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COMPARATIVE ASSESSMENT OF PRE-FELLING SAMPLING DESIGNS IN LOWLAND FOREST OF PENINSULAR MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, In Fulfilment of the Requirements for the Degree of Master of Science.

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June 2016

Chairman : Associate Professor Kamziah Abd Kudus, PhD
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In Peninsular Malaysia, forest sampling during pre-felling (pre-f) inventory is to gather information on tree stocking, species, forest condition, distribution of big trees, bamboo and rattan before commercial felling of trees ≥ 45 cm dbh. Currently, the pre-f inventory is carried out using 20 m x 50 m plot at 10% sampling intensity with 95% confidence level and ±20% sampling error. Even though the sampling design used in pre-f inventory is systematic sampling, it is not known whether this type of design is the most accurate one. Four tested sampling designs in this study are (i) random sampling, (ii) cluster sampling, (iii) systematic sampling, and (iv) transect line sampling. The objectives of this study were to compare the four sampling designs in pre-f of mixed tropical forest. This was done by comparing which sampling design is closer to population data set of 30 ha for trees ≥ 30 cm dbh in estimating mean basal area of trees per ha and volume per ha by species groups of Dipterocarp, Non-Dipterocarp and All Species. This study was carried out using a 30 ha (1000 m x 300 m) forest area within the 50ha Demography Project established by the Forest Research Institute Malaysia (FRIM) in Pasoh Forest Reserve, Negeri Sembilan. The sample estimates were done at 95% confident level and replicated three times based on 20 m x 50 m plot information. The following results were obtained when basal area per ha (m^2/ha) of All Species for trees ≥ 30 cm dbh was inventoried: (i) Systematic sampling underestimated by 0.94% for All Species; (ii) Transect line sampling overestimated by 2.18% for Dipterocarp species; (iii) Cluster sampling overestimated by 1.03% for Non-dipterocarp species. Similarly, to estimate mean volume per ha (m^3/ha) of All Species for trees ≥ 30 cm dbh, the following results were best obtained: (i) Systematic sampling underestimated by 1.16% for All Species; (ii) Transect line sampling overestimated by 1.06% for Dipterocarp species; (iii) Cluster sampling overestimated by 3.77% for Non-dipterocarp species. Meanwhile, in estimating dbh (cm) and height (m), it was found that random sampling would be a preferred sampling design to inventory Dipterocarp and Non-dipterocarp

species. The difference means of dbh (cm) and height (m) to the actual population is overestimated 0.39% and underestimates 0.31% for Dipterocarp species. For Non-dipterocarp species, the difference is underestimating 0.07% and overestimates 0.19% respectively. However, systematic sampling would be the most accurate sampling design to inventory dbh (cm) and height (m) of All Species which is only recorded overestimate of 0.13% and 0.18% respectively. Overall, systematic sampling was best to estimate basal area (m^2/ha), volume (m^3/ha), dbh (cm), and height (m) as it gave the closest, albeit underestimated or overestimated to the actual. Therefore, it is proven that systematic sampling is the most accurate sampling design for pre-f inventory.

Abstract testis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENILAIAN PERBANDINGAN REKA BENTUK PENSAMPELAN SEBELUM TEBANGAN DALAM HUTAN TANAH RENDAH SEMENANJUNG MALAYSIA

Oleh

NURUL ATIQAH BINTI ABD HAMID

Jun 2016

Pengerusi : Profesor Madya Kamziah Abd Kudus, PhD

Fakulti : Perhutanan

Di Semenanjung Malaysia, pensampelan hutan di dalam inventori sebelum tebangan (pre-f) adalah untuk mengumpulkan maklumat mengenai stok pokok, spesies, keadaan hutan, taburan pokok besar, buluh dan rotan sebelum penebangan pokok komersial ≥ 45 cm ppd. Kini, inventori pre-f dilakukan menggunakan 20 m x 50 m plot pada 10% keamatan pensampelan dengan 95% tahap keyakinan dan ± 20% ralat persampelan. Walaupun reka bentuk pensampelan yang digunakan dalam inventori pre-f adalah persampelan sistematik, ia tidak diketahui sama ada jenis reka bentuk ini adalah yang paling tepat. Empat reka bentuk pensampelan yang diuji dalam kajian ini ialah (i) persampelan rawak, (ii) persampelan kluster, (iii) persampelan sistematik, dan (iv) persampelan garis transek. Objektif kajian ini adalah untuk membandingkan empat reka bentuk pensampelan dalam pra-tebangan hutan tropika campuran. Ini dilakukan dengan membandingkan reka bentuk pensampelan yang manakah lebih dekat dengan keseluruhan set data 30 ha untuk pokok ≥ 30 cm ppd dengan menganggarkan jumlah purata pangkal pokok per ha dan isipadu pokok per ha oleh spesis kumpulan Dipterokarpa, Bukan Dipterokarp dan Semua Spesies. Kajian ini telah dilakukan di kawasan hutan 30 ha (1000 m x 300 m) di dalam 50ha Projek Demografi yang ditubuhkan oleh Institut Penyelidikan Perhutanan Malaysia (FRIM) di Hutan Simpan Pasoh, Negeri Sembilan. Anggaran sampel telah dilakukan di tahap keyakinan 95% dan replika tiga kali berdasarkan 20 m x 50 m maklumat plot. Keputusan berikut diperolehi apabila purata kawasan pangkal (m^2/ha) bagi Semua Spesies pokok ≥ 30 cm ppd telah inventori: (i) Persampelan sistematik di bawah anggaran oleh 0.94% untuk Semua Spesies; (ii) Persampelan garis transek di atas anggaran oleh 2.18% bagi spesies Dipterokarpa; (iii) Persampelan kluster di atas anggaran oleh 1.03% bagi spesies Bukan dipterokarpa. Begitu juga untuk menganggarkan jumlah purata isipadu pokok (m^3/ha) bagi Semua Spesies pokok ≥ 30 cm ppd, keputusan terbaik berikut diperolehi: (i) Persampelan sistematik di bawah

anggaran oleh 1.16% untuk Semua Spesies; (ii) Persampelan garis transek di atas anggaran oleh 1.06% bagi spesies Dipterokarpa; (iii) Persampelan kluster di atas anggaran oleh 3.77% bagi spesies Bukan dipterokarpa. Sementara itu, dalam menganggarkan ppd (cm) dan ketinggian (m), didapati bahawa persampelan rawak menjadi reka bentuk pensampelan pilihan untuk inventori spesies Dipterokarpa dan Bukan dipterokarpa. Perbezaan purata ppd (cm) dan ketinggian (m) kepada populasi sebenar ialah masing-masing 0.39% dan 0.31% untuk spesies Dipterokarpa. Bagi spesies Bukan dipterokarpa, perbezaan tersebut ialah masing-masing 0.07% dan 0.19%. Walau bagaimanapun, persampelan sistematik menjadi reka bentuk pensampelan yang paling tepat untuk inventori ppd (cm) dan ketinggian (m) Semua Spesies yang hanya mencatatkan masing-masing 0.13% dan 0.18%. Secara keseluruhannya, persampelan sistematik adalah terbaik untuk menganggarkan kedua-dua kawasan pangkal (m^2/ha) dan isipadu (m^3/ha) kerana ia memberikan anggaran yang paling dekat, walaupun di atas atau di bawah anggaran berbanding nilai sebenar. Oleh itu, ianya terbukti bahawa persampelan sistematik ialah reka bentuk pensampelan yang paling tepat untuk inventori sebelum tebangan (pre-f).

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I certify that a Thesis Examination Committee has met on 21 June 2016 to conduct the final examination of Nurul Atiqah binti Abd Hamid on her thesis entitled "Comparative Assessment of Pre-Felling Sampling Designs in Lowland Forest of Peninsular Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Signature: ______________________
Name of member of Supervisory Committee: Dr. Mohamad Roslan Mohamad Kasim

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASEAN	Association of Southeast Asian Nations
BL	Base Line
CONFORMS	Continuous Forest Resource Monitoring System
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
FDPM	Forestry Department Peninsular Malaysia
FRIM	Forest Research Institute Malaysia
GIS	Geographical Information System
ITTO	International Tropical Timber Organization
LSD	Least Significant Difference
MAJURUS	Majlis Urusan Hutan dan Silvikultur / Forests and Silviculture Affairs Council (Peninsular Malaysia)
MUS	Malayan Uniform System (Peninsular Malaysia)
NFI	National Forest Inventory
NSF	National Science Foundation (USA)
Post-F	Post-Felling
Pre-F	Pre-Felling
PSP	Permanent Sample Plot
SFM	Sustainable Forest Management
SL	Sampling Line
SMS	Selective Management System (Peninsular Malaysia)
STRI	Smithsonian Tropical Research Institute (USA)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Mixed tropical forests in most parts of the world are naturally regenerated, and thus comprise a mixture of age classes and species. In the tropical zone, they are generally characterized by a very large number of species compared with temperate and subtropical mixed forests. Mixed tropical forest occurs in a number of commonly recognized sub-types, including the true evergreen rainforests, seasonal semi-deciduous forests, drier forests on the margins of the forest zone, characterized by frequent fires and reduced species complexity, tropical montane forests at higher altitudes, and special types occurring in swampy or salinized soils (UNESCO, 1978; Whitmore, 1990).

The natural forest resources of Peninsular Malaysia are estimated at about 5.79 million ha or 43.9% of the total land area in 2012. They included 4.89 million ha of permanent reserved forest, 0.59 million ha of national and wildlife parks and 0.30 million ha of stateland forest (FDPM, 2013). In 2010 and 2011, Malaysia exported timber and timber products worth RM20.52 billion and RM20.06 billion respectively. Wood-related industry is one of the main revenue earners in Malaysia, generating a yearly export income of RM21.7 billion from 2006 until 2010 and creating about 300,000 job opportunities.

Malaysia's natural forests continue to play a major role in the economy, contributing much to the development of forestry-based industries, of primary as well as downstream manufacturing activities (Nakama *et al*, 2006). All decision-making concerning forest requires information. This information is acquired among other by means of forest inventories - systems for measuring the extent, quantity and condition of forests (Penman *et al,* 2003).

Forest inventory is to estimate means and totals for measures of forest characteristics over a defined area. Such characteristics include the volume of trees, the area of a certain type of forest and nowadays also measures concerned with forest biodiversity and carbon. The most current issue is estimating the carbon stock in the forest. Several types of inventory used in Malaysia are national forest inventory, forest management inventory, continuous forest inventory and permanent sample plot inventory.

A forest inventory could in principle be based on a complete census, i.e. on measuring every tree in a given area, but this is usually impossible in forestry because of the large areas involved. Therefore, the acquisition of information is typically based on sampling, i.e. only a proportion of the population, a sample, is inspected and inferences regarding the whole population are based on this sample.

Sampling is a necessary technique used in most forest inventories for economic reasons. Populations to be inventoried, e.g. population of trees for the construction of volume tables or assessment of defect, or for the estimation of mensuration parameters in plantations, are usually too large to be fully enumerated. Several sampling designs may be used in the same forest inventory in different parts of the operation. Their main, but not exclusive, use is to estimate forest areas and its parameters. In a sampling design of a forest inventory one generally refers to the disposition of the field samples. Thus, sampling techniques can be considered as only one among other tools of forest inventory and their importance must not be underestimated.

1.2 Forest Management Inventory in Malaysia

The historical development of natural forest management and silviculture led to the Malayan Uniform System (MUS) (Wyatt-Smith, 1963). MUS have been the basic silvicultural system since the 1950's. It was developed for lowland dipterocarp forests rich in Meranti (*Shorea* spp.) and Keruing (*Dipterocarpus* spp.). However, MUS has not been effective in the hill forest due to the comparatively more difficult terrain, uneven stocking, and lack of natural regeneration on the forest floor before logging due to irregular seeding from potential mother trees (Thang, 1986).

The MUS consists of removing the mature crop in one single felling of all trees down to 45 cm dbh for all species and releasing the selected natural regeneration of varying ages, which are mainly the light demanding medium and light hardwood species. This system had been successfully applied to the lowland dipterocarp forest with a cutting cycle greater than 50 years, but had been found to be unsuccessful in the hill dipterocarp forest (Wyatt-Smith, 1963). Since the bulk of the permanent forest estate now consists of hill forest, a new system has now been developed - Selective Management System (SMS): a polycyclic management system in which 25 to 30 years cutting cycle is anticipated (Thang, 1986).

Consequently, the SMS was introduced in 1978 to allow for more flexible timber harvesting regimes which are consistent with the need to safeguard the environment and at the same time to take advantage of the demand of the timber market. More importantly, it discourages the poison-girdling of the presently non-commercial species which will not only conserve the wood but also the genetic resources available in the forests for the future. The SMS requires the selection of harvesting regimes based on pre-inventory (Pre-F) data in order to ensure ecological balance and environmental quality.

Current Pre-F forest inventory practices use systematic sampling design. There are square plots nested inside larger rectangular plots. A base line (BL) is established for full coverage. The sampling lines (SL) are perpendicular to base line. Distance between the sampling lines is 100 m. First line starts 50 m from start point of the base line. The main plot is 50 m x 20 m (0.10 ha). The inventory design is systematic line plot sampling. The main plots are placed systematically.

Figure 1 shows the location of base line, sampling line and main plot and Figure 2 shows the main plot and small plots. In the present Pre-F system, all parameters of interest, such as number of trees per ha, basal area per ha, and volume per ha are estimated using a 10% sampling intensity with a confidence level of 95% and an error level of ±20% (Wan Razali and W. M. Shukri, 1999).

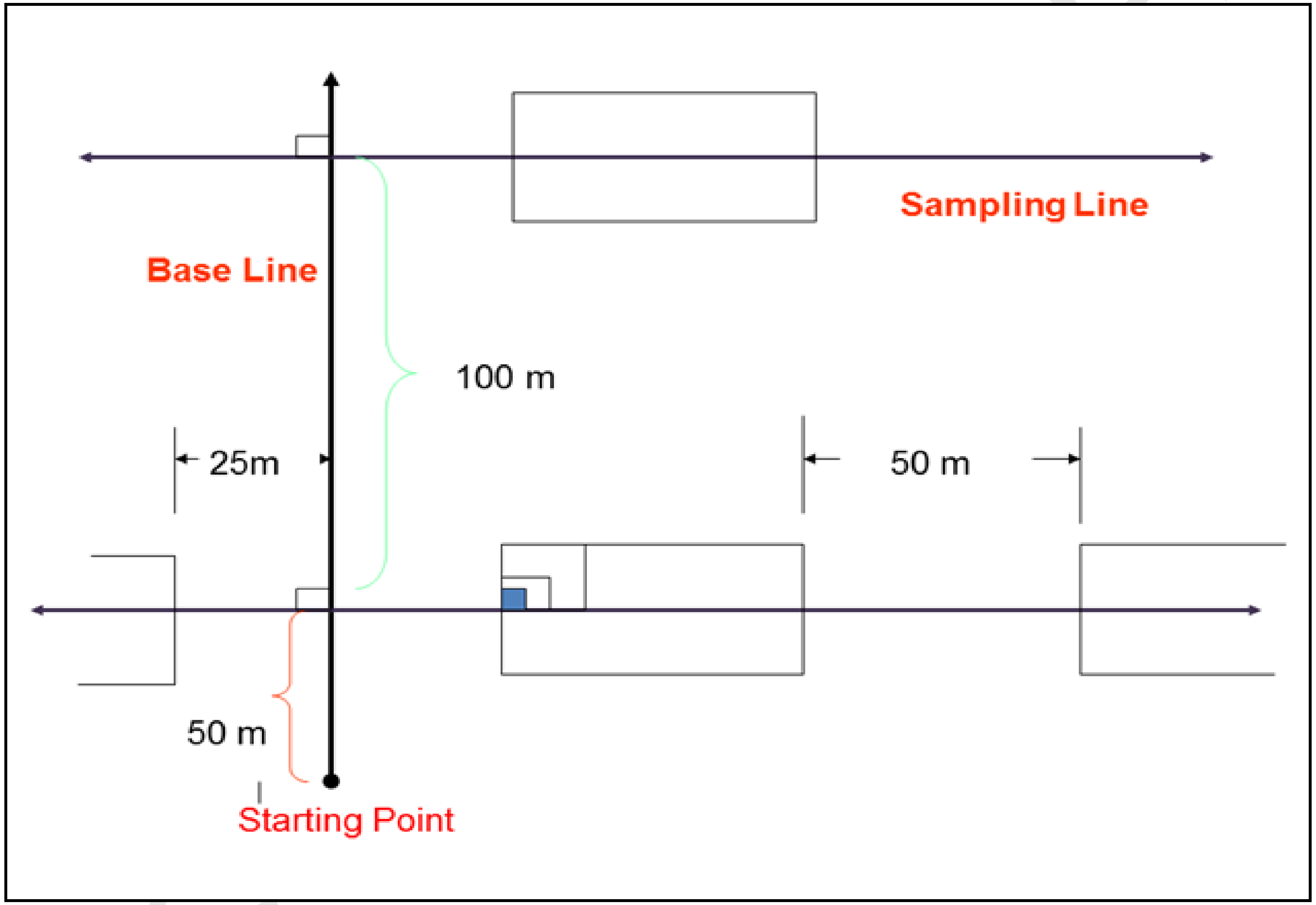

Figure 1: The location of base line, sampling line and main plot (Adapted from Thang, 1986)

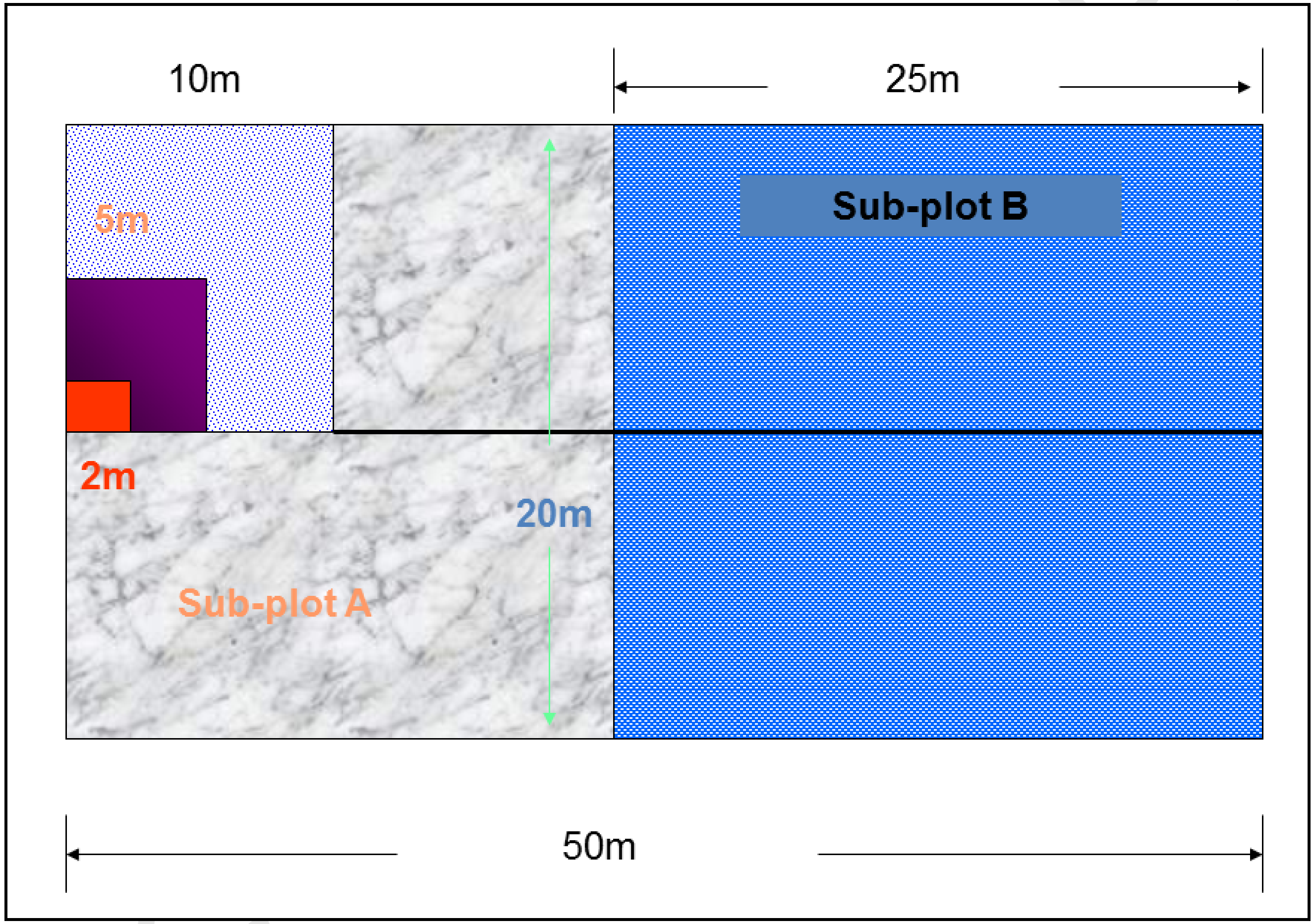

Figure 2: The main plot and small plots
(Adapted from Thang, 1986)

1.3 Problems statement

Complete inventories are expensive, tedious and as a result non-sampling errors (incorrect recording of tree diameters, heights and quality) tend to increase (Bell, 1997). For this reason, sampling has been introduced, which if properly done, provides reasonable estimates of the true population. Therefore, to allow for the most efficient collection of data, it is crucial to select a sampling method or combination of sampling methods.

There are numerous different sampling designs and there is no particular design meets the needs of all inventories. In meeting the objectives of an inventory for each forest area that varies, a design must be selected that provides best estimates at a reasonable cost. There are seven basic factors influence the choice of the design (Taylor *et al.,* 1989); information required and its desired precision, composition of the forest and its variability, topography and accessibility, human-resource availability and level of skills, availability of time and funds, availability of maps, aerial photographs and other relevant information, and designers' knowledge of statistics and sampling theory.

The most efficient sampling design is one that, for a specific cost gives the smallest error for the parameter to be estimated, or for an accepted error is the least cost (Taylor *et al.,* 1989). Defining efficiency is straightforward, but determination of the most efficient design is complicated because it is impossible to consider all possible sampling designs when choosing a design. Plus, some characteristics of the contemplated design are taken for granted. Based on prior experience in field sampling, the unit area at each stage, the number of stages and stratification are fixed prior to optimization which is leads to only partial optimization.

In another situation, a sampling design is optimal for a given parameter such as gross volume of large trees over 60 cm diameter at breast height (dbh) but it may not be optimal for considerably smaller trees. Consequently, for consideration in the design stage, it is crucial to select the most important inventory parameters which are sometimes not easy as consideration needs to be given to others as well.

In Peninsular Malaysia, forest sampling to determine the stocking available before commercial felling (Pre-F inventory) of trees above 30 cm dbh in 20 x 50 m plot was done using a 10% sampling intensity with 95% confidence level and ±20% sampling error (Wan Razali, 1995). Even though the sampling design used in pre-f inventory is systematic sampling, it is not known whether this type of design is the most accurate one that estimates the whole population at 95% confidence level. However, little research has been done to verify the accuracy of these current Pre-F inventory practices. One of research was evaluating design unbiasedness of the pre-felling inventory in Peninsular Malaysia which recommend the Random Point Start method, which is unbiased in all simulation trials in addition to retaining all the advantages of the current Pre-F protocol (Lam TY et al, 2013).

Verification of the current sampling technique is important to reorganise the forest inventory practices aiming at introducing sustainable management of the forest resources because it is the basis for the work of field officers, managers and research officers alike. Sustainable management with high outtum can never be put into practice without accurate measurements, efficient designs for inventories, data processing based on sound statistical procedures and without the knowledge of the trees' growth. Therefore, random sampling, cluster sampling, systematic sampling, and transect line sampling were the four sampling designs that tested in this study.

1.4 Objectives

a) To compare four sampling designs in terms of dbh, height, basal area and volume in mixed tropical forest of Peninsular Malaysia.
b) To choose the most accurate sampling design to be use in pre-felling forest inventory of 10% intensity with 95% confidence level in estimating average basal area and average volume of all trees ≥30 cm dbh by species groups (Dipterocarp, Non-dipterocarp and All species).
c) To choose the most accurate sampling design to be use in pre-felling forest inventory of 10% intensity with 95% confidence level in estimating average dbh and average height of all trees ≥30 cm dbh by species groups (Dipterocarp, Non-dipterocarp and All species).
d) To verify or validate the accuracy of the Pre-F sampling technique as currently practised by the Forestry Department of Peninsular Malaysia and others that use the same method.

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