THE BEST PRACTICE OF FOREST INVENTORY USING REMOTELY-SENSED DATA IN TROPICAL FOREST, INDONESIA

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Abstract

This paper described the implementation of the conventional terrestrial-based comprehensive and periodic forest inventory (TBFI) and the image-based forest inventory (IBFI) in nine forest management units, in the tropical forest of Indonesia. The study examined the best practices of high-resolution and very high-resolution imagery-based forest inventory. The aspects studied include 1) cost comparison, 2) completion time, and 3) sampling error. This study found that the IBFI was more efficient than TBFI, having a cost ratio from 0.358 to 0.859. Technically, the IBFI is more implementable than TBFI. The cost per unit area decreases as the area to be surveyed increases. The average cost per unit area of IBFI is always lower than the TBFI. From the duration of the survey and data analysis, the IBFI method could be completed from 42 days to 83 days, much faster than the TBFI method. The study also found the relative efficiency of image-based double sampling much more efficient than terrestrial simple random sampling.

Keywords: Periodic comprehensive forest inventory, standing stock, very high spatial resolution, double sampling, relative efficiency

Introduction

1. Background

Data on growing stock and total growing stock are basic and primary data requirement in forest management (FAO,2020). The volumes of growing stock were derived from NFIs, or remote-sensing-based method calibrated with plot data. According to GFRA (2020), the volume of growing stock in South and Southeast Asia is increasing from 102.5 m^3 per ha in 1990 to 106.5 m^3 per ha in 2020. Knowledge, skills, and experience of analysts, especially on forest ecosystems at each location greatly affect the product of remote sensing data-based analysis.

Since 2016, the implementation of the periodic comprehensive forest inventory using a remote sensing image-based approach (IBFI) has been increasing, in line with the increasing ease of obtaining high and very high-resolution images. From a technical and economic point of view, this approach could provide estimates of standing stock more economically and efficiently, because it requires a shorter time and lowers costs. The use of image-based forest inventory had been initiated by some previous studies as outlined in Jaya and Cahyono (2001), Jaya (2003), and Jaya *et al*. (2011).

Now, the IBFI method is more relevant than terrestrial-based forest inventory (TBFI), since the TBFI needs more financial support and a longer completion time. For an average forest concession area of 60,000 Ha, TBFIs need to observe 600 sample plots, six times the number of plots for IBFI. Based on considerations of cost efficiency, completion time, and sampling error, this paper examined the best practices of the IBFI.

2. The study objective

The objective of this paper is to evaluate and compare the implementation of IBFI and TBFI on the aspects of cost ratio, timely completion, and relative efficiency.

Methodology

1. Study Site

The study sites cover 9 management units located, namely 2 units in Papua Province (labeled as Pap1 & Pap2), 1 unit in North Maluku Province (labeled as Mlku1), 1 unit in Central Sulawesi Province (Ktn1), 2 units in East Kalimantan Province (Ktim1 & Ktim2), 2 units in North Kalimantan Province (Ktara1 & Ktara2) and 1 unit in Central Kalimantan Province (Ktn1).

2. Image-based Forest inventory

The study of image-based standing stock estimation includes several steps: (1) image procurement, (2) sampling design creation, (3) pre-processing, (4) image analysis, (5) field measurements, (6) development of standing stock estimation model, and (7) standing stock mapping (see Fig. 1). The use of remote sensing data ranging from very-high-resolution to low resolution could be found in Wimmer et al. (2000) and White *et al.* (2016).

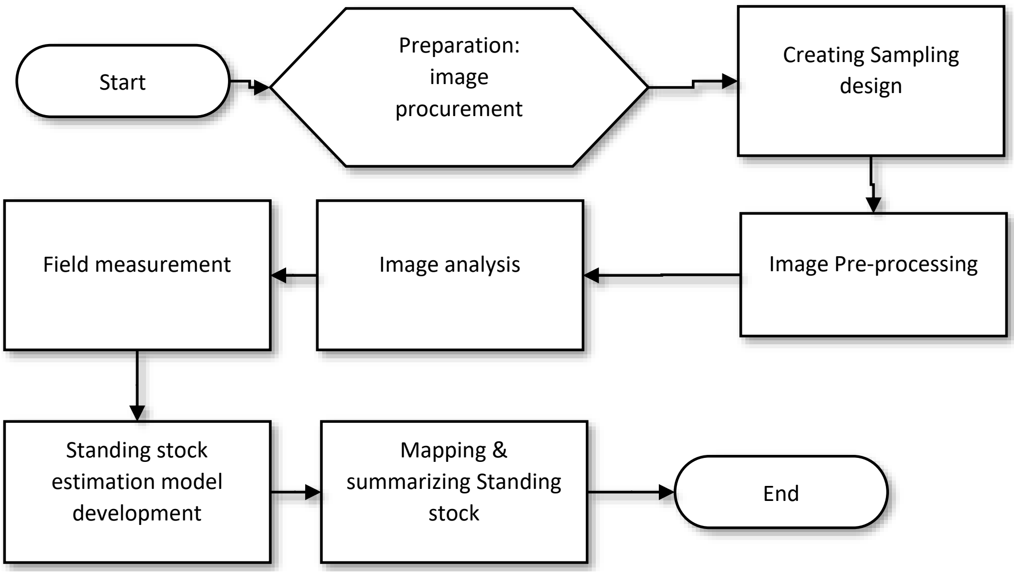
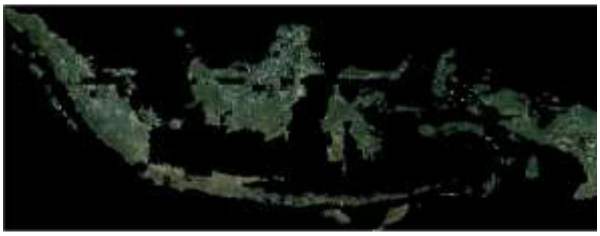


Fig. 1: Flow chart of the implementation of the Image-based Forest inventory.

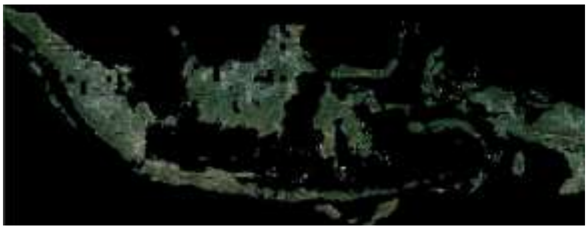
3. Image mosaic development

The National Aeronautics and Space Agency has routinely created an image mosaic based on SPOT 6/7 with a resolution of 1.5 m x 1.5 m with a "tile" size of 10 km x 10 km. To minimize the cloud cover, the mosaics are arranged by tiles from multi-date images. The maximum cloud cover allowed per tile is 10%. If one tile has some images with the same percentage of cloud cover, then the newer acquisition was prioritized. The size of the tiles can be modified according to the needs of each user. Fig. 2 is an example SPOT 6/7 image mosaics for all of Indonesia recorded between 2017 and 2019.

(a) Mosaic SPOT-6/7 acquisition date 2017



(b) Mosaic SPOT-6/7 acquisition date 2018



(c) Mosaic SPOT-6/7 acquisition date 2019

(d) Mosaic SPOT-6/7 acquisition date 2020

(e) Mosaic SPOT-6/7 acquisition date 2016-2020

Fig. 2: An example of SPOT Mosaic covering Indonesian Archipelagos using SPOT-6/7 annually (2017/2018/2019/2020). Source: Earth acquisition station of LAPAN, Prepare.

4. Standing stock estimation using IBFI

The mathematical model was developed by measuring about 90 to 100 sample plots having the size 50 m x 50 m both in the field and in the high/very-high-resolution images. In the models, the dependent variable is standing stock (m^3/Ha) while the independent variables are the percentage of crown closure (C), crown diameter (D), and/ or the number of trees per hectare (N) measured on the image. In practice, only variables C and D were applied. The technics and procedures for performing regression analysis could be found in Drapper and Smith (1981). In the future, this terrestrial measurement method might be developed using the terrestrial laser scanning method (Liang et al. 2016).

5. Comparison between image-based double sampling and terrestrial simple random sampling

In this study, the authors also performed a comparative study between forest inventories using image-based double sampling techniques (IBDS) and forest inventories using simple random sampling based on terrestrial (SRS) measurements. The comparison was done by calculating the relative efficiency o IBDS and SRS, with the following formula:

$$EFR = \frac{n_s C_f}{n_{fd} C_f + n_{pd} C_p}$$

Where n_s is the number of plots that should be observed in the SRS method; C_f and C_p are the costs required to perform measurements per plot in the field and images, respectively; n_{fd} and n_{pd} are the optimal number of plots for double sampling that have to be measured both in the field and in the image, respectively. The number of n_s, n_{fd} and n_{pd} is calculated using the following formulas (Paine 1981).

$$n_s = \frac{t^2 CV^2}{DSE^2}$$

$$n_{fd} = \frac{t^2 CV^2}{DSE\%^2} \left\{ \frac{C_f}{E\left(C_f + R\ C_p\right)} \right\}$$

In the above equation, t is the student's t value at 95% confidence interval, CV is the coefficient of variance of the standing stock in percent, DSE% is the desired sampling error in percent. Next, the values of efficiency (E) and the optimum ratio of image to field plots (RIF)) are calculated by the following formula:

$$E = \frac{C_f/C_p}{\left\{ \sqrt[2]{(1-r^2)\left(C_f/C_p\right)} + r \right\}^2}$$

$$RIF = \frac{n_{pd}}{n_{fd}} = \frac{1}{\left\{ \frac{1-r^2}{r^2} \frac{C_p}{C_f} \right\}^{1/2}}$$

$$n_{pd} = RIF\ n_{fd}$$

Where r is the correlation coefficient between the variables observed in the image from the regression equation.

Results

1. Comparison between TBFI and IBFI

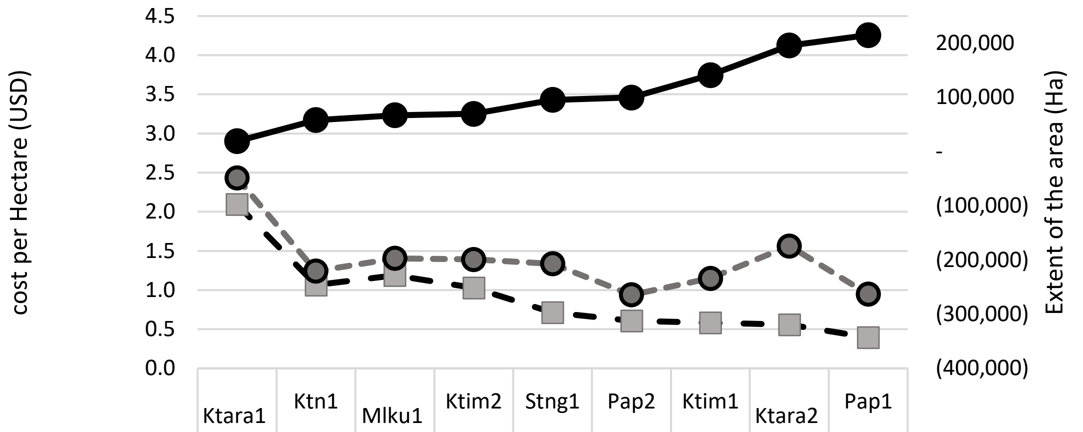
From the aspect of the costs required, the average costs required for the implementation of image-based IHMBs (CIBFI) ranges between 0.394 USD and 2,089 USD per ha, while terrestrial (CTBFI) ranges between 0.938 USD and 2,432 USD per ha. This study also found that IBFI costs less than terrestrial-based TBFI (Table 1).

Table 1: Comparison between the cost required for Terrestrial-based and Hires-image-based forest inventory

No	Symbol	Area (ha)	Cost Ratio	CIBFI /ha	CTBFI/ ha*	IBFI FWD	TBFI FWD
6	Ktara1	19,000	0.861	2.093	2.432	42	49
3	Ktn1	58,164	0.859	1.067	1.241	51	88
9	Mlku1	66,975	0.846	1.189	1.405	52	97
5	Ktim2	69,620	0.739	1.028	1.391	53	100
8	Stng1	95,270	0.535	0.714	1.336	58	125
2	Pap2	99,750	0.646	0.606	0.938	58	130
4	Ktim1	141,200	0.505	0.581	1.150	67	171
7	Ktara2	195,637	0.358	0.559	1.562	78	226
1	Pap1	214,935	0.417	0.394	0.947	83	245

Note: TBFI FWD & IBFI FWD are field working days (with 5 teams) required for TBFI and IBFI, including 30 days for data analysis; CIBFI and CTBFI are unit costs (in USD per hectare) for IBFI and TBFI. *) the cost for terrestrial forest inventory was calculated based on the actual cost for per unit activity and or per unit area that required for implementing image-based overall periodic forest inventory)

Fig. 3 shows that the cost per unit area, especially for IBFI, would tend to continue to decline in line with the increase of the area to be inventoried. The highest cost per unit area for IBFI was at the Ktara1 site at a cost of about 2,093 USD/ha for a concession area of 19,000 Ha, while the lowest IBFI was provided by the Pap1 site at a cost of only 0.394 USD/ha for area size of 214,935 ha. There is a decrease in the average cost for IBFI from 2,093 USD/ha to only half of 1,067 USD/ha if the surveyed area is increased from 19,000 Ha to 58,000 Ha.



	Ktara1	Ktn1	Mlku1	Ktim2	Stng1	Pap2	Ktim1	Ktara2	Pap1
IBFI /Ha	2.093	1.067	1.189	1.028	0.714	0.606	0.581	0.559	0.394
TBFI/Ha	2.432	1.241	1.405	1.391	1.336	0.938	1.150	1.562	0.947
Area (Ha)	19,000	58,164	66,975	69,620	95,270	99,750	141,20	195,63	214,93

Fig. 3: Comparison between IBFI, TBFI & extent of the concession area

From the relationship between relative the CR value of IBFI and the TBFI, it would be clearly described that the CR value decreased when areas surveyed increased (Fig. 4).

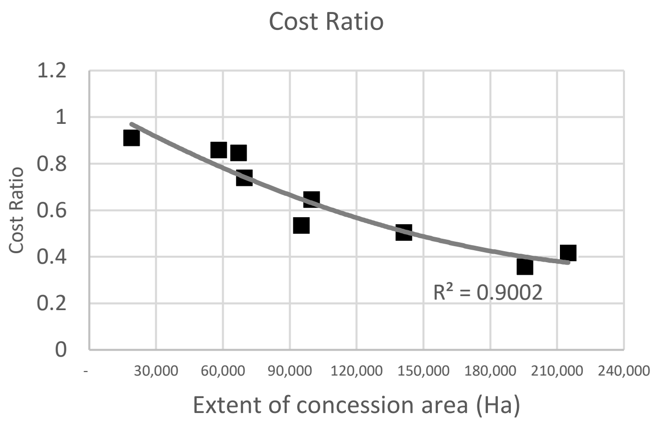


Fig. 4: The relationship between the extent of the surveyed area and ratio of image-based forest inventory (IBFI) and terrestrial-based forest inventory (TBFI)

From the completion time aspect, assuming the data processing time is the same, i.e., 30 days, the completion time of terrestrial-based forest inventories continues to increase sharply in line with the increase in the surveyed forest. This is significantly different from IBFI that shows only a slight increase (Fig. 5).

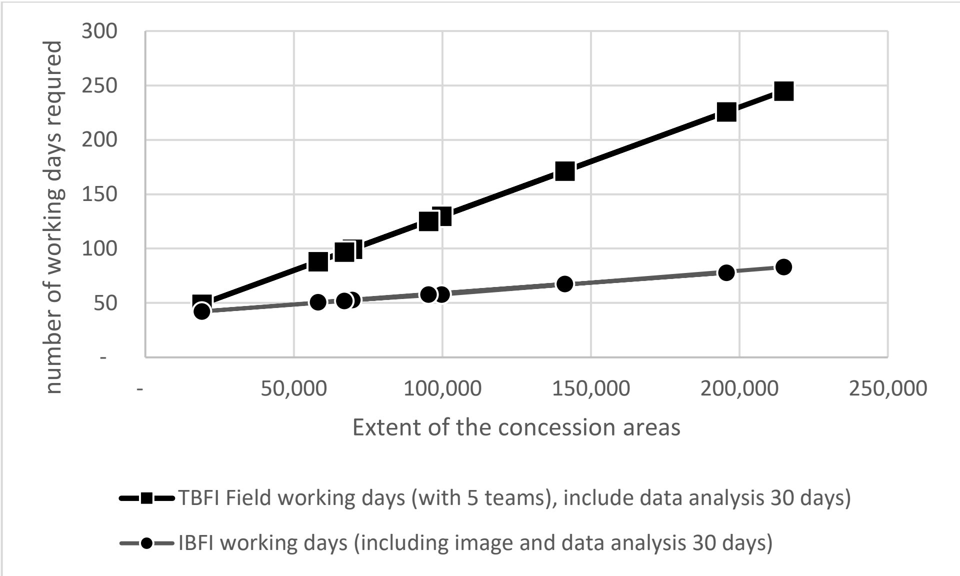


Fig. 5: The relationship between the area to be surveyed and number of working days required.

2. Comparison between Image-based double sampling and terrestrial-based simple random sampling

Table 7 summarizes the number of plots required for IBDS and SRS methods with a maximum sampling error of 5% and 10% for the areas ranging from 19,000 Ha to 214,935 Ha. From the nine management units examined, it is shown that the coefficient of variance of the stand preparations ranged between 31.5% and 73.5%. For DSE% of 5%, the IBDS needs field sample plots ranging from 11 to 181 plots, and image sample plots from 4,326 to 45,421 (see columns nf-5 and np-5 in Table 2). As for the 10% sampling error, the IBDS requires the number of field samples ranging from 3 to 45 plots (see columns nf-10 & np-10 in Table 2), and plots on the image range from 1.018 to 11,355 plots. The results also show that SRS requires a sample size ranging from 159 to 865 plots for a DSE% of 5%, and between 40 and 216 for a DSE% of 10%.

Table 2: Comparison between Double Sampling and Terrestrial Random Sampling for DSE 5% & 10%

Symbol	CV	Cp	Cf	RIF	E	DSE% = 5%			DSE% = 10%			EFR
						nf-5	np-5	ns-5	nf-10	np-10	ns-10	
Ktara1	31.5	23,610	3,526,118	122.5	2.2	40	4,871	159	10	1,218	40	219.8
Ktn1	33.0	14,736	1,799,957	105.2	2.3	41	4,326	174	10	1,082	44	227.7
Mlku1	52.3	17,863	2,036,887	231.5	5.7	25	5,880	437	6	1,470	109	568.2
Ktim2	31.6	11,778	2,016,262	161.6	2.5	33	5,380	159	8	1,345	40	246.2
Stng1	41.3	9,141	1,936,706	412.8	5.5	17	6,978	273	4	1,744	68	548.6
Pap2	55.3	7,548	1,360,822	284.5	4.2	46	12,956	489	11	3,239	122	416.8
Ktim1	32.0	7,489	1,667,266	238.9	2.8	29	6,837	164	7	1,709	41	276.5
Ktara2	46.0	7,529	2,264,756	776.5	8.3	11	8,813	338	3	2,203	85	832.5
Pap1	73.5	5,142	1,372,746	251.1	2.5	181	45,421	865	45	11,355	216	246.4

Discussion

1. The Cost Required for IBFI and TBFI

From the comparison of IBFI and TBFI costs per hectare, the IBFI costs are always cheaper than TBFI costs. Likewise, from the rate of decline point of view, the slope decline of IBFI costs is steeper than TBFI, which means that for a larger area, the use of the IBFI method would be cheaper. For an area of more than 200,000 ha, IBFI's cost per ha is less than half of TBFI's. From the CR value, it is shown that the CR value less than 1, ranges from 0.358 to 0.859. The CR value that is close to 1 means that IBFI costs are close to the TBFI. The small CR value indicates that the implementation of IBFI is very efficient. A minimum CR value of 0.358 found in this study means that IBFI only requires 35.8% of TBFI's costs, as provided by the Pap1 site (Table 1). In Fig 4, it is shown that the value of CR tends to decrease (more efficient) if the surveyed areas are increased. In this study, it was found that the maximum CR value obtained was 0.861. The study concluded that IBFI might save the costs of the survey, particularly for larger areas. For an area larger than 200,000 ha, the CR value can reach 0.4, while for an area of less than 60,000 ha, the CR value can reach 80%. Although the surveyed area was only 19,000, the cost of this image-based IHMB was also able to save about 20% (CR 0.8).

2. Completion Time

As summarized in Table 1, the survey for an area of 19,000 ha, only takes 49 days for TBFI and 42 days for IBFI method. For the wider area of 214.935 ha, the number of working days required for TBFI method is around 245 days (8 months) while for IBFI method it only takes 83 days (less than 3 months). This study noticed that for the completion time, the IBFI method is faster than the TBFI. Fig 5 shows that the time required for TBFI is increased very sharply while the increase in IBFI was slightly gentle, in line with the increase of area surveyed. For the area of 200,000 Ha or more, the working days of forest inventory were three times longer than the IBFI working days. This is related to the fact that the average of plot that could be measured per day at the TBFI is about 2 plots, while the average number of plots that could be measured per day for the IBFI was 4 plots since the distance between plots is around 200 ~ 500 m for IBFI, and about 1,000 m for TBFI.

3. Comparison between Image-based double sampling and terrestrial-based simple random sampling

The study shows that forest inventory using an image-based double sampling (IBDS) approach through very high spatial resolution images is much more efficient than terrestrial-based simple random sampling (SRS) without using images. The relative efficiency of all studied sites exceeds 200%, which ranges from 219.8% to 832.5%. This describes that the cost required for SRS forest inventory is 2 times to 8 times more expensive than using IBDS. The results are in line with previous studies, particularly the use of the aerial photograph to estimate the standing stock using the double sampling method (Jaya and Cahyono 2001).

Conclusions & Outlook

The empirical evidence performed in this study proved that the IBFI was more efficient than those TBFI. The wider the areas of concession the more efficient the IBFI is. The IBFI needs less labor and less time-consuming as well as low cost. This study also concluded that the estimation of stands stock using IBDS provided high relative efficiency, ranging from 219.5% to 832.5%. The cost for conducting forest inventory with a terrestrial SRS requires 2 to 4 times more expensive compared to using image-based double sampling.

The study outlooked that image-based forest Inventory is more transparent since the forest managers could see their concession information comprehensively, in real-time, and repetitively. The future challenge needs are a development of an algorithm to deriving standing stock using the use of ultra-high resolution imageries, e.g., an image of the UAV.

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