrated with fieldwork and statistic analysis. The 6 environmental parameters used in this suitability classification were elevation, inclination/slope, type of soil, rain precipitation, and the distance from the river and sea. First, spatial analysis was performed using the overlay method to generate a sago palm habitat suitability map. Then, fieldwork was carried out to examine the presence of sago palms in the habitat shown by the spatial model results. The palm was observed in the circular plot whose coverage follows the cluster's shape in this process. The circular plot was determined by following types of growth and systematically placing the measured plot in 30 sample spots designed.

Land elevation and slope gradient/inclination with a scale of 1:250,000 were derived from the Indonesian Topographic Map (RBI) published by the Geospatial Information Agency (BIG/Badan Informasi Geospatial). This map is generated from contour data analysis with an interval of 50 meters and classified into 6 (six) elevation classes. Based on the land elevation, the distribution of sago palm habitat is classified into plain, hill, and mountain. Meanwhile, slope gradient/inclination maps are based on contour data through interpolation to decrease slope (%). They are classified into six (6) classes of 0–1%, 2–8%, 9–15%, 16–25%, 26–40%, 41–60%, and < 60% for flat slope, gentle slope, moderate slope, slightly steep, steep, very steep and extremely steep habitats (Li et al. 2020). Furthermore, soil types were derived from maps with a scale of 1:250,000 published by The Centre of Soil Research and Agroclimate (Puslittanak). Since sago palm can grow in any soil type, the habitat was classified based on its soil order/great group. The classification was also based on measuring its annual rain precipitation (mm year^{-1}). Hydrology measurement was obtained by calculating the distance of the river and sea to the sago palm habitat (meter) using GIS and descriptive analysis. The spatial data collected in this study are presented in **Table 1**.

Table 1. The collected spatial data

No.	Data	Scale	Source
1	Indonesian Topography	1:250,000	BIG
2	Quickbird	2.4 m resolution	BIG
3	Landsat 8	30 m resolution	Earthexplorer.usgs.gov
4	Shuttle Radar Topography Mission (SRTM)	30 m resolution	Earthexplorer.usgs.gov
5	Soil type		Puslittanak
6	Elevation (DEM)	30 m resolution	Earthexplorer.usgs.gov
7	Rivers and Sea	1:250,000	Bappeda Papua
8	Watershed area	1:250,000	Ministry of Environment and Forestry (MoEF)
9	Yapen Island Administration Office	1:250,000	Bappeda Papua

3. Results and Discussion

Sago forest in Yapen Islands covers an area of 10,778.77 ha distributed in Angkaisera, Kosiwo, Poom, Raimbawi, Ampimoi Bay, Windesi, Wonawa, West Yapen, South Yapen, East Yapen, and North Yapen. The largest sago forest was in Kosiwo Subdistrict at 2,644.11 ha (24.53%), while the lowest sago forest was in North Yapen Subdistrict at 68.63 ha (0.64%). Sago palm in this region is the species of *Metroxylon sagu*. Traditionally, it is grouped by the Yapen indigenous community into several local varieties based on its morphological characteristics, including stem and petiole, spine length, and color of sago starch. These characteristics act as distinctive markers for each variety, especially in determining the sago palm diversity in the natural forest (Matanubun 2015). The Yapen indigenous community in Ampimoi Bay groups is divided into nine varieties of *Kurai* (spine), *Wewa* (solid hard bark and gray petiole), *Pampuma* (gray petiole), *Anta* (soft spine), *Amiri* (short spine), *Barari* (spineless), *Karawerari* (spineless), *Anangdami* (spineless), and *Awui* (solid hard bark). Meanwhile, the indigenous community in East Yapen classifies this palm into 5 (five) varieties of *Kurai* (white starch), *Wewa* (white starch), *Widoi* (short spine), *Kakawa* (red starch), and *Dami* (red starch). Morphological characteristics like the length of the rachis, plant height, petiole width, and spine are prominent characteristics in distinguishing genetic diversity and production (Pratama et al. 2018; Santoso et al. 2021). The field condition of the *Metroxylon sagu* forest area is presented in **Fig. 2**.

Fig 2. The field condition of the *Metroxylon sagu* forest area in Yapen Islands: (a) sago crown, (b) sago grove, and (c) sago habitat.

3.1. Sago Palm Habitat Based on Elevation

In the Yapen islands, forests are classified into (1) mountain, (2) lowland, and (3) swampy and coastal forests based on elevation. **Table 2** shows that the sago forest in Yapen islands is located between 9-250 masl, and the largest is shown in the elevation of 9-50 masl, covering an area of 9,456.26 ha (87.73%). The observation showed that the palm could adapt and thrive well in the 9–50 m elevation. The plant lives in large clusters of flooded, temporary flooded, and dry habitats and can grow in any elevation between 0–400 masl (Ehara et al. 2018). Lowland is the preferable area for sago palms to thrive due to its fertile soil, adequate water supply, and relatively flat nature. The ability to adapt to this elevation is exhibited in the cluster's larger shape and size, with a more homogenous population than those growing in higher areas. Sago palm can grow on land with high water content or even in flooded or waterlogged areas (Azhar et al. 2021). Land elevation affects growth as this relates to temperature, humidity, sunlight intensity, and duration. It could be caused by the micro-climate differences, especially temperature and humidity in the sago forest interior. The temperature measurement result in this interior part ranges from 24.89–26.20°C, while its humidity is 82–90%. In contrast, the temperature outside the sago forest ranges from 30.01-34.17°C with 68–73% humidity. It decreases with an increasing land elevation rate, affecting the plant's physiological processes, such as stomata opening, transpiration rate, photosynthesis rate, and plant respiration (Miyazaki et al. 2016). The low temperature in high plains will influence the metabolism and flowering of sago palms and lengthen the duration of vegetative growth (Muhidin et al. 2016). The number of individual plants in a habitat is strongly influenced by environmental conditions suitable for growth and development (Sartika et al. 2017).

Table 2. Sago forest in Yapen Islands based on elevation

No.	Subdistrict	Elevation (masl)					Coverage (ha)
		9–50	51–100	101– 150	151–200	201–250	
1	Angkaisera	631.04	89.19	24.57	0.67	1.05	746.52
2	Kosiwo	2,357.12	188.67	87.17	7.18	3.97	2,644.11
3	Poom	324.85	73.64	8.69	0.76	2.31	410.25
4	Raimbawi	1,543.85	8.3	-	-	-	1,552.15
5	Ampimoi Bay	1,645.86	74.83	34.36	4.54	7.74	1,767.33
6	Windesi	980.32	240.14	112.17	1.18	3.65	1,337.46
7	Wonawa	89.49	44.06	20.99	-	-	154.54
8	West Yapen	669.42	133.54	20.07	-	-	823.03
9	South Yapen	164.31	5.47	1.11	-	-	170.89
10	East Yapen	992.51	91.47	19.88	-	-	1,103.86
11	North Yapen	57.49	5.78	5.36	-	-	68.63
Total		9,456.26	955.09	334.37	14.33	18.72	10,778.77
Percentage (%)		87.73	8.86	3.10	0.13	0.17	100.00

Sago forests in 201–250 masl elevations cover an area of 18.72 ha and are spread over several subdistricts, namely Angkaisera, Kosiwo, Poom, Ampimoi Bay, and Windesi (**Fig. 3**). The sago forest is located on slightly steep slopes in small clusters. The higher plain usually has less water supply than the lower part of these areas. Therefore, it affects the pattern of sago palm distribution, and the plant responds to water scarcity.

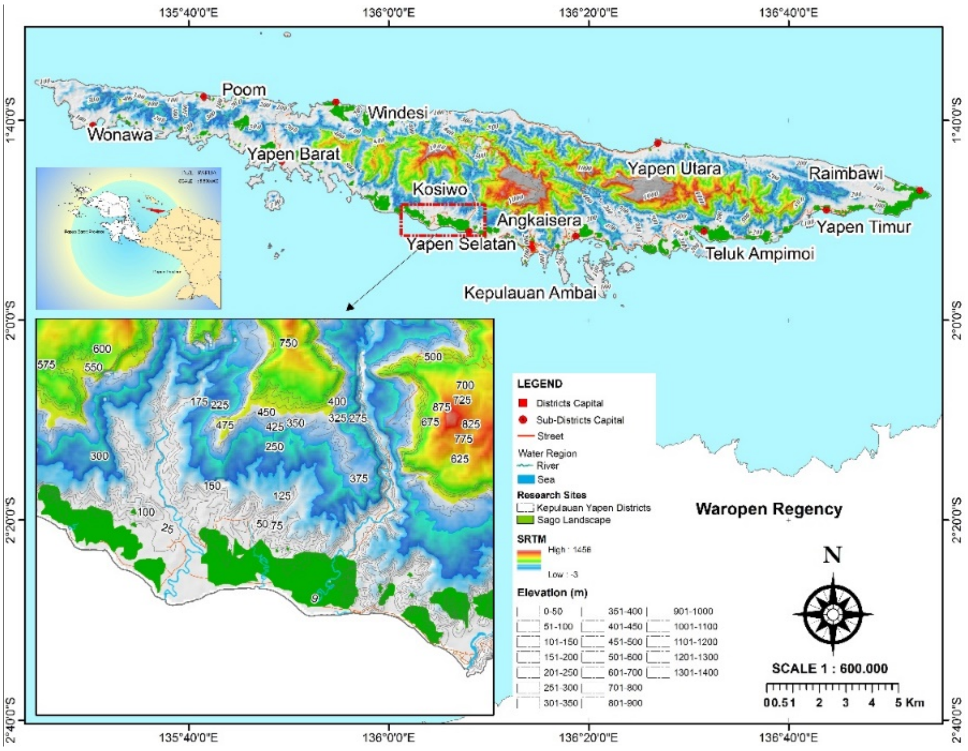

Fig. 3. Map of sago forest in Yapen Islands based on elevation.

This may involve adaptive change, damaging effects, and plant strategy to overcome drought or water stress by combining mixed 'strategies' of stress relief and varied toleration based on genotypes (Osakabe et al. 2014). Sago palm habitat in higher plains (> 200 masl) forms small clusters, especially in riverbanks and springs. Stomatal control preventing the loss of water content has been identified as the initial response to water deficiency (Osakabe et al. 2014). Generally, this sago palm grows near dry land and is associated with other woody vegetation. It is not optimal as there is competition among plants for nutrition absorption, water, and sunlight.

3.2. Sago Palm Habitat Based on Slope Inclination

Yapen islands have varied regional characteristics, including structure mountain zone, karst mountain, lowland, and coast. Generally, topography plays an important role in determining the surface flow speed containing earthen particles. Slope gradient and length are the two most-influencing topographic elements concerning surface flow and erosion. These elements affect the surface flow rate containing soil layers and nutrition from the high area to the lower one (Han et al. 2019). The slope inclination of the Sago forest is shown in **Table 3**.

Table 3. Sago forest in Yapen Islands based on land inclination

No.	Subdistrict	Slope inclination (%)						Coverage (ha)
		0–1%	2–8%	9–15%	16–25%	26–40%	41–60%	
1	Angkaisera	270.32	158.03	152.65	137.38	28.14	-	746.52
2	Kosiwo	441.3	1,294.54	570.96	225.91	110.71	0.69	2,644.11
3	Poom	18.17	126.6	140.28	102.75	19.8	2.65	410.25
4	Raimbawi	292.58	1,196.26	63.31	-	-	-	1,552.15
5	Ampimoi Bay	545.87	771.39	145.05	132.23	168.22	4.57	1,767.33
6	Windesi	78.53	404.51	405.51	274.41	174.5	-	1,337.46
7	Wonawa	3.35	12.12	58.12	51.51	29.44	-	154.54
8	West Yapen	39.5	228.56	382.61	165.18	7.18	-	823.03
9	South Yapen	44.18	57.15	26.58	19.35	23.63	-	170.89
10	East Yapen	53.83	418.8	306.86	193.5	130.87	-	1,103.86
11	North Yapen	13.68	24.49	12.02	9.06	4.37	5.01	68.63
	Total (ha)	1,801.31	4,692.45	2,263.95	1,311.28	696.86	12.92	10,778.77
	Percentage (%)	16.71	43.53	21.00	12.17	6.47	0.12	100.00

Notes: 0–1%= flat/no slope, 2–8%= gentle slope, 9–15%= moderate slope, 16–25%= slight steep, 26–40%= steep, 41–60%= extreme steep.

Sago forests in Yapen islands are found in varied inclinations, from flat to extremely steep slopes (**Fig. 4**). The largest habitat can be seen in the inclination of 2–8% (gentle slope), covering an area of 4,692.45 ha (43.53%). This gradient generally has deep soil solum (> 100 cm) on the rear boundary of mangrove and nypa palm forests. This area comprises alluvial sediment on the river estuary, with good soil fertility. The difference in soil inclination and moisture relating to environmental factors may affect plant morphological characteristics on the ground (Vitória et al. 2019). It shows they reflect the growth strategy used to overcome drought and water stress (Liu and Ma 2015). Additionally, the slope position difference affects the soil solum's depth. Its depth gets shallower with increased slope inclination. On the research site, the average depth of its soil solum is varied as follows: the lower slope (> 100 cm), the middle slope (80–90 cm), and the upper slope (50–60 cm), respectively. The top slope is prone to erosion, which leads to soil degradation and sedimentation on the lower slope. Furthermore, this causes the soil depth to be deeper than in the upper area. Therefore, the coverage of the sago forest decreases with increased slope inclination in this area. Additionally, slope inclination is the prominent topographical factor contributing to the plant distribution species. This may change the intensity of sunlight, temperature, and soil moisture (Xue et al. 2018).

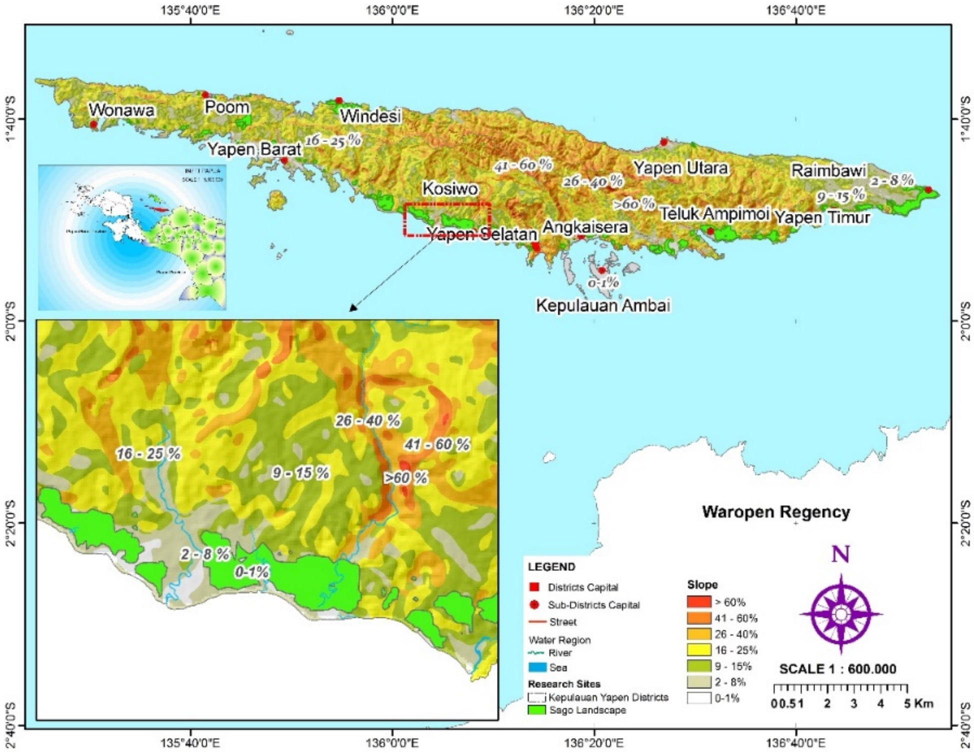

Fig. 4. Map of sago forest in Yapen Islands based on slope inclination.

Furthermore, sago forest found with an inclination of 41–60% (extremely steep) covers only an area of 12.92 ha (0.12%). Wild sago plants generally overgrew steep areas. The population of sago in this area was generally in the form of small clumps. The palm could grow and flourish in varied topography from steep to extremely steep and form small clusters. Based on the observation, it was found that slope inclination affects the river flow pattern in this area; a steeper slope creates an irregular river flow pattern. In contrast, flat slope inclination had a more regular river flow pattern. Therefore, the inclination and drainage patterns are prominent physiographic patterns in the plant's distribution, diversity, and abundance (Karami et al. 2015). This eventually leads to most sago forests scattering over the flat river estuary areas. There is also deterioration in soil physical characteristics in some areas with steep slopes. The surface flow speed is directly proportional to the destructive power energy. The rate of soil deterioration (erosion) varies depending on the shape and length of the slope and the water capacity for distributing earthen particles (Han et al. 2019).

In terms of the shape of slope inclination, Yapen islands have a crest (summit), mid-slope and slope toe, convex, concave, and slope toe. The position of landscape topography affects the local hydrology, spatial vegetation pattern, and water provision (Lei et al. 2021). The crest is the highest area affected by the erosion scour compared to other areas in the lower part. This is similar in the case of mid-slope, which tends to be convex or concave. It has a stronger relief surface flow than the crest area, while the slope toe (lower slope) becomes the area of eroded material sedimentation (Han et al. 2019). The lower slope is the habitat for sago palms in this designed region.

3.3. Sago Palm Habitat Based on Soil Type

Types of soil found in sago forests are latosol, mediterranean, rendzina, and gleysol. **Table 4** shows the different soil types found in their subdistricts.

Table 4. Sago forest in Yapen Islands based on soil type

No.	Subdistrict	Soil type				Coverage (ha)
		Latosol	Mediterranean	Rendzina	Gleysol	
1	Angkaisera	616.21	-	-	130.31	746.52
2	Kosiwo	507.90	1,611.45	524.76	-	2,644.11
3	Poom	129.40	280.85	-	-	410.25
4	Raimbawi	-	17.86	-	1,534.29	1,552.15
5	Ampimoi Bay	441.65	-	123.26	1,202.42	1,767.33
6	Windesi	1,295.69	-	41.77	-	1,337.46
7	Wonawa	-	154.54	-	-	154.54
8	West Yapen	-	823.03	-	-	823.03
9	South Yapen	170.89	-	-	-	170.89
10	East Yapen	228.27	2.99	-	872.60	1,103.86
11	North Yapen	68.63	-	-	-	68.63
	Total (ha)	3,458.64	2,890.72	689.79	3,739.62	10,778.77
	Percentage (%)	32.00	26.82	6.40	34.69	100.00

Notes: Soil map (Puslittanak, 1983) and spatial data analysis, 2021.

Sago forest growing in gleysol soil covers an area of 3,739.62 ha (34.69%) scattered across certain subdistricts, including Angkaisera, Raimbawi, Ampimoi Bay, and East Yapen (**Fig. 5**). Gleysol soil in this area is usually wet and flooded with poor drainage and experiences floods in the lowlands. This has medium solum, gray color, varied texture from loam to clay, varied structure ranging from muddy to massive, thick consistency, and organic material content. Meanwhile, sago forest in latosol soil covers an area of 3,458.64 ha (32.00%). It grows in moderate to larger clusters where the soil experiences a different horizon. Latosol soil in this area originated from the weathering of volcanic source rock and structure mountains.

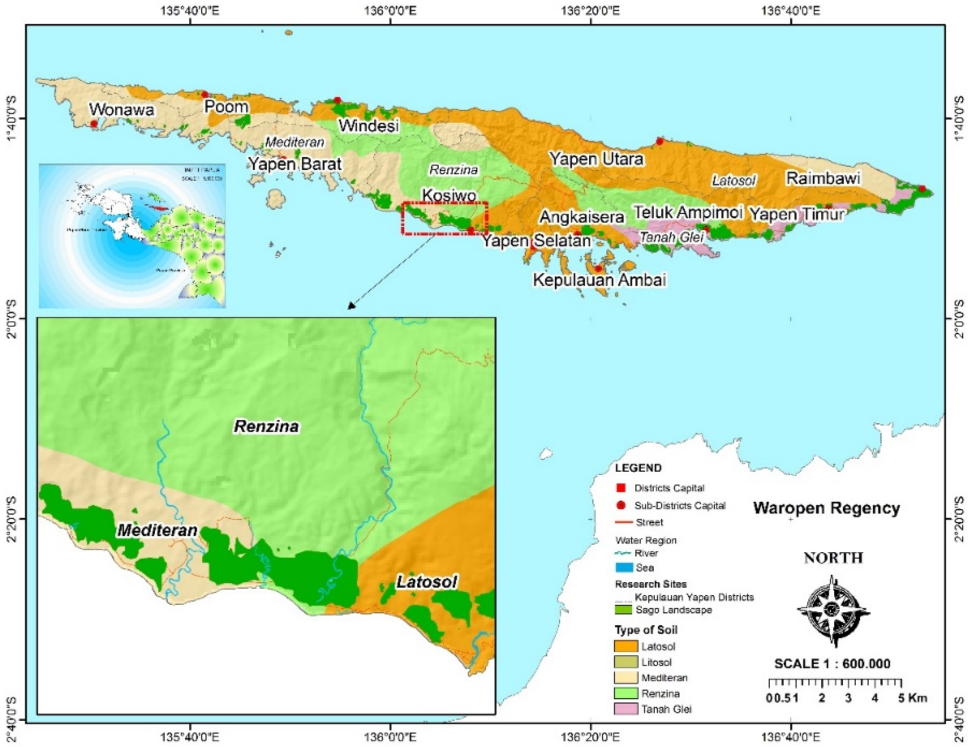

Fig. 5. Map of sago forest in Yapen Islands based on soil type.

This research indicates that latosol and gleysol soil in the lower slope has the deepest solum (> 100 cm depth). In contrast, the mid and the upper slope have 50–70 cm depth and 30–40 cm depth, respectively. Soil condition significantly contributes to the root growth in sago palm, which has moderate to great root numbers on deep soil layers. In contrast, the small soft roots tend to decrease and diminish on deeper soil layers due to oxygen deficiency (Miyazaki et al. 2016). The physical characteristics include volume weight, and soil porosity, affecting the sago palm system depth, length of lateral roots, numbers of root order, and the direction of root distribution. Deep soil solum and the low volume weight and high porosity will guarantee the sago palm root growth to spread over in a maximum way in any given area. Additionally, environmental factors, such as physiography, climate, and soil (porosity, drainage, and others), play a significant role in the distribution of plant types and their diversity (Karami et al. 2015). The growth of the sago palm root is important as this functions to absorb water and nutrients and maintain this plant stand firm. The increased diameter size of the root is directly proportional to the number of those below the ground (Miyazaki et al. 2016). Soil's physical characteristics also significantly affect how the roots reach nutrients (Azhar et al. 2020). Furthermore, soil with shallow root growth and solum tends to have horizontal distribution and less subsoil vertical root growth (Anugoolprasert et al. 2012).

Sago palm also flourishes in two types of soil; the Mediterranean covering 2,890.72 ha (26.82%), and rendzina covering 689.79 ha (6.40%). Mediterranean soil is generated from the weathering of limestone and sediment spread across several subdistricts; Kosiwo, West Yapen, Poom, Raimbawi, Wonawa, and East Yapen. Its color is varied from gray to brownish, and this has high contents of aluminum, iron, water, and essential nutrients that are beneficial for sago palm growth. In contrast, the forests growing on rendzina soil can be seen in several subdistricts; Kosiwo, Raimbawi, Ampimoi Bay, and East Yapen. This soil is generated solely from the weathering of limestone. It is also suitable for sago palms to grow as this has specific soil characteristics; high clay content, fine texture, low permeability, and good water retention features. In general, soil condition in the research site tends to have high bulk density and depth in any given land condition (ranging from 0.61–1.35 gr cm^{-3}). It is challenging for plant roots to penetrate the soil layer in the land provided with high bulk density conditions. Hence, bulk density portrays soil compaction, making it more difficult for water to permeate compacted soil. Furthermore, as a barrier to root penetration, compacted soil deprives plants of essential nutrients and hinders their growth. Sago palm in the research site also thrives well in acidic soil with a pH of 4.6–6.1. The rate of photosynthesis at pH 3.6 is relatively lower than at pH 5.7 due to reduced stomatal conductance (Anugoolprasert et al. 2012).

3.4. Sago Palm Habitat Based on Climate

The climate observation comprises rain precipitation, light intensity, temperature, and humidity in this research. Based on the Oldeman Climate classification, Yapen islands have Climate Type-A with a high precipitation rate distributed evenly all year round without any sign of a distinctive dry season. The dry season lasts from March to August, while the wet season lasts from September to February. The wet season in this region lasts all year round, following the climate type A pattern, with an average rain precipitation of 2,000-3,500 mm. Sago forests classified based on the rain precipitation rate are shown in **Table 5**.

Table 5. Sago forest in Yapen Islands based on rain precipitation

No.	Subdistrict	Rain precipitation (mm)				Coverage (ha)
		2900-3000	3000-3100	3100-3200	3200-3300	
1	Angkaisera	-	15.32	729.51	1.69	746.52
2	Kosiwo	-	2,384.95	259.16	-	2,644.11
3	Poom	51.47	358.78	-	-	410.25
4	Raimbawi	-	1,525.33	26.82	-	1,552.15
5	Ampimoi Bay	-	-	1,767.33	-	1,767.33
6	Windesi	796,89	540.57	-	-	1,337.46
7	Wonawa	4.69	149.85	-	-	154.54
8	West Yapen	-	823.03	-	-	823.03
9	South Yapen	-	-	170.89	-	170.89
10	East Yapen	-	99.12	1,004.74	-	1,103.86
11	North Yapen	-	68.63	-	-	68.63
	Total	853.05	5,965.58	3,958.45	1.69	10,778.77
	Percentage (%)	7.91	55.35	36.72	0.02	100.00

Sago forest covering an area of 5,965.58 ha (55.35%) thrives well in rain precipitation ranging from 3,000–3,100 mm (**Fig. 6**). Rainwater is vital in maintaining the water provision of the sago palm metabolism process. Based on the average monthly data published by Indonesia's Agency for Meteorology, Climatology, and Geophysics (BMKG) in Yapen islands, sago palm in this region has average monthly rain precipitation between 119.31 mm in January to 294.16 mm in December. In other words, the annual rain precipitation ranges between 1,867.20–2,982.61 mm/year. Sago forests in Papua province are seen in areas with average annual rain precipitation of 2.118 mm/year (Matanubun 2015). Meanwhile, for the rain precipitation rate of 3,200–3,000 mm, the forest only covers an area of 1.69 ha (0.02%), as shown in the Angkaisera Subdistrict (**Table 5**).

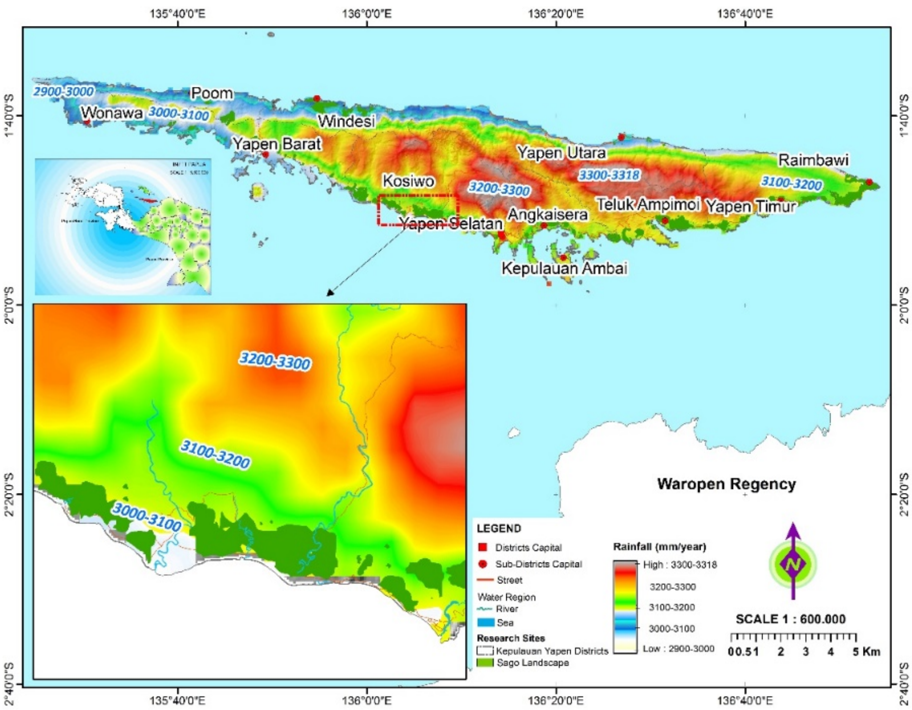

Fig. 6. Map of sago forest in Yapen Islands based on rain precipitation.

Rain precipitation pattern in this region increases with the land elevation. The influence on sago palm growth and production is seen in how rain precipitation helps maintain the balance of water salinity in the coastal area. Increased rainfall contributes to a more balanced water salinity, which is necessary for the growth and production of sago palms. Due to stable hydrological conditions, the organic material cycle and nutrients produced from decomposition can be controlled when the plants grow. The increase in inundated conditions can shift the vegetation community (Normand et al. 2017). Optimal water sufficiency aids the sago palm metabolism process, particularly for plants growing in the arid habitat, as more rain precipitation increases underground water. This process can perform well when the palm's needs for water and other photosynthesis elements are met. This also increases the rate of growth and production.

Sago forests flourish in natural forests and need adequate sunlight significantly. The duration of exposure ranges from 3 to 6 hours, with an average of 4.58 hours. Additionally, the result depicts that only partial sunlight intensity can penetrate the forest floor. The average sunlight measured near sago palm cluster areas is about 192.31 lux. Meanwhile, the number shown between one cluster to another is 457.16 lux. The sunlight intensity measured in the open space reaches 918.14 lux. This implies that less than 50% can penetrate the interior part of the sago forest. The blockade of the forest canopy causes low sunlight exposure. Light intensity plays a prominent role in maintaining the CO_2 fixation rate to produce high starch content. The maximum photosynthesis rate value of sago palm ranges from 25-27 mg CO_2 dm^{-2} h^{-1}. However, the saturation rate on light intensity is approximately 500 $\mu m^{-2} s^{-1}$ (Miyazaki et al. 2016). The dense forest canopy is caused by the sago growth type in cluster form. In this case, each cluster consists of several individuals of different phases, including tree, stand, sapling, and seedling. Land elevation and slope inclination also contribute to light distribution in sago forests. This forest has a daily intensity decrease due to the difference in land elevation. There is a tendency to have less light distribution in a higher area than the lower one. Therefore, this affects the microclimate in the forest interior (Xue et al. 2018).

Air temperature is significantly influenced by light intensity as the thermal source and wind speed to distribute the hot air. The research conducted from March to June 2021 shows that the temperature in the sago forest interior ranged between 24.89 – 26.20°C with an average point of 25.63°C. The temperature outside this forest ranged between 30.01–34.17°C, with an average point of 32.8°C. Therefore, air temperature fluctuation under the sago palm stand is relatively small or lower. The air temperature change surrounding the sago palm usually follows the fluctuation of local temperature conditions, which is 1.42°C. Sago forest, above 200 masl, has a lower temperature due to the denser canopy and low light intensity. The optimum for sago palms to flourish ranges between 24.5 – 29°C, with the lowest being 15°C and relative humidity of 70-90% (Morrison et al. 2012; Okazaki and Kimura 2015). The air temperature value has been linked closely to two plant metabolism processes, namely photosynthesis and respiration. Sago palm photosynthesis activity tends to be more sensitive to the minimum ambiance of air temperature than the maximum (Azhar et al. 2018).

The rise in air temperature is followed by an increase in photosynthesis and respiratory rate. This eventually leads to increased storage of carbohydrates used for growth and decreases accumulation time. Meanwhile, climate differences can cause the plant to develop different functional characteristics, especially tree height, canopy size, and leaf structure (Yamamoto et al. 2020a). As a result, the air humidity in the sago forest ranges from 82–90%, with an average of 84%, while the humidity outside the forest ranges from 68–81%, with an average of 79%. However, when extreme humidity increases, this will decrease sago palm transpiration activity, which may trigger slow nutrient absorption. The underground water provision and canopy density also influence air humidity inside sago forests. High density tends to create high humidity regardless of the season.

3.5. Sago Palm Habitat Based on the Distance to the River and Sea

Sago forests in this region are distributed in several habitats, i.e., tidal brackish-water wetland, waterlogged freshwater habitat, permanent waterlogged habitat, and dryland habitat. The tidal brackish-water wetland is close to and borders with nypa palm vegetation and mangrove. In general, the sago palm in this habitat grows in the rear borders of the nypa palm from the coastal part to the upland. It experiences flood during the tide and gets dried during a non-tidal session. Freshwater waterlogged habitat is found during rainy days lasting one to two weeks and one month. This habitat is usually dried during the dry season. Permanent waterlogged habitats are flooded for more than one month. This stagnant water comes from rain or river. Dryland habitat does not have any wet conditions from the rain or river. This habitat has varied slopes ranging from moderately steep to steep slopes. The sago forests based on the distance to the river are presented in **Table 6**.

Table 6. Sago forest in Yapen Islands based on the distance of the river

No.	Name of river	River length (m)	Sago forest* (ha)	No.	Name of river	River length (m)	Sago forest* (ha)
1	Ambaoi	1,529	44.55	16	Rapapeip	3,147	293.52
2	Antunai	3,209	13.09	17	Sawori	5,147	39.54
3	Arumpi	7,852	146.37	18	Sonui	5,996	23.91
4	Dawai	1,633	74	19	Sumboi	3,596	332.11
5	Dayari	8,719	104.05	20	Sumunwari	15,493	154.37
6	Panduami	2,591	10.22	21	Wabompi	1,716	27.46
7	Karariri	1,826	26.89	22	Waditawai	3,083	26.36
8	Manainumi	649	50.56	23	Waidorongrong	1,551	19.99
9	Mananeam	1,049	84.28	24	Waitayar	8,721	98.1
10	Manawati	10,621	169.65	25	Warkairawi	12,189	106.13
11	Manawini	10,808	194.38	26	Webi	32552	204,59
12	Mararema	3,085	15.76	27	Werandomi	630	47.09
13	Mariadoa	3,591	44.46	28	Werebai	1137	20.22
14	Merebuai	16,618	107.75	29	Worui	1017	305.58
15	Namai	892	24.44	30	Yoai	3763	38.93
					Total		2,855.68

Notes: *Distance 0-200 meters from river body to sago palm habitat.

The perennial rivers in this region have a constant stream for the entire year. Sago's palm spreads downstream because this is in the lowland. The rivers have a massive sediment concentration, organic materials, less current, and slow water flow. This research indicates that the largest sago forests are found in the areas of two rivers; Sumboi (332.11 ha) and Worui (305.58 ha). Sago palms flourish and thrive well on the alluvial sediment formation and flood plain in these areas. Sumboi and Worui Rivers are located in Mariarotu (57.61 km^2) and Ambaidiru (120.04 km^2) watersheds with a density of 3.60 km^{-1} and 3.59 km^{-1}. Half of the sago forests in this region are distributed in rivers with moderate current density. Therefore, the tendency is to form dry and temporary flood habitats. The palm in the Yapen islands grows in diverse land characteristics, from flood to dry. This plant has visible aerial roots (pneumatophores) on the ground, as seen in the lower part of the trunk. This plant can form aerenchyma tissue in the root cortex to adapt to wet conditions in freshwater and brackish water (Dewi et al. 2016).

In contrast, the smallest sago forest coverage of 10.22 ha in a small cluster associated with other woody vegetation lies in the Panduami River. This river is in Kamanap Watershed (81.34 km^2) with a river flow density of 3.42 km^{-1} and can be flooded during heavy rain. However, prolonged wet conditions exceeding two months negatively affect the sago palm's capacity to perform photosynthesis (Azhar et al. 2020). High water level ranging from 25-50 cm submerges the root system resulting in a limited oxygen supply. Oxygen deficiency triggers damage to root tissue, hampering sago palm growth (Azhar et al. 2021). The decrease in a common response to photosynthesis activity may lead to several effects on the leaf, i.e., leaf necrosis and chlorosis, decreasing leaf number, and shoot biomass (Anugoolprasert et al. 2014). However, the sago palm thrives well in temporarily flooded habitats due to its pneumatophores (aerial roots). Miyazaki et al. (2016) stated that the roots grow horizontally in the initial phase preceding trunk formation. Lateral roots are concentrated more on the ground, while the adventive are found underground.

Sago forest, with a distance ranging from 0–250 m from the coastline, covers an area of 153.87 ha, and the East Yapen Subdistrict has the largest area (56.66 ha). In contrast, West Yapen Subdistrict has the smallest (0.08 ha) (**Table 7**). Sago palms flourish at this distance and have good life ability. They grow in alluvial sediment formation and mud on the rear border of mangrove and nypa palm forests. Mangrove plants in this region contribute significantly to saline water intrusion to maintain the water table stability and decrease waves in the stream. According to the salinity measurement in the flooded sago palm habitat, the value found is 1-3‰ which means that the salinity value in the Yapen islands supports growth. Sodium chloride (NaCl) concentration in the water of the growing area of *Metroxylon* near the mangrove forest is changed based on the tidal rate. Lim and Chung (2020) explained that sago palms could grow in areas with low salinity. Mangrove ecosystems can control saline water intrusion through prevention mechanisms of calcium carbonate ($CaCO_3$) sedimentation by employing root exudate bodies. Saline rate decrease through organic materials generated from decomposition litter production (Matatula et al. 2019). Sago's palm has a high adaptation ability to the environment, especially for swamp and marginal land, which is impossible for other crop plants. Hence, it can serve as a conservation plant (Anugoolprasert et al. 2012; Azhar et al. 2020).

Table 7. Distance of sago forest in Yapen Islands to the sea

No	Subdistrict	Sago forest (ha)				Coverage (ha)
		0-250 m	%	251-500 m	%	
1	Angkaisera	5.00	3.25	23.51	6.39	28.51
2	Kosiwo	24.24	15.75	41.94	11.39	66.18
3	Poom	2.18	1.42	5.37	1.46	7.55
4	Raimbawi	12.99	8.44	88.52	24.04	101.51
5	Ampimoi Bay	20.77	13.50	42.51	11.55	63.28
6	Windesi	11.09	7.21	53.01	14.40	64.10
7	Wonawa	13.66	8.88	12.90	3.50	26.56
8	West Yapen	0.08	0.05	6.06	1.65	6.14
9	South Yapen	4.90	3.18	9.27	2.52	14.17
10	East Yapen	56.66	36.82	75.94	20.63	132.60
11	North Yapen	2.30	1.49	9.16	2.49	11.46
	Total	153.87	100	368.19	100.00	522.06
	Percentage (%)	29.47		70.53		100.00

With a distance ranging from 251 – 500 m, the sago forest covers an area of 368.19 ha. The Raimbawi Subdistrict has the largest (88.52 ha), and the Poom Subdistrict has the smallest (5.37 ha). Sago palms can thrive well in alluvial sediment formation, but some grow slower than in dry habitats. Physical and chemical obstructions facing flooded habitats include low content, poor drainage, high water retention capacity, high acidity, and low macro-nutrient element supply (Anugoolprasert et al. 2012). Even though this plant can grow in an area with a poor drainage system, the waterlogged condition affects the photosynthetic capacity, making this process less optimal (Anugoolprasert et al. 2014).

This research depicts that sago palm habitat conditions in Yapen islands can be classified into several types, including (1) tidal brackish-water wetland, (2) freshwater waterlogged, (3) permanent waterlogged, and (4) dryland. Based on land suitability classification for sago forests, there are three classes seen in this region, namely high suitability (4,169.23 ha), moderate suitability (6,600.91 ha), and low suitability/marginal (8.63 ha). The largest area classified as high suitability is the Raimbawi Subdistrict covering 1,389.30 ha. This area becomes the preferable place for sago palm to thrive as its sago forest lies in an elevation ranging from 0-50 masl. The inclination ranges from flat to moderate slope, with gleysol soil and rain precipitation ranging from 3000-3100 mm. Furthermore, the largest sago forest in the moderate suitability class can be seen in the Kosiwo Subdistrict, covering an area of 2,159.04 ha (**Fig. 7**). Land-limiting factors seen in the class are low soil fertility rate and slope gradient (steep to extremely steep). Finally, the largest sago forest classified in marginal land suitability can be seen in Windesi Subdistrict (4.20 ha). The limiting factors hamper sago palm's ability to flourish and thrive in this class.

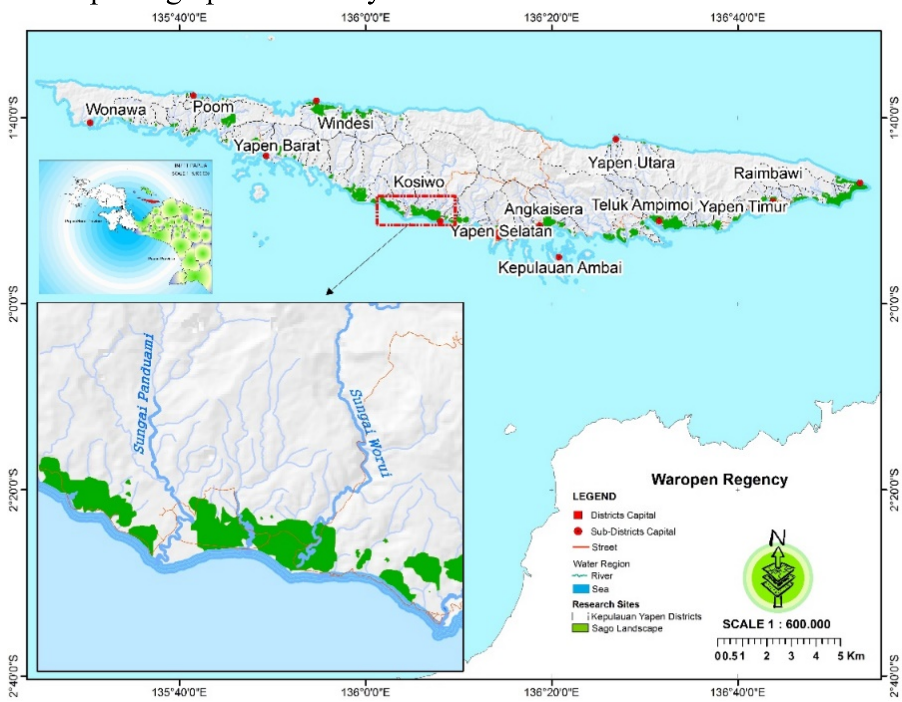

Fig. 7. Map of sago forest in Yapen Islands based on its distance to river and sea.

4. Conclusions

Yapen islands have sago forests thriving well in the lowland areas in the elevation between 9 – 150 masl dan an extremely gentle slope (2-8%). Generally, these forests are mostly found in the gleysol and latosol, with rain precipitation of 3000-3100 mm, an average temperature of 25.63°C, and relative humidity of 84%. In terms of distance, Sumboi and Worui Rivers have the most sago forests. For the distance between the sago forest to the sea, the range between 251-500 m is a suitable habitat for this plant. Sago in this natural forest has the potential to provide food for the local community, with a total sago forest of 10,778.77 ha. In addition, sago palms can adapt to the current climate change. Sago can be a provider of carbohydrate foods other than rice, corn, and wheat. To increase the role of sago in the region, it is necessary to have a pilot model of sago management area that is in accordance with ecological conditions and is economically profitable.

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