SAMPLING PROTOCOLS FOR FOREST AERIAL SURVEY IN COLORADO, US

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SUMMARY

Aerial sketch-mapping is a common technique that has been used to estimate the extent and severity of observe damaged forest from an aircraft. In Colorado State, data on forests survey by aircraft using sketch-mapping has been collected from 1994 until now. Because of very large data has been collected each year so it is difficult and takes time and cost of money. Choosing appropriate sample designs to estimate for population estimators is necessary and economical.In this paper, three sample designs (Simple Random Sampling - SRS, Systematic Sampling - SYS, and Probability Proportion to Size - PPS) with different sample sizes were conducted and compared to find the best and applicable one to the reality of forest management. The comparing is conducted by doing simulation with 20,000 times for each sample design and based on the values of some important estimators between sample designs and the population's values. The biased and unbiased characteristics of estimators are considered as the main evidences for conclusions.

Keywords: Aerial survey, sketch-mapping.

I. INTRODUCTION

Aerial surveys are commonly used in countries such as the United States, Zambia, Kenya and Uganda to estimate the extent and severity of forests damaged by insects and diseases (Caughley 1974). In forest inventories, aerial survey, which is also known as aerial sketch-mapping, is a technique of observing damaged forests from an aircraft. By this method, the areal extent of damaged forests can be transferred to existing maps as polygons by observers. These polygons are coded with additional information such as type of forest, causal agent, and so on. This information is considered to be qualitative in nature. Magnussen and Alfaro (2012) recommended that aerial surveys provide valuable information on the scale and severity of defoliation and mortality caused by forest insects (Magnussen and Alfaro 2012). This approach was potentially useful for estimating the forest growth effects from their symptoms of damage by defoliating insects or diseases.

Naturally, populations are often very large and almost impossible to measure completely. Sampling in this case plays an important role. Getting good estimates of population parameters at minimum cost and time while maximizing the utility of data is one of the main objectives of survey sampling (Tokola and Shrestha 1999). Sample design is considered basic in sampling theory (Traat et al. 2004). Different sample designs have been employed depending on the objectives of the survey. The choice of a sample design also influences the size and shape of the sampling unit.

Even though different sampling techniques could be applied to natural resources inventories for monitoring, some sample designs have been widely used in these approaches, such as simple random sampling (SRS) (Nusser et al. 1998, Gregoire and Valentine 2007, Theobald et al. 2007, Ståhl et al. 2010), stratified random sampling (STRA) (Smith 1981, Gregoire and Valentine 2007, Ståhl et al. 2010), probability proportional to size (PPS) (McGinn 2004, Stevens and Olsen 2004, Gregoire and Valentine 2007), and so forth. In practice, each sampling method has some advantages and disadvantages depending on the population being sampled. Actually, in forest aerial survey damage caused by insect and disease, there is no report concerning about applying sampling techniques. With aerial survey for large animals, Caughley (1977) commented that systematic sampling could eliminate navigation problems associated with random sampling and would be the most efficient means of mapping the distribution of animals. But when money, manpower, or time is limited, stratified sampling is the most precise for estimating population sizes (Caughley 1977).

In Colorado such surveys cover 100% of the forested lands. Because of increasing cost of aerial surveys and the risk to human lives can aerial surveys be conducted using some probabilistic sampling design and still provide unbiased estimated of the total area damaged by the various causal and disorder agents know to occur in the state. The objective of this project is to evaluate the statistical properties of three sample designs (e.g., Simple Random Sampling, Systematic Sampling and Probabilities Proportion to Size) in estimating the total area damaged by causal and disorder agents in the state.

II. MATERIALS AND METHODS

2.1. Study site

The study was carried out in western Colorado, which is dominated by forested lands covering about 9,308,000 ha (37 - 410N, 102 -1090 W). This region has a wide range of topography, soils, and environmental conditions that influence the diversity of forest types found in this area. The landscape ranges from plains to high plateaus to steep mountains with deep canyons and sloping foothills. Major forest types found in this area include 1) aspen, 2) piñon-juniper, (3) spruce-fir, 4) mixed-conifer, 5) oak shrubland, 6) ponderosa pine, 7) lodgepole pine, 8) riparian, and 9) plains (agroforestry).

2.2. GIS data

A GIS layer dividing the state into 155 parallel transects (3.2 km wide and 625 km long) was developed to cover the study area. All transects were oriented east to west and numbered from 1 to 155, south to north.

Two sources of GIS information were clipped with the state's forestland boundary and used to obtain the data used in this study. The first was a GIS layer of the major vegetation types of the state at a 30m spatial resolution. This information was used to create a binary surface indicating if a given raster cell was classified as being forested or non-forested. This layer was intersected with the GIS layer of transects to obtain estimates of the area of forested and non-forested on each transect. Five of the transects did not contain any forest lands and were deleted leaving 150 transects. The second were GIS layers of causal and disorder agents and disorders obtained from aerial surveys of the state carried out from 1994 to 2013. These layers were intersected with the GIS layer of transects to obtain estimates of the area of damage caused by eight agents: spruce beetle (Dendroctonus rufipennis) (SB), mountain pine beetle (Dendroctonus ponderosae) (MPB), Douglas-fir beetle (Dendroctonus pseudotsugae Hopkins) (DFB), western spruce budworm (Choristoneura occidentalis (Freeman)) (WSB), sudden aspen decline (SAD), subalpine fir mortality (Picea englmanii - Abies lasiocarpa) (SUB), pine engraver (Ips pini (Say)) (PE), and all causal and disorder agents and disorders combined (Comb.).

2.3. Sample Designs

The statistical properties of three sample designs were evaluated as an alternative to complete aerial census of the damage to forest resources in the state: simple random sampling, systematic sampling and unequal probability sampling.

Simple random sampling (SRS)

Simple random sampling is the most basic sample design in which a sample of size n is drawn from a population of size N in such a way that every possible sample of size n has the same chance (probability) of being selected. SRS is the simplest of the probability sampling techniques and is considered best suited for situations where not much information is available about the population of interest (i.e., spatial extent and severity of the damage). In this study, six sample sizes of n = 10, 15, 20, 25, 30 and 35 transects were selected, without replacement. The total area damaged (τ) by the various casual agents was estimated by

$$\hat{\tau} = N\frac{\sum_{i=1}^{n} y_i}{n} \quad (1)$$

with estimated variance

$$\widehat{V_{\hat{\tau}}} = N^2\left(\frac{S^2}{n}\right)\left(\frac{N-n}{N}\right) \quad (2)$$

and 0.95 bound on the error of estimation (B)

$$B = 2\sqrt{\widehat{V_{\hat{\tau}}}} \quad (3)$$

where y_i an estimate of the area damaged on the ith flight line, s^2 is the sample variance and N is the total number of transects in the state.

Systematic sampling (SYS)

A systematic sample obtained by randomly selecting one element from the first k elements in the frame and every kth element thereafter is called a 1-in-k systematic sample with a random start, where k = N/n. If the population is homogeneous, systematic sampling is comparable to a simple random sample. In general, systematic sampling is easier to perform and more cost efficient when compared to a simple random sample. The decision to use systematic sampling will also depend on if there are any patterns in population If there is a gradient in the population, systematic sampling will be more precise than simple random sampling. If on the other hand, there is a cyclic trend in the population systematic sampling will be less precise than that of a simple random sample. To evaluate systematic sampling, the equations and sample sizes (n = 10, 15, 20, 25, 30, 35) used for SRS were used to estimate the total area damaged by the various causal and disorder agents and place a bound on the error of estimation.

Probabilities proportional to size (PPS)

Probability proportional to size (PPS) is a sampling technique for use with surveys in which the probability of selecting a sampling unit (e.g., village, zone, district, and health center) is proportional to some characteristic that is correlated to the variable of interest (Therese McGin, 2004). PPS sampling will be more precise than SRS if the selection probabilities (π_i) are correlated to the variable of interest (y_i). If the selection probabilities are known, an estimate of the population total is given by

$$\hat{\tau} = \frac{1}{n}\sum_{i=1}^{n}\frac{y_i}{\pi_i} \quad (4)$$

with estimated variance

$$\hat{V}(\hat{\tau}) = \frac{1}{n(n-1)}\sum_{i=1}^{n}\left(\frac{y_i}{\pi_i} - \hat{\tau}\right)^2 \quad (5)$$

and 0.95 bound on the error of estimation

$$B = 2\sqrt{\hat{V}(\tau)} \quad (6)$$

In this study, the probability of selecting a given flight line was taken as the proportion of the flight line was classified as being forested, irrespective of the length of the flight line. Sample sized evaluated were the same as used in SRS and systematic sample, except all sampling was done with replacement.

Evaluating the Statistical Properties of the Sample Designs

To evaluate the statistical properties of the three sample designs (D), each design was implemented M = 20,000 times for each of the six sample sizes and the following statistics complied:

The grand total:

$$\hat{\hat{\tau}}_D = \frac{1}{M}\sum_{i=1}^{M}\hat{\tau}_D \quad (7)$$

The mean variance:

$$\bar{V}\left(\hat{\hat{\tau}}_D\right) = \frac{1}{M}\sum_{i=1}^{M}\hat{V}\left(\hat{\hat{\tau}}_{Di}\right) \quad (8)$$

The variance of the total:

$$\tilde{V}(\hat{\hat{\tau}}_D) = \frac{\sum_{i=1}^{M}(\hat{\tau}_{Di}-\hat{\hat{\tau}}_D)}{M(M-1)} \quad (9)$$

If the sample design (D) provides and unbiased the estimate of the population total, the grand total should equal the true population total (τ). Likewise, if the estimated variance is unbiased, the mean variance should equal the variance of the total, the latter of which is taken as the true variance. To evaluate the variance estimates, the ratio of the mean variance to the variance of the total were calculated. If this ratio equals one, this would indicate the variance estimates are unbiased. If the ratio is greater than one, this would indicate an over-estimation of the variance, while a ratio less than one would indicate an under-estimation of the variance.

In survey sampling, normality plays an important role in the ability to make inferences about a population based on the information contained in a sample. An important theorem in survey sampling is the Central Limit Theorem (CLT) which states that for any population with mean μ and variance σ^2 if the population is repeatedly sampled over and over again using a sample of size n, the sample mean $\bar{y}$ will be normally distributed with mean μ and variance σ^2/n. To test the validity of this theorem the frequency distribution of the M estimates of the population total for the various sample size – sample design combinations were generated and visually assessed as to their normality. In addition, the proportion of confidence intervals containing the true population total was calculated for each sample size - sample design combination. If the various estimators are normally distributed, the proportion of confidence intervals containing the true population total should equal the nominal value of 0.95.

III. RESULTS AND DISCUSSION

3.1. Characteristics of the transects

Seven main causal and disorder agents affecting the forests in Colorado were considered in this paper: western pine beetle, mountain pine beetle, douglas-fir beetle, western spruce budworm, sudden aspen decline, subalpine-fir mortality, and unknown.

The transects covered an area of 18,905,565 ha of which 8,764,410 ha were classified as forested. The percentage of forest lands on an individual flight line varied from 10.4% to 63.4% with an average of 46.4%. All causal and disorder agents caused some form of damage totaling of 900,328 ha or 10.3% of all forest lands, with the mountain pine beetle being the most destructive (46.3%) and the western pine beetle the least destructive (0.01%). This information is summarized table 1.

Table1. Summary statistics characterizing the population and aerial survey sample units

Statistic	
Total forest area (ha)	8,764,410
Total flight line area (ha)	18,905,566
Total damaged forest area (ha)	900,328
Average damaged area per flight line (ha)	5,962
Average forest area per flight line (ha)	58,042
Proportion of forest per flight line	0.464
Proportion of damaged forest per flight line	0.048
Standard deviation of estimating forest area	0.490
Causal and disorder agents	
Western pine beetle (ha)	96
Mountain Pine beetle (ha)	416,666
Douglas-fir beetle (ha)	9,100
Western Spruce (ha)	154,363
unknown1 (ha)	51,899
Sudden aspen decline (ha)	138,278
Subanpine-fir mortality (ha)	73,187
Others causal and disorder agents (ha)	56,739
Total (ha)	900,328

The distribution of the area damaged on individual transects for the various causal and disorder agents varies by causal and disorder agents. The spatial distribution (i.e., random, aggregated or regular) of damage across transects can influence not only the variability of the estimates but also the accuracy. Looking to the pattern of the area of damage across transects one can see that individual causal and disorder agents have unique spatial patterns. For example, areas affected by the western pine beetle and western spruce beetle are clustered primarily in the southern part of the state, while the damage caused by the mountain pine beetle is clustered in the northern part of the state. In contrast, sudden aspen decline and subalpine-fir morality exhibited somewhat of a curvilinear relationship with the highest levels of mortality in the central part of the state and decreasing going north and south. Except for a few transects in the northern and southern part of the state there was damage of some kind on each flight with a decreasing trend from south to north. There was also less variability in the amount of damage across transects compared to individual causal and disorder agents.

3.2. Statistical Properties of Sample Designs

Estimation of Population Total

All three sample designs provided unbiased estimates of the total area of damage caused by all causal and disorder agents using the six sample sizes (table 2). Estimates from the systematic sampling were consistently closer to the true value than that observed for SRS and PPS sampling. SRS and PPS sampling showed a tendency to underestimate the population total at small and large sample sizes.

Table 2. Influence of sample size and sample design on estimates of the total area damaged by all causal and disorder agents in Colorado. The true value is 900,328 ha

Sample Size (Number transects)	Sample Design		
	SYS	SRS	PPS
10	899,978	898,934	898,892
15	900,092	899,607	899,025
20	900,539	900,711	900,229
25	900,485	900,597	900,270
30	900,710	900,007	900,128
35	900,212	899,836	899,302

The total of seven main causal and disorder agents was estimated. These values vary by sample size and agents with different tendencies indicate that they are not only affected by sample size but also area of damaged and its distribution. The maximum and minimum differences between estimate values and total values are 1.9629% (n = 10, systematic design, western pine beetle) and 0.00086% (n = 10, simple random design, subanpine-fir morality), respectively.

Summary of t-tests used to test the null hypothesis that a sample design – sample size combination provided unbiased estimates of the total area damaged by various causal and disorder agents observed on transects in Colorado. Results are based on 20,000 simulations of the sample design – sample size combination (table 3). These outputs show that all causal and disorder agents, three sample designs give all unbiased estimate of the total indicating that to find which sample design is the best we need to base on the values of variance.

Table 3. Summary t-tests with different sample designs and causal and disorder agents

Causal and disorder	Sample Design[1]	Sample Size					
		10	15	20	25	30	35
Western pine beetle	SRS	U[2]	U	U	U	U	U
	SYS	U	U	U	U	U	U
	PPS	U	U	U	U	U	U
Mountain pine beetle	SRS	U	U	U	U	U	U
	SYS	U	U	U	U	U	U
	PPS	U	U	U	U	U	U
Douglas-fir beetle	SRS	U	U	U	U	U	U
	SYS	U	U	U	U	U	U
	PPS	U	U	U	U	U	U
Western spruce budworm	SRS	U	U	U	U	U	U
	SYS	U	U	U	U	U	U
	PPS	U	U	U	U	U	U
Sudden aspen decline	SRS	U	U	U	U	U	U
	SYS	U	U	U	U	U	U
	PPS	U	U	U	U	U	U
Sub-alpine-fir mortality	SRS	U	U	U	U	U	U
	SYS	U	U	U	U	U	U
	PPS	U	U	U	U	U	U

[1]SRS – simple random sampling; SYS – systematic sample; PPS – probability proportional to size.

[2]U – estimate of the population total is unbiased

Variance Estimates

Estimates of the variance for the total area of damage by all causal and disorder agents decreased with increasing sample size. Both SRS and SYS produced almost identical estimates while estimates of the variance from PPS sampling were consistently larger. This is due to the fact that the area of damage is independent of the amount of forest lands on a given flight line. Thus, selecting transects that are heavily forested does not produce a gain in precision as expected.

Except for SYS sampling the variance of the total showed similar trends as observed for the mean variance. In fact, the ratio of variances were not significantly different from one, indicating the variance estimates obtained using SRS and PPS sampling are unbiased. The variance of the total for SYS sampling was approximately constant across sample sizes resulting in ratio of variances significantly greater than one suggesting the variance estimates are biased. In a 1-in-k systematic sample there are only k possible outcomes. For example, when n = 15, k = 151/15 ≈ 10. These 10 estimates of the population total are repeatedly sampled 20,000 times. The variability among these 20,000 estimates of the total area of damage is significantly less than that observed from SRS and PPS sampling. This is an artifact of systematic sampling applied to small finite populations with a gradient.

Similar trends were observed in the relationship between sample size and estimates of the mean variance of the total area damaged caused by the western pine beetle. At small sample sizes, there is more variability among the possible sample estimates that the estimate of the variance of the total is similar to the mean variance leading to a ratio of variance near one. As the sample size increases the variability among possible sample estimates decrease and the variance of the total decreases at a rate faster than that observed for SRS and PPS sampling.

Assumption of normality

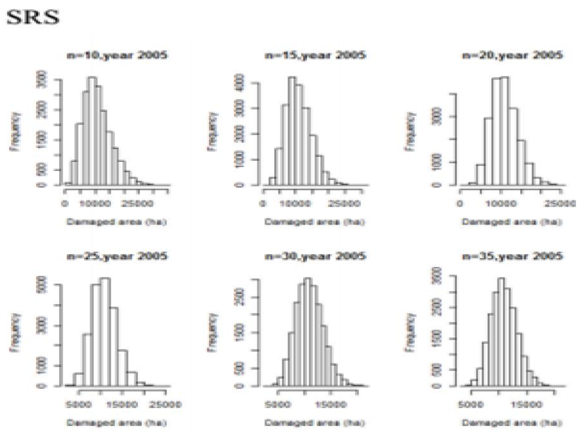

Figure 1. An example of the frequency distribution of 20,000 estimates of the total damage caused by sudden aspen decline (SAD) of SRS design and selected sample sizes. The x-axis is area damaged (ha), the y-axis is frequency

Normality is an important assumption attached to estimates of the population mean and total in survey sampling. It follows from the Central Limit Theorem that for any population with mean μ and variance σ2, if the population is repeatedly sampled using the sample size, estimates of the population mean will be normally distributed with mean μ and variance σ2/n.

To test this assumption, the frequency distribution of the 20,000 estimates of the total damage associated with the individual causal and disorders agents for each of the 20 years and four sample designs were usually inspected. Results of this process showed that the frequency distributions of estimates of the total damage were approximately normally distributed for the four sample designs. The frequency distribution approached normality with increasing sample size. Figure 1 provides an example of the frequency distribution for area damaged caused by sudden aspen decline. The frequency distributions for the other causal and disorder agents and disorders showed a very similar trend. Hansen (1953) mentioned in his book about the important role of testing normality before generating further statistical properties, of which in practical problems of sampling from finite population very often that the initial population from which the sample is drawn is far from normal, and thus the assumption of a normal distribution may lead to grossly wrong impressions as to the precision of variance estimates (Hansen et al. 1953). The ability to assume normality simplifies the interpretation of the statistical properties of the four sample designs.

Confidence coverage rate

Coverage rate is known as the proportion of actual probability that the interval contains the true mean in samples is also estimated. The results show that they are always close to or equal 0.95.

The coverage rate values of SRS and PPS method increase by increasing of sample size and close to 0.95 (figure 2). It is found that SYS's varies by sample size by different agents (douglas-fir beetle, for instance) or always equal to 1.00. It could be caused of selection sample, by using SYS method; some transects are inadequately represented in the sample, called under-coverage. Results also show the coverage rate for SRS is better than PPS's.

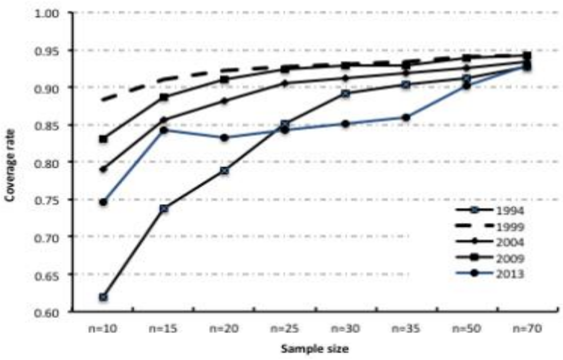

Figure 2. Coverage rates for estimating the total area damaged by mountain pine beetle using SRS for five selected years. Similar trends were observed for the other causal and disorder agents and sample designs

3.3. Discussion

Using different sample designs in different circumstances could help us to obtain more advantages and limit their disadvantages. For systematic sampling, it is easy to conduct in the field. Systematic sampling also has advantage when it could eliminate other source of bias, however, it also could introduce bias where there are patterns which used for samples coincides with patters in the population. In this research, we found that mean variances that derived from SYS are always larger than the variance of mean of each sample size, respectively, differ from that of SRS's and PPS's. The estimated values are always over-estimated. This could be explained as the patterns in sample and population were met. Actually, when we plotted the sample that used for SYS, cyclic patterns was found and samples were systematical picked at almost the peak values. The distribution of systematic sampling is also affected. We found that SRS and PPS have normal distribution with the more sample size increases, the more precision is but does not SYS. This is also affected by number of taking sample. For example, with sample size equal 15 (n=15), using systematic sampling there are only 10 times of taking sample. When n increases, the time of taking sample will be decreased therefore sampling distribution will be more separated means that far from normal distribution.

Using PPS with vary probabilities will lower the variance of an estimator thus allowing for more precise if the probabilities are proportional to the size of sampled measurements. As showing in the results, the sampling distributions follow to the Central Limit Theorem. The shapes of distribution are close to the bell-shape around the mean value with narrower space when sample size increases. The variances decrease with increasing sample size and tend to get stable value from sample size equal 35 transects. The estimators for total using PPS are always higher than that using other different sample designs. However, the sample mean is always less than the population mean and varies although increasing sample size. These suggest that PPS should be considered when we want to use to estimate the total infested area although the estimators are unbiased. The thing that could affect to PPS's precise and decision that should we use PPS in this research is sample infested area does not have strong relationship with the total forest area.

Simple random sampling is free from bias but to get high precision, a large of sample size will be needed. This will take time and cost of money which researchers do not want. In this paper, the outputs from SRS are close to PPS when sample size increases to 35 transects. However, the slope of decreasing lines still high so sample size could be increased more than 35 transects. Alike PPS, the sampling distributions of SRS follow the Central Limit Theorem. The total estimated values and true values are very close together indicate that the estimators are unbiased and SRS is appropriate method to estimate population parameters of our interest.

Result shows all most coverage rate of the sample designs are less than 1 and have trend to close to 0.95. However, sometime it could be found equal 1 (SYS). This could be explained as the sample data include data outside of the population or the starting point was in the peak of cyclical population (called over-coverage). This is normal when data was collected by aircraft from parallel transects with U-turn outside state's boundary which could be difficult to determine clearly sometime.

There are small different between population mean and sample mean both for each agents and for total area of infested forests. These could be random errors when we do simulation. The different values are too small so it could be accepted as unbiased estimates.

IV. CONCLUSION

Distributions of damage forest areas are normal and more precision with increasing sample size. This is true for simple random sampling and probability proportional to size sampling but not systematic sampling. For all three sample designs, the variance means trend to decrease by increasing sample size, also. The distribution of damage area by agents concentrates to small areas than large one. The simple random sampling and probability proportional to size sampling distributions agree with the Central Limit Theorem and the estimates of the population mean and variance are unbiased.

Simple random sampling and probability proportional to size could be applicable used for estimating population in which simple random sampling is the best method.

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MỘT SỐ PHƯƠNG PHÁP LẤY MẪU TRONG ĐIỀU TRA RỪNG BẰNG MÁY BAY TẠI BANG COLORADO, HOA KỲ

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TÓM TẮT

Phác họa (sketch-mapping) thông qua điều tra từ trên không là một kỹ thuật đã được sử dụng để ước lượng diện tích cũng như mức độ rừng bị hại từ trên máy bay. Tại bang Colorado, dữ liệu về điều tra rừng bằng máy bay sử dụng kỹ thuật phác họa đã được triển khai từ năm 1994 tới nay. Do số liệu điều tra hàng năm thường rất lớn, việc phân tích số liệu để có các thông tin về tổng thể thường rất mất thời gian và tiền của. Lựa chọn phương pháp lấy mẫu hợp lý để ước lượng tổng thể do đó là một việc làm cần thiết và mang lại giá trị kinh tế. Trong bài báo này, ba phương pháp lấy mẫu (phương pháp lấy mẫu ngẫu nhiên đơn giản – SRS, phương pháp lấy mẫu hệ thông – SYS, và phương pháp lấy mẫu xác suất theo tỷ lệ - PPS) với các dung lượng mẫu khác nhau được áp dụng và so sánh nhằm tìm ra phương pháp lấy mẫu hiệu quả nhất và có tính khả thi nhất phù hợp với thực tế quản lý tài nguyên rừng của bang. Việc so sánh được tiến hành thông qua các chỉ số ước lượng thống kê có được từ 20,000 lần chạy mô hình cho mỗi phương pháp lấy mẫu với giá trị tương ứng của tổng thể. Những đặc điểm về độ chệch và độ không chệch của các ước lượng được quan tâm và sử dụng như những cơ sở chính cho việc thảo luận.

Từ khóa: Điều tra rừng từ trên không, kỹ thuật phác họa từ máy bay, phương pháp lấy mẫu.

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