SPATIAL STATISTICS FOR ESTIMATING SAGO STOCK IN WEST PAPUA, INDONESIA

Statistika Spasial untuk Estimasi Stok Sagu di Papua Barat, Indonesia

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Abstrak
Sagu sawit adalah salah satu Genus Metroxylon dari keluarga Palmae , yang mengakumulasi sejumlah besar pati di batangnya. Sebagai sumberdaya makanan bertepung, sagu bisa menjadi peran penting sehubungan dengan kemungkinan kekurangan pangan di dunia di masa depan. Sagu sawit adalah tanaman tropis yang tidak hanya tumbuh di lahan kering, tetapi juga tumbuh dengan adaptasi yang tinggi terhadap lahan basah seperti rawa air tawar, rawa gambut atau brakish. Asal-usul sagu diyakini membentang dari Maluku dan Papua dari Indonesia ke New Guinea. Namun, perhatian untuk mengeksplorasi penyebaran dan potensi sagu belum dilakukan secara memadai di Papua. Tujuan dari penelitian ini adalah untuk mengembangkan metode statistik spasial untuk pemetaan dan memperkirakan saham sagu di Inanwatan District, Kabupaten Sorong Selatan, Papua Barat. Kerangka sampling area berupa metode segmen persegi yang diterapkan untuk memperkirakan stok sagu, yang melibatkan beberapa tahapan, yaitu, (1) Stratifikasi daerah penelitian dengan menggunakan resolusi tinggi dari data satelit, (2) Desain survei kerangka sampel, (3) Survei lapangan untuk truthing tanah, dan (4) analisis data. Hasil menunjukkan bahwa total daerah penelitian adalah 13.315 ha terdiri dari 2.892 ha hutan non - sagu dan 10,423 ha hutan sagu. Hutan sagu dibagi menjadi 3 strata, yaitu kepadatan rendah, kepadatan sedang, dan kepadatan tinggi, yang memiliki luas wilayah 630 ha, 392 ha, dan 9.401 ha. Populasi sagu matang di kepadatan rendah , kepadatan sedang , dan kepadatan tinggi 22,680 berdiri , 32,928 berdiri , dan 549,018 berdiri sebesar 4.930 ton , 7,226 ton , dan 109,044 ton pati sagu , masing-masing. Sehingga , total saham sagu di daerah penelitian adalah seluruh 121,200 ton pati sagu.

Kata Kunci *: statistik spasial, area kerangka sampling, penginderaan jauh, sagu sawit*

Abstract
Sago palm is one of Genus Metroxylon belonging to Family Palmae, that accumulates a huge amount of starch in its stem.As invaluable resouces of starchy food, sago palm could be an important role in respect to possible food shortage in the world in future. Sago palm is a tropical plant which not only grows in the dry lands but also grows with high adaption to low-lying wetlands such as fresh water swamp, peat swamp or brakish water. The origin of sago palm is believed to be the area extending from Moluccas, and Papua of Indonesia to New Guinea. However, the attention to explore spread and potential of sago stock has not been done adequately in Papua. The Objective of this study is to develop spatial statistics method for mapping and estimating sago stock in Inanwatan District, Sorong Selatan Regency, West Papua. Area frame sampling of square segment method is applied for estimating sago stock, which involves some stages, i.e., (1) Stratification of study area by using high resolution of satellite data, (2) Design of sample frame survey, (3) Field survey for ground truthing, and (4) Data analysis. The Results show that the total of study area is 13,315 ha consisted of 2,892 ha non-sago forest and 10.423 ha sago forest. Sago forest is divided into 3 strata, namely low density, medium density, and high density, which has area of 630 ha, 392 ha, and 9,401 ha respectively. The population of ripe sago palm in low density, medium density, and high density are 22.680 stands, 32.928 stands, and 549.018 stands equal to 4.930 tons, 7.226 tons, and 109.044 tons of sago starch, respectively. So that, the total sago stock in the whole study area is 121.200 tons of sago starch.

Keywords: spatial statistics, area frame sampling, remote sensing, sago palm

1. INTRODUCTION

Sago palm is one of Genus Metroxylon belonging to Family Palmae, That accumulates a huge amount of starch content in its stem[1] and as a significat source of raw material of high economical value[2]. Furthermore[3] say that sago palm has been described as 'human kinds' oldest food plant. In contrary to its important role in economical and cultural aspect since hundred years ago[4], currently sago palm is still found as underutilized plant.

It is estimated that Indonesia has 1.398.000 hectars of sago palm; of which 1.250.000 hectars are sago forest growing wildly and 148.000 hectars are cultivated sago palm. Meanwhile, Papua one of island belongs to Indonesia has 1.200.000 hectras sago palm forest and 14.000 hectars cultivated sago palm[1]. Based on several sources state that Indonesia has only about 1 million hectars of sago palm[5], whereas[6], estimates 1,5 million hectars, but both researchers agree that 90 % spread of Indonesian sago palm is in Papua (including West Papua). In West Papua, sago palms have been reported to exist mainly in low-lying marshlands and wetlands of southwestern Manukwari. Among the local people of West Papua, a part of sago palm and its product is utilized as food staffs in those area, while the other part is exported to other region.

Interests in this palm species has increased considerably in the last 3 decades because of its advantages of being economically acceptable, relatively sustainable, environmentally friendly, uniquely versatile, vigorous, and promotes socially stable agroforestry systems[7]. In Indonesia, the sago palm has recently gained interest, especially as one of alternatives for subsitution of staple food in respect to national food security. However, information on its present location and distribution is missing, and it cannot be ascertained whether there is enough supply of sago to drive and sustain a large scale sago starch industry.

The objective of this study is to apply spatial statistics method to estimate sago stock in West Papua. High resolution of Geo-eye satellite data is employed to stratified sago palm forest, and area frame survey is constructed for deriving field data of sago palm. Location of study is in ANJ AgroAnual Work Plan Area, South Sorong, West Papua.

2. MATERIALS AND METHODS

Figure 1 is the overall flowchart of activities starting from preparation upto data analysis. There are 3 main works to estimate sago stock in the study area, (1) developping area frame sampling, (2) grounth truthing survey, and (3) data analysis. The following discussion is more detailed description of each work.

2.1 Developing Area Frame Sampling

In the sago forest inventory in South Sorong regency, West Papua will be done by area frame sampling of square segmen. Rules-based spatial statistics is used on the construction of the sampling frame. The stages of the contruction includes stratifying study area, defining sampel size, and extracting sampel segment.

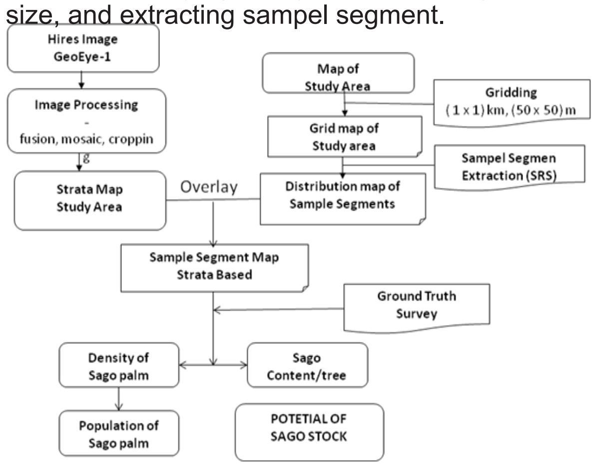

Figure 1. Flowchart of activity to estimate sago stock in South Sorong

Stratification of study area

Stratification is the division of a population Ω of size N into H non-overlapping subpopulation Ω_h (strata) of size N_h. The closer the behaviour of the N_h elements within each stratum, the more eficient the stratification[8]. In this research, the study area is stratified into 4 catagories based on domination of sago palm canopy interpreted from satellite data, namely:

- Strata-0: Non-Sago Forest
- Strata-1: Low Density (domination of palm canopy around 1-30 %)
- Strata-2: Medium Density (domination of palm canopy around 30-60 %)
- Strata-3: High Density (domination of palm canopy around 60-100 %)

As a tool for stratifying study area is high resolution of satellite (Geo-Eye) data in 2012 and 2013. Interpretation of satellite data is conducted by on screen delination. It is explained by[9] and[10]that the key of interpretation of sago palm is recognized by: star canopy with 10 m length, irreguler pattern, and grow in low land.

Definition of Sample Size

Definition of sample size refer to the guidence of forest inventory by[11], where the number of sample size is defined to have error level of 5 % and the size of sampel segment is 0.25 hectar. Mathematical formulation to count sampel size is as follo

$$n = \left(\frac{CV\%}{SE\%} xt \right)^2 \quad \ldots\ldots\ldots\ldots\ (1)$$

Where,
n :sampel size
SE : Sampling Error (5%)

CV :Variance of volume from the average (%)
t :Convidence level of 95% (t value close to 2)

Ministry of Forest state that Indonesian forest has 65%-75% variance of volume based on the empirical data. By the asumption of 80.000 hectars forest consession, the size of sampel segment is around 0.2%-0.3%. The size of sampel segment in this research is defined 0,5 % of the study area, that is assumed to meet 5 % error level.

Extraction of sample segment

Sampling frame of square segment sized 50 m x 50 m is used for extracting sample segment, so that, it is need to convert digital map of study area from vector map into grid map. Statistical rule applied to extract sampel segment is SRS (Systematic Random Sampling) in order to have a good spatial distribution of selected sampel segments. GIS software is employed to process spatial based of digital map. To do so, the first step is to divide study area into large grid 1 km x 1 km size, and those grids are then divided into smaller subgrid 50 m x 50 m size, so that, one large grid consists of 400 small grid. Second step is to go to first large grid (upper left) and select sampel segment of 0,5 % small grid randomly. Third step is to copy the selected sample segments pattern and paste it to the other large grids.

To know distribution and number of selected segments in each stratum, it is need to overlay between strata map and extracted sampel segment map. Each selected sample segment has it own identity such as stratum, and geographical coordinate, number of randomization. The identiry of selected segment is important for not only ground surveying but also filed data processing.

2.2 Ground-truth Study

Ground-truth survey conducted to each selected sample segments aims to derive parameters data of quantitative densities and starch contents of sago palm. Eventhough, high resolution of satellite image is available, but GPS is the only a tool to find the exact location of each selected sample segment becouse of difficulties to find physical features of sago palm forest on the image.

Parameters of sago palm density measured from each sampel segmen are number of bunch (RS) and number growing stages, namely before mature stage (BMT), mature stage (MT) and after mature stage (LMT). There are 6 growing stages of sago palm, namely shoot, seedling, sapling, before mature stage, mature stage, and after mature stage[12)]. But, this research,we observe the last 3 growing stages only because of the research objective reason.Whereas, parameters of sago starch content are to measure diameter of trunk at breast height (Dbh) and midrib free height (Tbp). The measurement of diameter and height are only for maturing trees, because those trees.

2.3. Data Analysis

Density Estimate

Density of sago palm forest is the average of sago stand per hectar for each growing stage, i.e. Before Mature Stage (BMT), Mature Stage (MT), and After Mature Stage (LMT). Mathematical formulation to count sago palm density is as follow:

$$\bar{y}_h = \frac{1}{a}\frac{1}{n_h}\sum_{i=1}^{n_h} y_{ih} \quad (2)$$

Where,

$\bar{y}_h$: sago palm density (stand/ha) in strata, a : area of sampel segment, n_h : total of sampel segment in strata h, y_h : total sago stand in sampel segment i^th strata h.

Population Estimate

Sago palm population is calculated by multiplying between sago palm density (stand/hectar) and area of strata (hectar). The mathematical formulation is as follow:

$$Z_h = A_h \bar{y}_h \quad \text{.................... (3)}$$

Where,

Z_h : population in strata h, A_h: area of strata h (hectar).

The result of population in each strata is used to calculate total population of sago stand in the whole study area with formulation as follow:

$$Z = \sum_{h=1}^{H} Z_h \quad \text{..................... (4)}$$

Where,

Z : population of sago palm in the whole study area, *H* total number of strata

Sago Stock Estimate

The content of sago starch in each tree refer to previous reseach conducted by[13] in South Sorong, West Papua. Those research generates a correlation between diameter at breast height and midrib free height, and sago starch content. The correlation is described by the mathematical formulation below:

$$W_s = 1{,}792\left(D_{bh}\right)^{0{,}648}\left(T_{bp}\right)^{0{,}874} \quad \text{... (6)}$$

Where,

Wsisfresh weight (kg/tree), Dbhisbreast height diameter (cm), Tbp :midrib free height (m).

Based on the above equation we can calculate fresh weight of each tree inside sample segment since field data of breast height diameter and midrib free height are obtained. Then, the following step is to calculate the average sago content in each stratum by the formulation below:

$$\overline{W}_{S_h} = \frac{1}{n_h}\sum_{i=1}^{n_h} W_{S_k} \qquad \text{.............................. (7)}$$

The potential of sago in each stratum is calculated by multiplication between total population and theaverage of sago content per tree. The formulation is as below: Where,

$\overline{W}_{S_h}$ is the average sago content per tree in strata-h (kg/tree), n_h is number of sampel segment in strata-h, W_{S_k} is the average sago content in strata-h, sample ith(kg/tree).

$$P_h = \frac{1}{1000} Z_h \overline{W}_{S_h} \qquad \text{................................(8)}$$

Where,

P_h is the potential of sago in strata h (ton)

Finally, the estimation of sago stock in the study area can calculated by using formulation below:

$$P = \sum_{h=1}^{H} P_h \qquad \text{………………………….. (9)}$$

Where,

P is the potential of sago stock in the whole study area.

3. RESULTS AND DISCUSSION

3.1. Contruction of Area Frame Sampling

Stratification of study area is generated by interpreting GeoEye satellite data acquired on January 2013. GeoEye is one of high spatial resolution data, where multispectral reflectances have 1,65 m spatial resolution, and panchromatic reflectance has 0,41 m spatial resolutin. Data fusion for combining multispectral and panchromatic data was applied to enhance its interpretability which the color derived from multispectral and the sharpness derived from panchromatic (**Figure 2**).

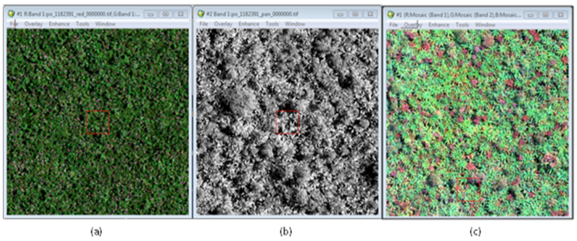

Figure 2. Satellite data fusion; (a) Multispectral, (b) Panchromatic, and (c) Data fusion

Since sago trees have specific star canopy on the image, it is easy to recognise and differenciate between sago and non-sago forest. Strata map then can be obtained by on screen delineation of data fusion image for whole study area (**Figure 3**). The areas visually interpreted as non-sago forest are stratified into Strata-0, whereas the areas visually interpreted as sago forest are stratified into strata-1, strata-2, and strata-3.

- Strata-1 is defined as Low Density forest which has 1-29 % of sago palm
- Strata-2 is defined as Low Density forest which has 30-59 % of sago palm, and
- Strata-3 is defined as Low Density forest which has 60-100 % of sago palm

Based on strata map, the extracted study area is 13.315 hectars consist of 2.892 hectars strata-0, 630 hectars strata-1, 392 hectars strata-2, and 9.401 hectars strata-3.

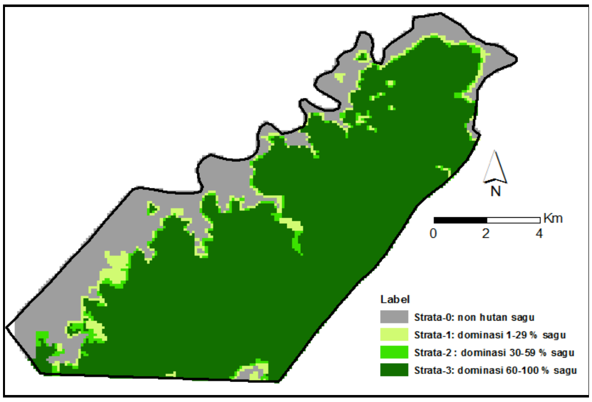

Figure 3. Result of sago palm stratification in the study area

Area sample frame construction is done to set the field data collection strategy in each stratum. GIS Soft-ware is an effective tool to process digital map for producing area sample frame. Sample segments are selected in stratum-1, level-2 and level-3 only, while sample segment in stratum-0 (non-sago forest) is eliminated.

Systematic random sampling rules are used to extract 0,5 % sample segment, then the extracted sampel segments is overlaid with strata map. The total selected sample segments in the study area are 208 segments, where 119 segments fall in strata-3,56 segments fall in strata-2, and 33 segments fall in strata-1 (**Figure 4**).

3.2. Ground-truth Survey

Ground-truth survey is conducted to observe all extracted sample segment as shown in **Figure 4**. The main tools to reach desired sample segment are map of high resolution image and GPS. The map is used as road-guide for approaching the segment based on physical fitures on the image, such as river, canal, settlement, road and so on. After closing to the segment, GPS is very useful to find exact location of the segment.

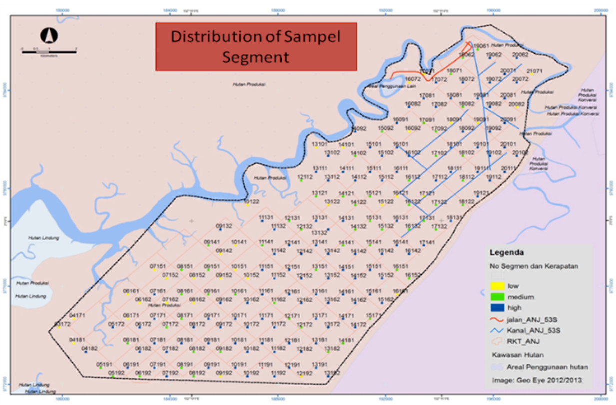

Figure 4. Distribution map of sampel segments in each strata

Parameters of sago palm density measured from each sampel segmen are number of bunch (RS) and number growing stages, namely before mature stage (BMT), mature stage (MT) and after mature stage (LMT). Whereas, parameters for estimating sago stach content is done by measuring diameter of trunk at breast height (Dbh) and midrib free height (Tbp). The measurement of diameter and height are only for mature stages, because those stage is considered containing sago starch.

Heavy constrains were found when entering sago forest because of very high dense-forest and deep swamp. A part of field data has been done, the other part is still in progress. Based on the field observation, it indicates that sago forest has low variance of sago population, so that, it is considered to have smaller size of sample segment than 0,5 %. In general, sago forest is located several kms from the main river and under flooded water environment.

Table 1. The result of density, population and Sago Stock estimation in the study area

Parameter	Unit	Strata-1	Strata-2	Strata-3	Whole Area
Area	(ha)	630	392	9.401	10.423
RS	Density (bunch/ha)	40	44	63	
	Population (bunch)	25.200	17.248	594.143	636.591
BMT	Density (tree/ha)	52	72	80	
	Population (Tree)	32.760	28.224	752.080	813.064
MT	Density (tree/ha)	36	84	58	
	Population (Tree)	22.680	32.928	549.018	604.626
LMT	Density (tree/ha)	16	36	26	
	Population (Tree)	10.080	14.112	240.666	264.858
Sago	Average (Kg FW/tree)	217,4	219,4	199,6	
Content	Sago Stock (Ton FW)	4.930	7.224	109.584	121.200

3.3 Data Analysis

The overall results of the data analysis is summarized in Tabel 1. It is to note that collecting field data is still in progress so that the **Table 1** is still temporary results.

RS density in each stratum is 40 bunch/ha, 44 bunch/ha , and 63 bunch/ha for strata-1, strata-2, strata-3, respectively. This results indicate that quantitative density respecting to the field data analysis is match to qualitative density respecting to the image interpretation. Sago palm density in strata-1 and strata-2 is quantitavely not significantly different, but those density of strata-1 and strata-2 is remarkably different comparing to the density in strata-3. Total RS in each strata is 25.200 bunches, 17.248 bunches, and 594.143 bunches, so that it produce 636.591 bunches in the whole study area. We can find growing stages of sago palm inside each bunch, namely before mature stage (BMT), Mature Stage (MT), and After Mature Stage (LMT).

The result of field data analysis shows that density of BMT in each strata is 52 tree/ha, 72 tree/ha, and 80 tree/ha for strata-1, strata-2, and strata-3, respectively. The population of BMT in each strata can be calculated by multiplying the density and its corresponding area. The result is 32.760 trees, 28.224 trees, and 752.080 trees for strata-1, strata-2, and strata-3, respectively. The total population of BMT in the whole study area can be derived by adding up the population in each stratum, i.e. 813.064 trees.

BMT has not ready to harvest yet, and it needs around 2 years to harvest. Such BMT population data is important to manage harvest rotation and predict sago starch potential to harvest in the future.

MT density in each stratum is 36 tree/ha for strata-1, 84 tree/ha for strata-2, and 58 tree/ha for strata-3. Similarly, the calculation results of MT population are 22.680 trees, 32.928 trees, and 549.018 trees for strata-1, strata-2, and strata-3, respectively. So that, total MT population for the whole study area is 604.626 trees. MT is the only growing stage which is ready to harvest due to its sago starch content. MT population data is used to estimate sago starch production at the present time.

LMT density in each stratum is 16 tree/ha, 36 tree/ha, and 26 tree/ha for strata-1, strata-2, and strata-3, repectively. The calculation of LMT population produces 10.080 trees, 14.112 trees, and 240.666 trees, for strata-1, strata-2, and strata-3, respectively. The population of LMT in the whole study area is 264.858 trees. LMT population indicates sago palm should be cut in order to increase starch yield.

As mentioned in the methology that the starch content in each tree refers to the correlation between diameter at breast height and midrib free height and sago starch content. Of course, the correlation between diameter, height and sago starch content depends on local specific evirontments, such as soil, terrain, and climate where the sago palm grows. Based on those field data of diameter and height, we can calculate the average starch content/tree in kg fresh weight (kg FW). Tabel 1. shows that the yield of sago starch/ tree in strata-1 and strata-2 are much higher than those of yield in strata-3 indicating the less density of sago forest the higher yield of sago starch. The yield of sago starch/tree in the study area is much less compared to the the yield in Meranti Islands District. It is reported by[14] that the average yield in Meranti Islands can get 398 kg/tree. The stock of sago starch in each stratum then can be obtained by multiplying average starch content/tree and its corresponding population. The potential of sago stock is 4.930 ton FW, 7.224 ton FW, and 109.582 to FW for strata-1, strata-2, and strata-3, repectively. The final estimation of sago stock in the whole study area is 121.200 ton FW.

4. CONCLUSION

Data fusion of high-resolution satellite imagery between panchromatic and multi-spectral is very useful to interprete visually relating to differenciate non-sago forest and sago forest. Spatial statistics is an efective tool to develop area frame sampling for implementing field survey strategy. The size of sample segment could be reduced by the fact that sago forest is more homogenous comparing to normal tropical forest. Sago palm density in strata-1 and strata-2 is quantitavely not significantly different, but those density of strata-1 and strata-2 is remarkably different comparing to the density in strata-3. At the time of the survey, there are: (a) 813.064 trees ready to harvest 2 years later, (b) 604.626 trees ready to harvest, and (c) 264.858 trees unutilised resource. Potential stock of sago starch at the the time of the survey is 121.200 tons

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