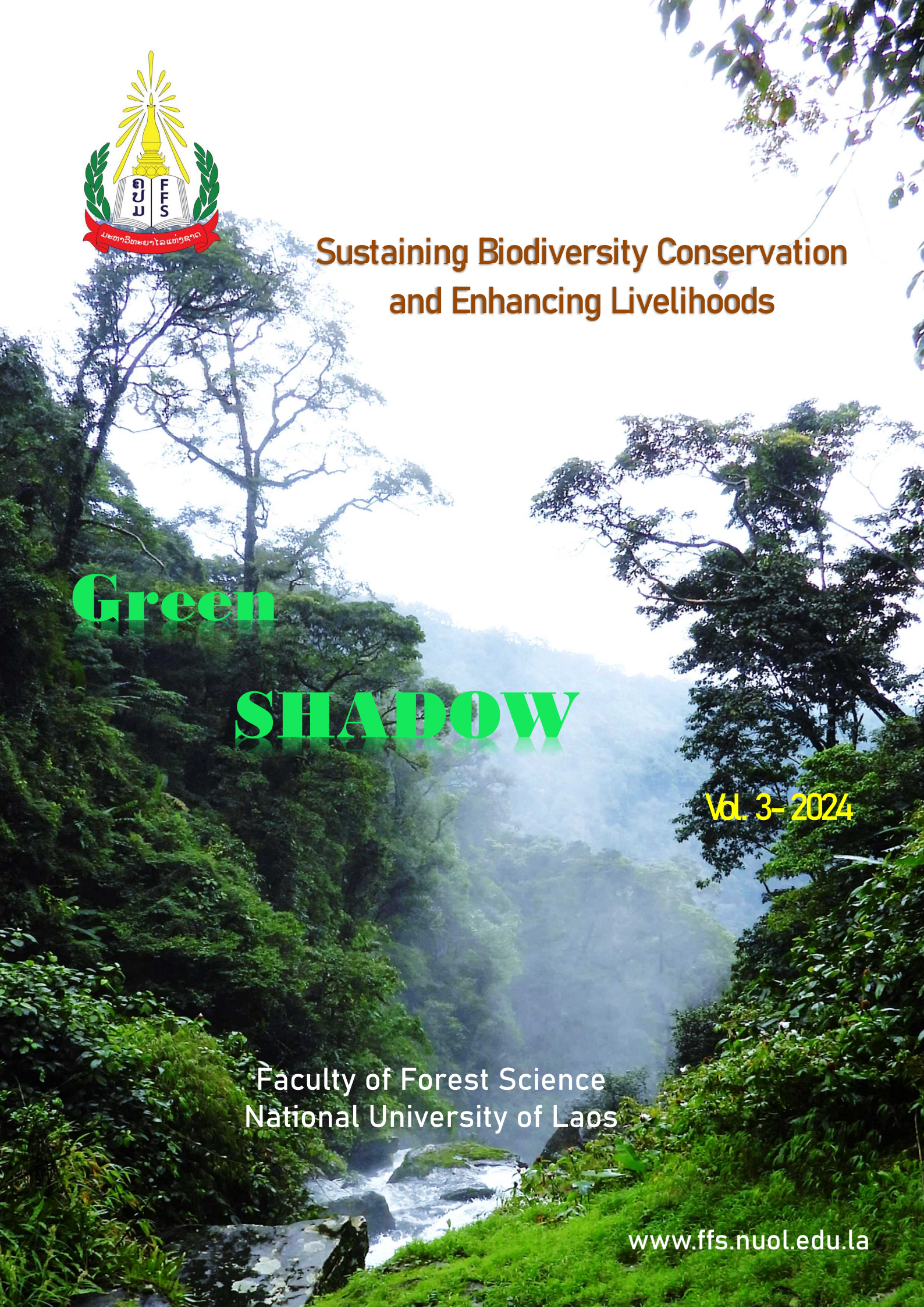


# Sustaining Biodiversity Conservation and Enhancing Livelihoods

# Green SHADOW

Vol. 3- 2024

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National University of Laos

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**Back cover: Limestone karst and Laotian Langur, The Rock Viewpoint, Khammouane Province**

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# *Green Shadow*

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*Faculty of Forest Science*
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**March 2024**

# Forword

Welcome to the Third Volume of Journal, *Green Shadow*, an esteemed publication by the Faculty of Forest Science at the National University of Laos. This journal stands as a beacon of innovation, dedicated to the exploration and dissemination of groundbreaking research in ecology, wood technology, and environmental sustainability. In this volume of the Journal, we reaffirm our dedication to deepening the global understanding of the complex ecosystems that underpin natural resource experimental data.

The publication of this journal is driven by our ambition to establish a scientific forum that not only fosters academic dialogue but also provides essential insights for informed decision-making in the sustainable management of our nation's precious natural resources.

In alignment with our core principles of accessibility and inclusivity, we have made concerted efforts to ensure this volume reaches a diverse readership. This includes both established researchers and emerging scholars, by presenting content in their preferred languages. While this volume is written in English, we are dedicated to broadening our linguistic range in subsequent editions to encompass both Lao and English. This initiative reflects our commitment to honoring the linguistic diversity of our scholarly community.

We would like to extend our deepest appreciation to all contributors, reviewers, and readers, whose unwavering support and commitment have been pivotal in bringing this volume to fruition. It is our earnest hope that the Journal ***Green Shadow*** will ignite curiosity, inspire passion, and serve as a catalyst for positive environmental transformation. Together, we embark on a collective quest towards a more sustainable and flourishing future.

The publication of this third volume stands as a testament to the dedication and expertise of our contributors, coupled with the steadfast support of our readership. We fervently hope that ***Green Shadow*** will spark curiosity, stimulate dialogue, and cultivate a shared dedication to preserving our resources for future generations.



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# 1
# Assessing the Efficacy of Distance Sampling in Estimating the Population Abundance of the Endangered Long-Tailed Macaque *(Macaca fascicularis)*

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**Abstract**

*Accurately estimating the population abundance of endangered species is crucial for the implementation of effective conservation and management strategies. This study utilized Distance Sampling to estimate the population abundance of Long-tailed macaques in the southern provinces of Laos. The survey area encompassed a variety of habitats, including semi-evergreen forests, mixed deciduous forests, bamboo areas, and agricultural lands. Distance analysis involved the calculation of perpendicular distances from line transects to macaque observations. The study faced challenges such as reduced detection probability at greater distances due to dense forest cover and environmental disturbances during field surveys. Despite these obstacles, the average density of Long-tailed macaques in Southern parts of Laos was estimated at 39.66 individuals per square kilometer, with a total estimated population size of 30,586 individuals. The study underscores the importance of acknowledging limitations and challenges in distance sampling, such as sample size and distance estimation accuracy, to enhance the reliability and applicability of population estimates. Future research endeavors should concentrate on refining survey methodologies and improving data collection techniques to enhance the accuracy and precision of population estimates using Distance Sampling in similar wildlife studies. This research provides valuable insights into Long-tailed macaque population dynamics and offers implications for wildlife conservation and management programs in Laos.*

Keywords: Long-tailed macaque; *Macaca fascicularis*; Distance sampling; Population abundance estimation

## Introduction

Understanding the dynamics and structure of wildlife populations, including their density or abundance, is a cornerstone of wildlife research. This knowledge is pivotal for grasping how populations adapt to environmental changes (Allendorf et al., 2013). For example, comprehending the relationship between vital rates, instantaneous population growth rates,

and population density or abundance is essential (Lounsberry et al., 2015). Moreover, accurate assessments of population density or abundance are fundamental for setting management goals, such as achieving a sustainable balance between resource availability and population size, alongside considering other demographic factors (Royle & Nichols, 2003)

Accurate insights into the distribution and abundance of animal species significantly enhance their management (Cassey, 1999), However, obtaining these insights can be challenging, especially for rare or elusive species (Bellemain et al., 2005). Over the past two decades, Distance Sampling methods have evolved and been extensively applied to animal population studies. Their primary advantage is the ability to adjust for varying detection probabilities, thereby providing more precise population estimates by accounting for the likelihood of observing individuals at different distances (Buckland et al., 2015).

Despite the availability of various estimators and methodologies for population size estimation, Distance Sampling is distinguished by its robust scientific foundation (Silvy, 2012). However, reliance on a single method may introduce method-specific biases. There is a need for a more comprehensive exploration of Distance Sampling to address identified gaps and enhance its application.

This study aimed to evaluate the accuracy and precision of Distance Sampling in estimating the population of Long-tailed macaques in Southern parts of Laos, and to explore the implications of these findings for wildlife conservation and management programs.

## Methodology

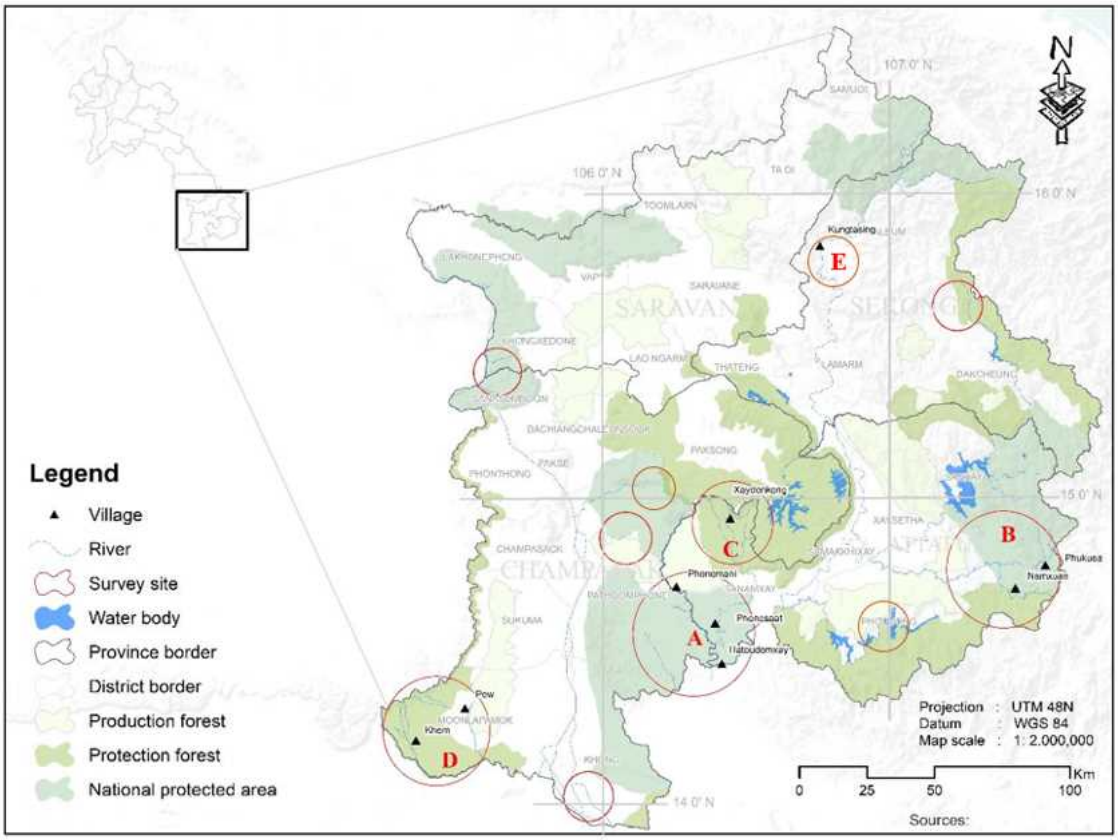
We conducted fieldwork in the southern provinces of Laos, known for their abundant population of long-tailed macaques (*Macaca fascicularis*) as documented by Hamada et al. (2011). Our study area encompassed three provinces: Attapeu, Champasak, and Sekong, situated between N14.00°–16.00° and E105.00°–108.00°.

The survey area consisted of semi-evergreen forests, mixed deciduous forests, bamboo areas, and agricultural lands, all in close proximity to rivers, streams, and wetland areas. These diverse habitats within the study site provided a suitable environment for the long-tailed macaque (*Macaca fascicularis*) population.

### *Surveys Design and Data Collection*

The surveys were conducted between November 2022 and January 2023, covering a total of 75.6 km across thirty line transects within a study area of 234.18 sq. km. Each transect was a minimum of 2-3 km in length, with a minimum distance of 200 meters between them, creating a systematic yet random grid pattern in terms of habitats. Survey activities took place in the morning from 6-11 am and in the afternoon from 1-5 pm, with a walking speed of 1.5 km/h. During the surveys, stops were made frequently to listen for movement and scan the area. Surveys were not conducted during rain or windstorms to ensure accurate data collection.

The survey teams consisted of pairs, with an 'observer' and a 'recorder'. The observer led the way, focusing on scanning forward along the transect up to angles of 45°, while the recorder followed behind, scanning wider angles from the transect bearing. Target animals were identified either visually or by vocalizations, and counting began when the animal was visible within 15 minutes (Plumptre & Cox, 2006).




(Source) The Authors.

Upon observation, the observer used binoculars to identify the species and a laser rangefinder to measure the distance to the animal. The recorder then took a bearing using a compass and recorded the time of observation, transect number, age/sex composition (if possible), estimated group size, and habitat quality. If the animal was in motion, the distance and bearing were measured to the point where it was first sighted.

Conducting surveys in pairs helped minimize the chances of missing animals near the transect line and reduced the risk of double-counting individuals. To prevent overlap in group observations between transects, observers spent no more than 10 minutes observing a group once the target animal was encountered.

### *Distance Analysis*

The method for determining the perpendicular distance from the transect line to each observation involved calculating the product of the sine of the angle between the bearing to the LTM and the transect bearing, and the distance from the observer to the LTM. Following this, the data on perpendicular distances were analyzed using a histogram divided into 20 equal-sized intervals to identify any potential biases. This analysis indicated a negligible movement relative to the observer and a lack of significant clustering of observations within specific distance intervals. As a result, the data were examined without grouping, and a truncation method was employed to exclude the 5% of observations that were the furthest from the transect line, as suggested by Buckland (Buckland et al., 2015).

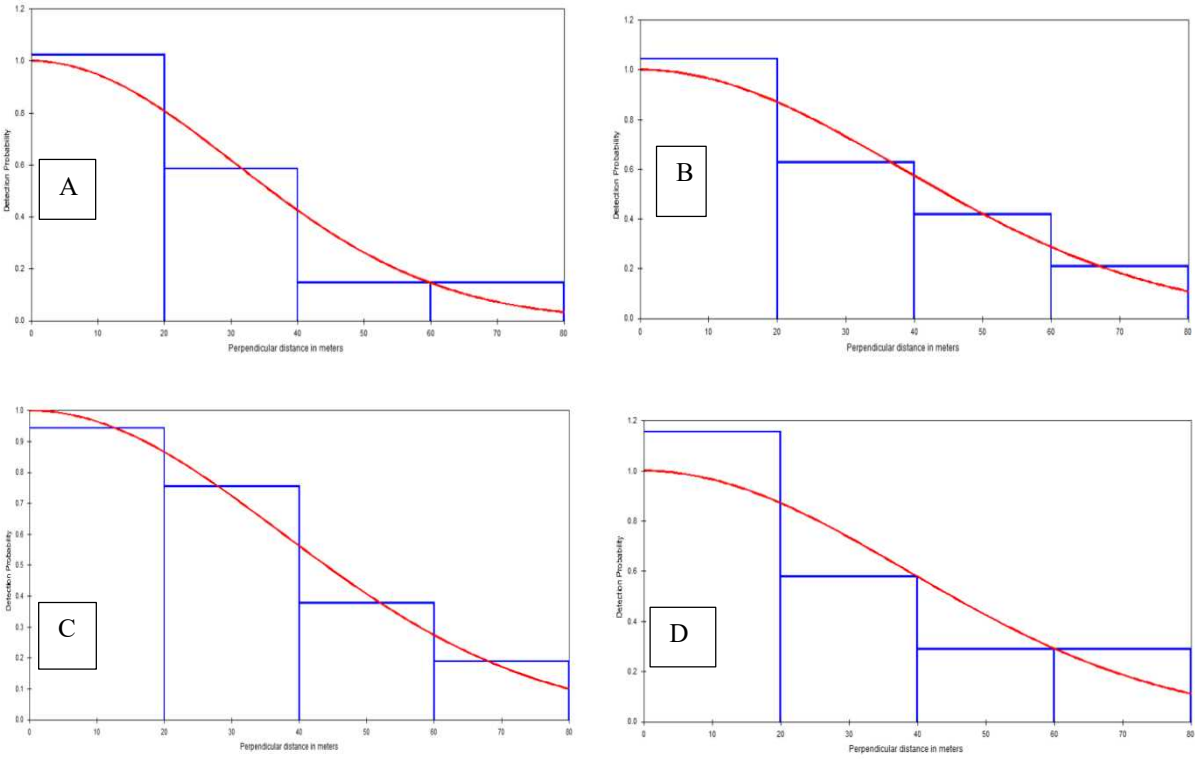
For the estimation of LTM density, the DISTANCE 7.5 software was utilized. Following the guidelines of Buckland et al. (2015), various models were evaluated to estimate density. The detection probability histogram and goodness-of-fit test statistics of each model were

meticulously examined. The selection of the optimal model was based on the model that presented the lowest Akaike's Information Criterion (AIC) value, which was the uniform key function model with a single cosine adjustment term, indicating it as the most suitable for fitting the detection function. It is important to note that all models were carefully considered to ensure the most accurate estimation of LTM density.

## Results

The 111 line transects were repeatedly surveyed over four potential site area and 88 observations of LTM were recorded. A total transect length of 256.1 km was surveyed. The detection function histogram of the perpendicular distance data for each site (Fig. 1) exhibited a broad shoulder, suggesting that there was no movement of LTM away from the line. The half-normal cosine model provided a good fit with the distance data from the four surveyed area are ($\chi$ 2 = 0.86, d.f. = 2, P = 0.64), ($\chi$ 2 = 0.11, d.f. = 2, P = 0.94), ($\chi$ 2 = 0.02, d.f. = 2, P = 0.98), ($\chi$ 2 = 0.58, d.f. = 2, P = 0.74) in zone A, B, C and D respectively. The population density of LTM averaged 39.66 per square kilometer. The estimated habitat for LTM in southern Laos is 727.07 square kilometers, with Attapue, Cham-pasak, Salavan, and Sekong representing 439.72, 229.67, 40.68, and 17 square kilometers, respectively. As a result, the estimated LTM population was 30,586.

Figure 1: Probability Detection Function g(x) (Half Normal Model with Adjustment) for LTM in Four Survey Sites, by Perpendicular Distance from the Transect Line.




(Source) The Authors.

**In Zone A:** We conducted comprehensive field surveys across the estimated habitat for the LTM, covering a total of 75.6 kilometers along thirty line transects within an area of 234.18 square kilometers. Throughout these surveys, we successfully recorded 13 visual sightings of

the LTM, as detailed in Table 1. Our analysis revealed that the average density of the LTM within this habitat stands at 50.42 individuals per square kilometer. Furthermore, we estimated the total population of LTM in the surveyed area to be approximately 11,809 individuals, with a 95% confidence interval ranging from 5,425 to 25,705 individuals.

Table 1: Density and Population Estimates Summary of Zone A

| Parameter | Point estimate | Standard Error | Percent Coef. of Variation | 95% Confidence interval (CI) | |
|---|---|---|---|---|---|
| | | | | Lower CI | Upper CI |
| DS | 2.26 | 0.81 | 35.86 | 1.11 | 4.57 |
| E(S) | 22.28 | 4.06 | 18.22 | 14.97 | 33.17 |
| D | 50.42 | 20.28 | 40.23 | 23.16 | 109.77 |
| N | 11,809.00 | 4,750.40 | 40.23 | 5,425.00 | 25,705.00 |

(Source) The Authors.

**In Zone B:** We conducted a comprehensive survey by walking twenty-seven line transects, covering a total distance of 63.00 kilometers. During these walks, we recorded 44 sightings of the LTM species across an estimated habitat area of 161.70 square kilometers. Utilizing DISTANCE 7.5 for our analysis, we determined the average density of LTM within this zone to be 42.78 individuals per square kilometer. Furthermore, the estimated population size of LTM in the area was calculated to be 6,918 individuals, with a 95% confidence interval ranging from 3,021 to 15,838 individuals (refer to Table 2 for details).

Table 2: Density and population estimates Summary of Zone B

| Parameter | Point estimate | Standard Error | Percent Coef. of Variation | 95% Confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower CI | Upper CI |
| DS | 1.89 | 0.68 | 35.96 | 0.92 | 3.88 |
| E(S) | 22.52 | 5.14 | 22.83 | 13.52 | 57.49 |
| D | 42.78 | 18.22 | 42.60 | 18.68 | 97.94 |
| N | 6,918.00 | 2,946.80 | 42.60 | 3,021.00 | 15,838.00 |

(Source) The Authors.

**In Zone C:** thirty line transects were walked, totaling 71.7 km within 117.1 sq.km of the total estimated habitat for LTM. During our surveys, we made 12 visual observations of LTM (table 6). The result showed that the average Density and estimated population size of LTM was 36.78 indi./sq.km and 4,308 individuals (95% CI: 2,132-8,706), respectively.

Table 3: Density and Population Estimates Summary of Zone C

| Parameter | Point estimate | Standard Error | Percent Coef. of Variation | 95% Confidence interval (CI) | |
|---|---|---|---|---|---|
| | | | | Lower CI | Upper CI |
| DS | 1.84 | 0.62 | 33.71 | 0.94 | 3.61 |
| E(S) | 19.90 | 2.34 | 11.79 | 15.31 | 25.85 |
| D | 36.78 | 13.13 | 35.72 | 18.20 | 74.34 |
| N | 4,308.00 | 1,538.60 | 35.72 | 2,132.00 | 8,706 |

(Source) The Authors.

**In Zone D:** We conducted comprehensive field surveys, traversing thirty line transects that spanned a total distance of 71.7 kilometers, covering an area of 117.1 square kilometers, which represents the estimated habitat range for the LTM species. Throughout the course of our surveys, we successfully made 12 visual sightings of LTM, as detailed in Table 6. The findings from our analysis indicate that the average density of LTM within this habitat is approximately 36.78 individuals per square kilometer. Based on this density, we estimate the total population size of LTM in the surveyed area to be around 4,308 individuals, with a 95% confidence interval ranging from 2,132 to 8,706 individuals.

Table 4: Density and Population Estimates Summary of Zone D

| Parameter | Point estimate | Standard Error | Percent Coef. of Variation | 95% Confidence interval (CI) | |
|---|---|---|---|---|---|
| | | | | Lower CI | Upper CI |
| DS | 1.86 | 0.77 | 41.60 | 0.80 | 4.31 |
| E(S) | 15.37 | 2.61 | 16.98 | 10.17 | 23.22 |
| D | 28.67 | 12.88 | 44.93 | 11.79 | 69.67 |
| N | 2,655.00 | 1193.00 | 44.93 | 1,092.00 | 6,452.00 |

(Source) The Authors.

## Discussion

The analysis of detection probability revealed that the most appropriate distance sampling model was a half-normal model with adjustments. The graphical representation of the four-site survey (Figure 1) illustrated a sharp decline in detection probability as distance increased, particularly noticeable between 20 and 40 meters, with no detections beyond 80 meters. This decline in detection probability could be attributed to the dense forest cover in the survey area, which included bamboo, shrubs, and tall grasses, reducing visibility up to 3 meters. Additionally, the presence of strong winds during field surveys may have caused disturbances, such as loud noises and tree movements, potentially impacting the sensory perception of the target animals. Failing to consider reduced detection at greater distances could result in an underestimation of LTM abundance by approximately two times across all survey zones, as indicated by the detection probabilities ($P = 0.47$, $P = 0.57$, $P = 0.56$, and $P = 0.57$ for Zones A, B, C, and D, respectively).

Despite these challenges, the average density of LTM in Southern parts of Laos, estimated at 39.66 individuals per square kilometer, was relatively high compared to LTM densities reported in other natural habitats. For example, the average density of LTM in Indonesia was recorded at 33.6 individuals per square kilometer on Tinjil Island (Leeson et al., 2004) and 41.4 individuals per square kilometer in Baluran National Park (Hansen et al., 2019). This suggests that the LTM population in Southern parts of Laos is thriving within its habitat despite the encountered challenges during the survey. It is important to note that the number of visual observations of LTM in each survey zone was below the recommended threshold of 60–80 observations by Buckland et al. (Buckland et al., 2015) for accurately fitting the detection function. Additionally, using estimated distances in the analysis may introduce biases due to potential human errors during surveys. Therefore, careful consideration should be given to the number of observations and the accuracy of distance estimations to ensure the reliability and applicability of the density estimates derived from this study. By acknowledging these limitations and challenges, future research efforts can focus on optimizing survey

methodologies, increasing sample sizes, and enhancing data collection techniques to improve the accuracy and precision of population estimates using Distance Sampling in similar wildlife studies.

In 2023, the Long-tailed Macaque population in Southern parts of Laos was estimated to cover an area of 727.07 sq.km, with a total estimated population size of 30,586 individuals. These findings present varying estimates and perspectives on the population and distribution of macaques LTM in Laos compared to previous reports, reflecting the challenges and complexities involved in studying LTM populations. The discovery of LTM represents a significant advancement in understanding the population dynamics of Long-tailed macaques in Southern parts of Laos. The estimated population size of over 30,000 individuals within the study area underscores the importance of Southern parts of Laos as a stronghold for this species. However, these findings should be interpreted in the context of earlier research, such as Hamada's work in 2011, which also contributed to our understanding of LTM population in Laos. Hamada (Hamada et al. 2011) estimated the national population of Laotian Long-tailed macaques to range from 420 to 4,200 individuals, providing valuable insights into the broader context of LTM conservation in Laos. Nevertheless, more recent observations by Hansen (Hansen et al., 2022) indicate a significant decline in the LTM population in the country, referencing Phaivanh Phiapalath's personal observations. He reported a drastic decline in the national population, estimating it to be as low as 300–500 individuals for the entire country. This alarming revelation represents a 90% decline from estimates published in 2011 by Hamada. The contrasting findings between these studies may be attributed to methodological differences, including survey techniques and data analysis approaches, as well as variations in spatial and temporal factors such as habitat distribution, sampling biases, and changes in population dynamics over time. Additionally, differences in data quality and reliability could contribute to variations in the reported estimates. However, these factors underscore the complexity of LTM population studies and emphasize the importance of careful consideration and ongoing monitoring efforts to ensure accurate assessments and effective conservation strategies for Long-tailed macaques in Laos.

## Conclusions

The study concluded that the half-normal model, after adjustments, was the best for estimating the detection probabilities of Long-tailed macaques in Southern parts of Laos, revealing a decrease in detection probability with increasing distance from the observer, particularly between 20 and 40 meters, and no detections beyond 80 meters. This decrease was mainly due to dense vegetation and disturbances from strong winds, which could lead to underestimation of the LTM population. Despite these challenges, the study reported a high average density of LTMs in Southern parts of Laos, indicating a thriving population, with an estimated average density of 39.66 individuals per square kilometer, higher than in other regions. However, the study acknowledged limitations such as fewer visual observations than recommended and potential distance estimation biases, suggesting future research should focus on improving survey methodologies and data collection for more accurate wildlife population estimates. In 2023, the LTM population in Southern parts of Laos was estimated at 30,586 individuals over 727.07 square kilometers, significantly higher than previous estimates. This contrasts with reports of a national decline to 300–500 individuals, highlighting the need for careful monitoring and methodological improvements.

## Acknowledgment

We extend our heartfelt gratitude to the local government agencies, particularly the Provincial Agriculture and Forestry Office of Attapue, Champasak, and Sekong Provinces, for their invaluable support and permission to conduct our fieldwork. A special thanks goes to the staff of the District Agriculture and Forestry Office (DAFO), whose assistance in conducting fieldwork and data collection was indispensable. Their dedication and hard work made the challenging task of fieldwork significantly more manageable.

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# 2
# Estimating Stiffness of Rubber Plantation Timber: A Comparative Study Smart Thumper Application and Universal Testing Machine

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**Abstract:**

*This study aimed to examine the accuracy of estimating the modulus of elasticity (MOE) of rubber plantation timber using both the SMART THUMPER™ application and the universal testing machine. The results indicated that there was no significant difference between the MOE values obtained from the two testing methods, as determined by a P-value of 2.06 (P>0.05). Specifically, the average MOE for the universal testing machine was calculated to be 10048±2610 MPa, while for the Smart Thumper App, it was 10155±2415 MPa. To further enhance the findings, it is recommended to conduct additional experiments involving groups of specimens with defects and clear specimens.*

**Keywords:** Rubber timber, stiffness properties, Smart Thumper Application, modulus of elasticity.

## Introduction

The world population have been continuously increasing and it was projected to reach 9.2 billion by 2040, this growth in higher demand for wood fibre and wooden products. In response to this demand various sectors within the wood industry have shown interest in planting rubber tree for latex production with the added benefit of harvesting logs once the latex is depleted. As an example, Laos currently has 446,000 hectars of plantation which covered by rubber tree area of 58% out of acacia, eucalyptus species, and teak (Smith et al. 2020).

Normally, the mechanical properties of timber are assessed using a Universal Testing Machine, in accordance with industry standards for MOE (Modulus of Elasticity). In Australia, the primary test method for determining timber MOE is the static bending test, as outlined in the Australian and New Zealand Testing Standard (AS/NZS 4063.1, 2010).
The prediction of the modulus of elasticity (MOE) for timber has become increasingly important within the operational value chain, particularly in grading and pre-sorting processes.

While traditional testing methods have been widely used, there is a growing interest in non-destructive techniques (NDT) for characterizing wood and other materials. These NDT methods offer advantages such as non-destructiveness, faster testing times, and the flexibility to be performed outside of a laboratory setting.
One notable innovation in this area is the SMART THUMPER™ smartphone application, developed by the Department of Sustainable Bioproducts at Mississippi State University. Leveraging the convenience of a smartphone, this application provides an easy-to-use, cost-effective, and portable solution for obtaining indicative stiffness properties of timber. By utilizing a well-established and published relationship, the SMART THUMPER™ application calculates the MOE in the longitudinal direction using input variables such as natural frequencies of soundwaves, sample density, and dimensions. This technology has the potential to make timber evaluation more accessible to a wider community by enabling on-the-go assessments at a lower cost as Eq. 1,

$$E_L = 4\rho L^2 \left(f_{L,n}/n\right)^2 \qquad (1)$$

where $\rho$ is the density (kg/m$^3$), $L$ is the length (m), $f_{L,n}$ is the $n^{th}$ longitudinal mode frequency, and $n$ refers to the mode number (1, 2, 3, *etc.*). The application uses the first mode, *i.e.*, $n$ = 1. The application calculates density based on the mass and dimension input by user.

The SMART THUMPER™ application has been extensively tested on various wood species, including Spotted Gum, Blackbutt, Jarrah, Messmate, Pine, and Southern Pine. The results have consistently shown a robust and positive correlation (R2=0.97) between the MOEs measured using the BING© method and those estimated by the SMART THUMPER™ application. This indicates that the application is highly effective in accurately predicting the MOE of timber, even when dealing with different density variations among the tested wood species (Kumar et al., 2021).
However, in order to promote widespread adoption, it is imperative to identify and understand the feasibility, accuracy, and limitations of the SMART THUMPER™ application in measuring the indicative stiffness of timber. This includes assessing its performance across different timber species and sample conditions. Therefore, the objective of this study is to investigate the results obtained from estimating the modulus of elasticity of rubber plantation timber using both the SMART THUMPER™ application and the universal testing machine.

## Materials and Methods

### *Specimen preparation*

The rubber plantation is located in Huaylerk village, Thaphabath district, Bolikhamsay province. It was established by Thaphabath DAFO in 1986, using seed cultivation with a spacing of 3 x 7 meters. The plantation has not been thinned or pruned. Latex tapping in the rubber trees began in 2001 and continues to the present. The geographical coordinates of the plantation are "18° 23.011' N, 103° 9.260' E", with an elevation of 151 meters above sea level. For this study, a total of 63 boards of rubberwood (Hevea brasiliensis) were sawn from 10 log billets. The boards were cut to nominal dimensions of 1,300 × 92 × 32 mm. After sawing, the boards were stripped and stacked in an airdrying shed until they reached the fibre saturation point (FSP). Subsequently, the boards were docked to a nominal length of 900 mm. Some of the boards included random specimens with defects. The boards were graded based on their modulus of elasticity (MOE).

A computerized Electric Universal testing machine (ETM-100) with a maximum load capacity of 100KN was employed to conduct mechanical property tests such as modulus of rupture (MOR), modulus of elasticity (MOE), hardness, etc. This testing machine was manufactured by Jinan Marxtest Technology Co; Ltd in China and operated using the SmartTest Set software.
In addition to traditional testing methods, the SMART THUMPER™ application offers an efficient alternative for evaluating the stiffness properties of lumber and custom-sized wood pieces. It utilizes the dynamic modulus of elasticity (dMOE) concept by detecting vibrations through either the built-in microphone or accelerometer of a smartphone. The SMART THUMPER™ application is exclusively available on the App Store for iOS devices and was utilized in this experiment using an iPhone 12.

From the off-cut sections of the rubberwood boards, moisture content (MC) measurements were taken through the oven dry method. Pieces of the full cross section were extracted (weighing a minimum 50 g) from the boards and submitted to a 103±2°C drying oven. The difference between initial and dried weights are used to calculate the MC percentage.

***Kiln drying process***

After the boards were stripped and stacked, they were transferred to a solar drying kiln located at the Faculty of Forestry Science (FFS) within the National University of Laos (NUoL). The kiln drying process lasted for a period of 30 days, enabling the boards to achieve a targeted equilibrium moisture content (EMC) of 12%. Throughout the kiln drying process, the temperature and humidity conditions were carefully monitored using a temperature and humidity data logger (MX1101, Onset Computer Corporation, Bourne, MA). This data logger recorded and transmitted the temperature and relative humidity (RH) of the indoor environment using its integrated sensors. The accuracy of the temperature readings was approximately ± 0.21 °C within a temperature range of 0°C to 50°C. Regarding relative humidity, the accuracy was around ± 2% within an RH range of 20% to 80%. For RH measurements below 20% and above 80%, the accuracy decreased slightly to ± 6%. During the kiln drying period, the nominal temperature and humidity settings were maintained at 45°C and 60% relative humidity (RH), respectively.

***Acoustic grading***

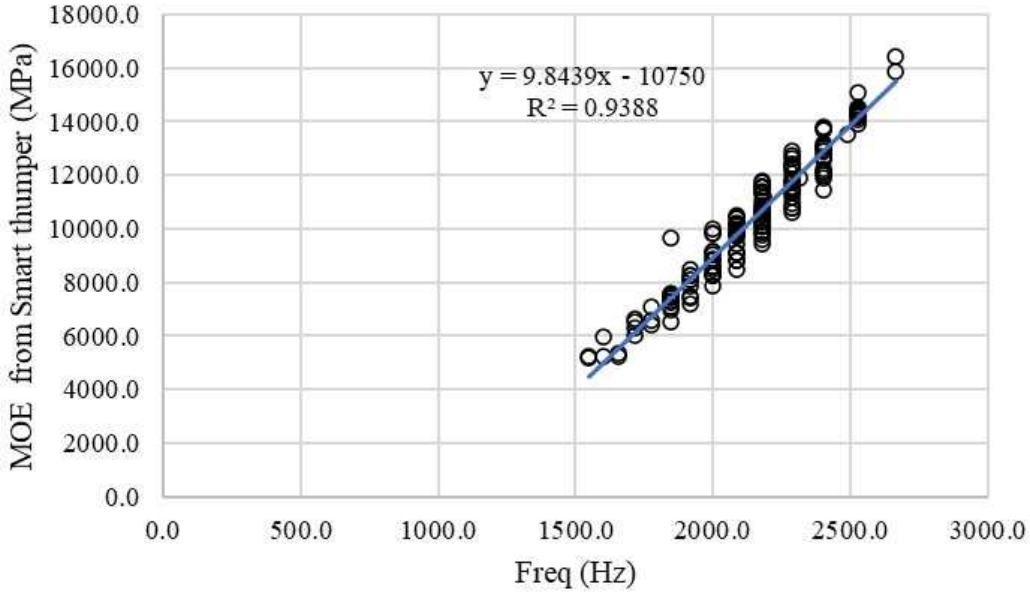
From the 900 mm long boards the iPhone© application, Smart Thumper™ (Department of Sustainable Bioproducts, 2019) was used to acoustically grade each board for their predicted MOE. The MC measurements taken at the time of testing were used to correct the predictions. The setup for conducting these tests consisted of a freely supported boundary condition in which the boards were enabled to move freely when impacted, an impactor (*small steel hammer*), and an iPhone© (*Apple, USA*).

The testing procedure included entering the sample specific details such as dimensions and weight into the application, and then while the sample is on the supports the phone's microphone is positioned at one end of the beam while an impact is applied to the opposite end; creating a longitudinal impulse. The application then makes a prediction based on dimensions, mass and frequency of the measured material. The Smart Thumper™ application had been validated for a series of Australian species in conjunction with a laboratory scale acoustic tool, BING™ (*Centre for International Agriculture Research (CIRAD), France*). The details of this study can be found here (Kumar et al. 2021).

## Results and Discussion

Figure 1 shows a remarkable correlation between the frequency of acoustic testing and the MOE data, resulting in an R2 value of 0.9388. The frequency ranged from 1,500.0 Hz at an MOE of 1,548.39 MPa to a noticeably exponential increase of 2,666.7 Hz (15,863.5 MPa) for specimens with an average density of 614 ± 38 kg/m3. This suggests that the higher frequency encoded by the smartphone accurately represents the MOE values, particularly for newer models like the iPhone 12. Conversely, it was concluded that frequencies exceeding 2,000 Hz can introduce errors due to the limitations of the microphone in older models such as the iPhone 5s (Kumar et al. 2021).

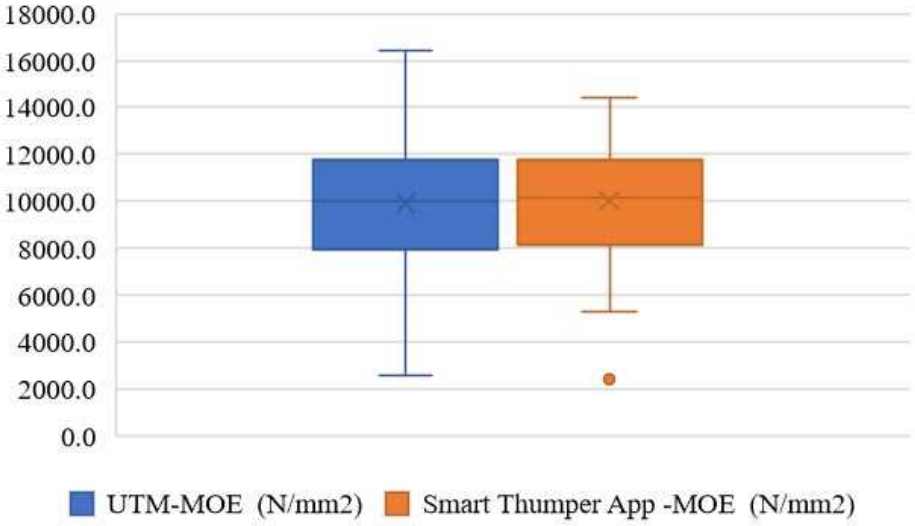
**Fig. 2 Relationship between Acoustic Frequency and Modulus of Elusticity as the Results of the Smart Thumper Application**




(Source) The Authors.

An analysis of variance (ANOVA) was conducted to compare the testing responses from the Universal testing machine and the Smart Thumper. The results of the ANOVA indicated that there was no significant difference between the two testing methods, with a p-value of 2.06 ($p > 0.05$), as depicted in Fig. 3. The mean value of the modulus of elasticity (MOE) obtained from the Universal testing machine was 10,048 ± 2,610 MPa, while the Smart Thumper produced results of 10,155 ± 2,416 MPa. These values are comparable to those reported in a case study of air-dried rubber timber in Malaysia where the MOE was found to be 9,240 N/mm2 (Teoh et al. 2011) and 9,070 MPa at a moisture content of 12%.

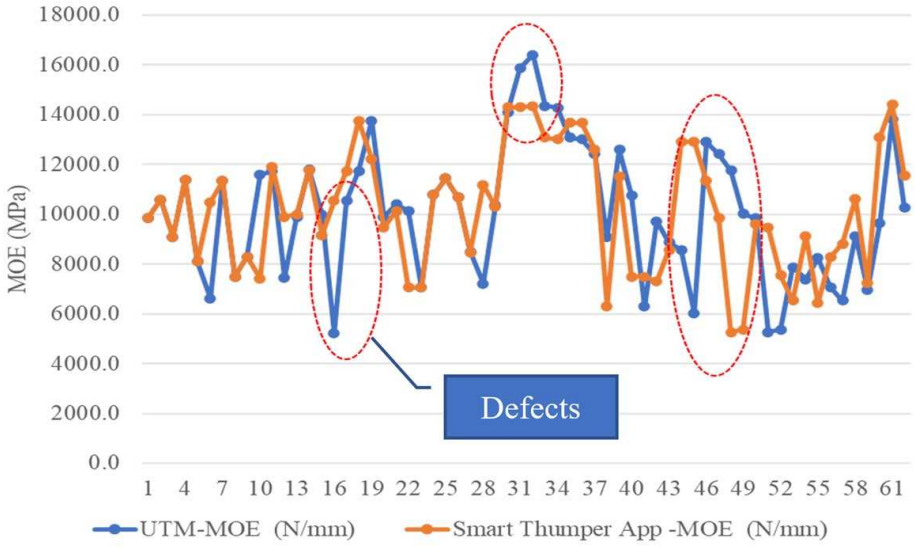
**Fig. 3 Statistical Comparison of the Results between the Universal Testing and the Smart Test Thumper**




(Source) The Authors.

However, it should be noted that there were a few instances where the results obtained from the Universal testing machine differed from those obtained from the Smart Thumper, as depicted in Fig. 4. This discrepancy may be attributed to the presence of defects such as knots, gum veins, and mold on the tested specimens. This observation aligns with a study conducted by Hossein et al. (2011) on specimens containing knots, where it was found that the correlation between the damping factor and the static method MOE was reduced by approximately 60% for the Cupressus arizonica species. As mentioned earlier, this study utilized boards randomly selected, including specimens with various defects, as depicted in Fig. 5.These defects may have contributed to the variation in the test results obtained from the Universal testing machine and the Smart Thumper.art Thumper.

**Fig. 4 The MOE Testing Results of the Smart Thumper and the Universal testing machine**




(Source) The Authors.

**Fig. 5 Defects on Boards Specimens**



**(Source) The Authors.**

## Conclusions

In conclusion, the study reveals a promising correlation between the frequency of acoustic testing and the responded data of the MOE, with an $R^2$ value of 0.9388. Interestingly, the MOE results obtained from testing using the Universal Testing Machine and the Smart Thumper application did not differ significantly. This finding is particularly noteworthy considering that the specimens used in this experiment contained various natural defects. However, further experiments are recommended to validate these results, particularly by testing plantation rubber timber using both the Smart Thumper application and the Universal Testing Machine, with separate groups of specimens consisting of defects and clear specimens. These additional experiments will help to provide a more comprehensive understanding of the applicability and reliability of the Smart Thumper application in assessing the mechanical properties of timber.

## Acknowledgement

We would like to express our sincere gratitude to the team members from the Wood Science and Wood Product Research Centre who played a crucial role in sourcing the timber materials from the field in Borikhamxay province, Lao P.D.R. Their assistance and contribution were invaluable in the successful completion of this study.

Additionally, we would like to extend our thanks to VALTIP3-ACIAR for their generous support in funding this research and publication. Without their financial backing, this study would not have been possible. Their commitment to advancing the field of wood science is greatly appreciated.

Once again, we would like to thank all the individuals and organizations involved in this study for their contributions and support.

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# 3
# Exploring the Plant Diversity within Phou Xieng Thong National Protected Area in Southern Laos

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**Abstract:**

*This paper presents a comprehensive assessment of plant diversity and the development of a plant checklist for the Phou Xieng Thong National Protected Area in southern Lao PDR. This is the first survey of its kind since the establishment of the protected area in 1993. The field survey was conducted in March 2023, utilizing five Transect Lines (TL) to capture the plant diversity in three distinct ecological areas: two dry dipterocarp forests, two mixed deciduous forests, and one dry evergreen forest spanning an altitude range of 229 to 439 meters. A total of 843 records were collected, documenting 253 plant species belonging to 61 families, including 216 Dicots, 33 Monocots, 2 Gymnosperms, and 2 Pteridophytes. The dominant families observed in the survey area include Rubiaceae, Fabaceae, Apocynaceae, Dipterocarpaceae, and Orchidaceae. Among the recorded species, eleven global threatened species were identified, namely Anisoptera costata Korth., Dalbergia cochinchinensis Pierre, Dalbergia oliveri Gamble ex. Prain, Dialium cochinchinensis Pierre, Dipterocarpus intricatus Dyer, D. obtusifolius Teijsm. ex Miq., D. tuberculatus Roxb., Hopea ferrea Laness., Pterocarpus macrocarpus Kurz, Shorea obtusa Wall. ex Blume, and S. roxburghii G. Don. All voucher specimens collected during the survey were deposited in the FOF herbarium at the Faculty of Forest Science at the National University of Laos in excellent condition, ensuring accessibility for those interested in exploring the flora of Laos.*

Keywords: Champasak, flora of Laos, Salavan, survey, taxonomy,

## Introduction

Laos is situated in the Indo-Burma Hotspots, a region known for its exceptional biodiversity and endemism. The protection of biodiversity and ecosystems within this region is crucial, particularly in Southeast Asia. Plants are vital components of ecosystems as primary producers and contribute to global environmental conservation by sequestering carbon dioxide in forests. Furthermore, Laos boasts unique ecosystems and landscapes that have attracted tourists, leading to the designation of national parks and protected areas.

However, our understanding of Laos' flora remains limited, and the documentation of its plant diversity is still ongoing. The most recent comprehensive checklist by Newman et al. (2007) recorded 4,850 species, but this is far from complete due to the scarcity of plant taxonomists and low accumulation of plant specimens in herbaria compared to other Southeast Asian countries. Therefore, conducting detailed plant surveys and creating checklists for each protected area are crucial for effective management and conservation efforts.

This study focuses on the Phou Xieng Thong National Protected Area, located in Salavan and Champasack Provinces in southern Laos. Covering 120,000 hectares, the area is predominantly found in Lakhonpheng and Khongxedon districts of Salavan Province, along with Sanasomboun District of Champasack Province. The NPA's topography is mountainous, with elevations ranging from 120 meters along the banks of the Mekong River to 600 meters at the highest point. The southern part generally has elevations between 300-500 meters, while the northern part ranges between 200-400 meters. The major forest types within the NPA include mixed deciduous forest, evergreen forest, dry dipterocarp forest, and wetland habitats along the Mekong River.

Phou Xieng Thong NPA is globally recognized for its biodiversity conservation, serving as a habitat for various large and medium-sized mammal species. These include rare species such as Banteng and Gaur, as well as Red-shanked Douc Langur, Pangolin, Silvered Langur, Leopard, Sun Bear, Dhole, and Green Peafowl, among others. Despite its significance, there is limited knowledge about the flora of the area. Only a few economically valuable timber tree species, such as *Dalbergia cochinchinensis* (Mai Kha Ngoung), *Pterocarpus macrocarpus* (Mai Dou), *Dalbergia bariensis* (Mai Khamphi or Mai Padong), *Afzelia xylocarpa* (Mai taekha), *Hopea odorata* (Mai Khaen heua), Xylia kerril (Mai Deng Nam), *Michelia champaca* (Mai Champa, a synonym of *Magnolia champaca*), Fagraea fragrans (Mai Manpa), *Sindora siamensis* (Mai Champi), and others, have been documented.

According to the five-year Collaborative Management Plan 2022-2026 (DoF, 2021), the presence of several endangered species has been confirmed in the NPA. These species include *Afzelia xylocarpa* (EN), *Dalbergia cochinchinensis* (CR), *Dalbergia bariensis* (also known as *Dalbergia oliveri* (CR), *Hopea odorata* (VU), and *Pterocarpus macrocarpus* (EN).

The Government of Lao (GoL) has recently nominated Phou Xieng Thong NPA as an ASEAN Heritage Park (AHP). This designation aims to ensure the protection and management of natural resources while promoting the development of local communities. To gain a comprehensive understanding of the biodiversity aspect, it is crucial to gather additional data on the flora species found in the area, along with their conservation status. In order to achieve this, a plant survey was conducted within the area, resulting in a detailed plant checklist based on data and specimens collected in the field. Furthermore, the survey also identified global

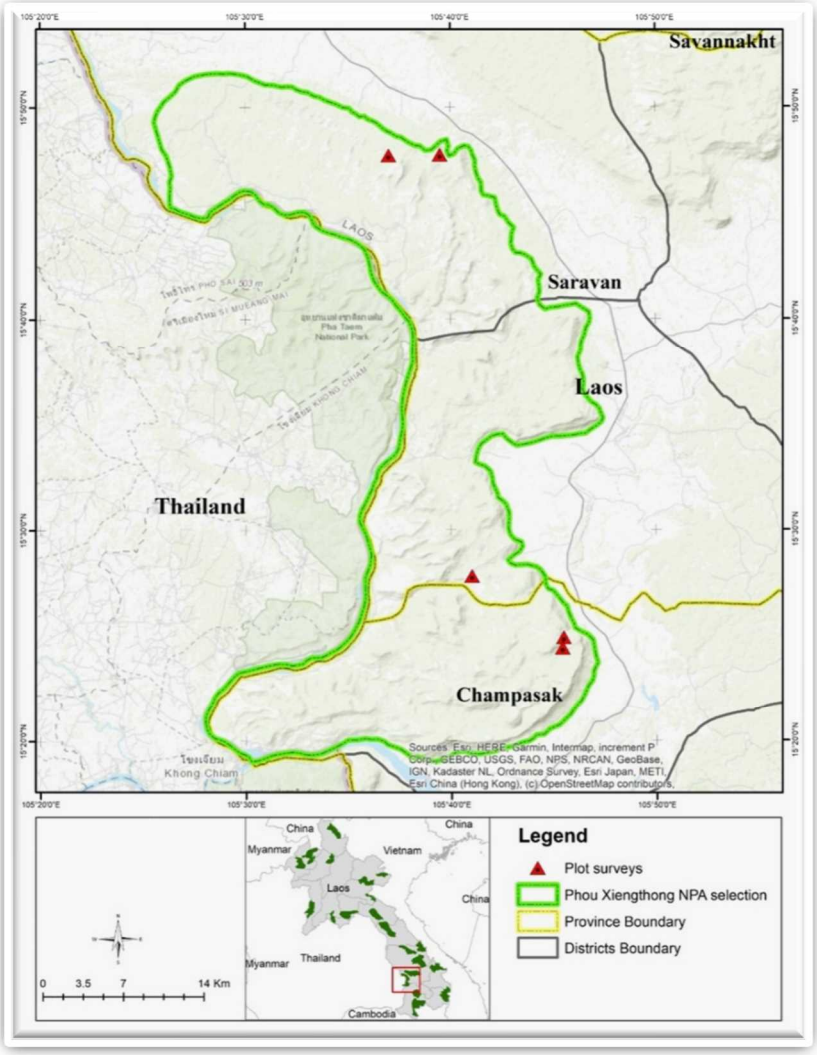
threatened species within the area, with collaboration from both central and provincial levels of the PA authority.

## Methodology

### *Field survey and Data collection*

To investigate plant species diversity in the NPA, we implemented a field survey using the following methodology. Five Transect Lines (TL) were strategically placed to cover different forest types within the NPA: two TL in mixed deciduous forest (at 401-439 m alt.), two TL in evergreen forest (at 249-255 m alt.), and one TL in dry dipterocarp forest (at 229 m alt.).

Figure 1. Map howing the five Transect Lines distributes in PTX NPA. Triangle symbol (▲) indicates to Transect lines: 2 TL in dry evergreen forest in Lakhonepheng, 2 TL in mixed deciduous forest in Sanasomboun, and 1 TL in dry dipterocarp forest in Khongxedon.



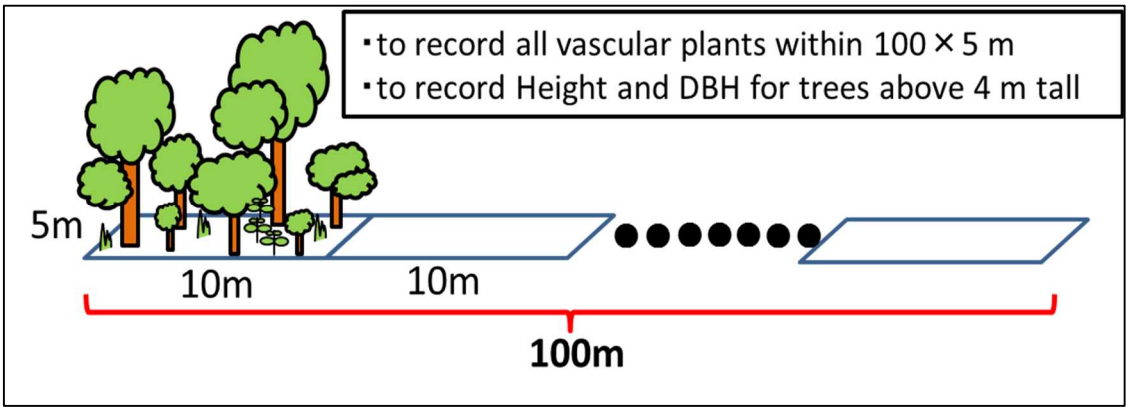

(Source) Department of Forestry (2021).

***Survey method and specimen collection:***

During the survey, we established five transect lines, each measuring 100 m x 5 m, along altitudinal or other forest/environmental gradients (refer to Figure 2). Each transect was further divided into 10 sections of 10 m x 5 m. Our objective was to document all vascular plants within each section, focusing on trees that were 4 m or taller. For these trees, we recorded their Diameter at Breast Height (DBH)/Girth and Height.

To accurately determine the starting point of each transect, we utilized GPS technology to record the latitude, longitude, and altitude. Additionally, we employed a grass-fiber pole that could be extended up to 15 m in height to measure tall trees, and measurement tapes were used to measure tree girth.

Figure 2. A standardized belt-transect method (100 m x 5 m).




(Source) Plot designed by T. Yahara.

In order to capture as many plant species as possible, we also documented plant species found outside the transects. We collected specimens with flowers and fruits, as these are particularly useful for plant identification and naming (refer to Figure 3). For Lao plant names, we followed the guidelines provided in "A Checklist of Plants in Lao PDR" (Jin et al., 2016; Lamxay et al., 2021). To identify species and determine their distribution, we compared our findings to the information presented in "Forest Plants of Central Laos: A Field Guide for Forestry" (Kameda et al., 2019).

***Voucher specimens and identification***

In order to ensure the accuracy and reliability of our plant specimens, we took the following steps. Firstly, we created duplicate sets of voucher specimens, making at least two copies of each. These duplicates were then deposited at the herbarium in the National University of Laos, specifically at the Faculty of Forestry (FOF) and the Faculty of Natural Science (Biology herbarium).

To guarantee precise information about the flora in the NPA (National Protected Area), we conducted a thorough examination of our collection and identified the plant species. This task was primarily carried out by our team leader, botanical team, and students. We meticulously compared our findings with relevant taxonomic documents, both online and published versions such as Jin et al. (2016) and Newman et al. (2007 & 2017 onwards). Additionally, we sought guidance from experts specializing in specific plant groups to confirm the accuracy of our identifications.

Figure 3. Field survey activities in PXT NPA. A-E&G. taking plant photos, colleting tree data, and specimens; F. making voucher specimen in guesthouse after one day drying plant materials.



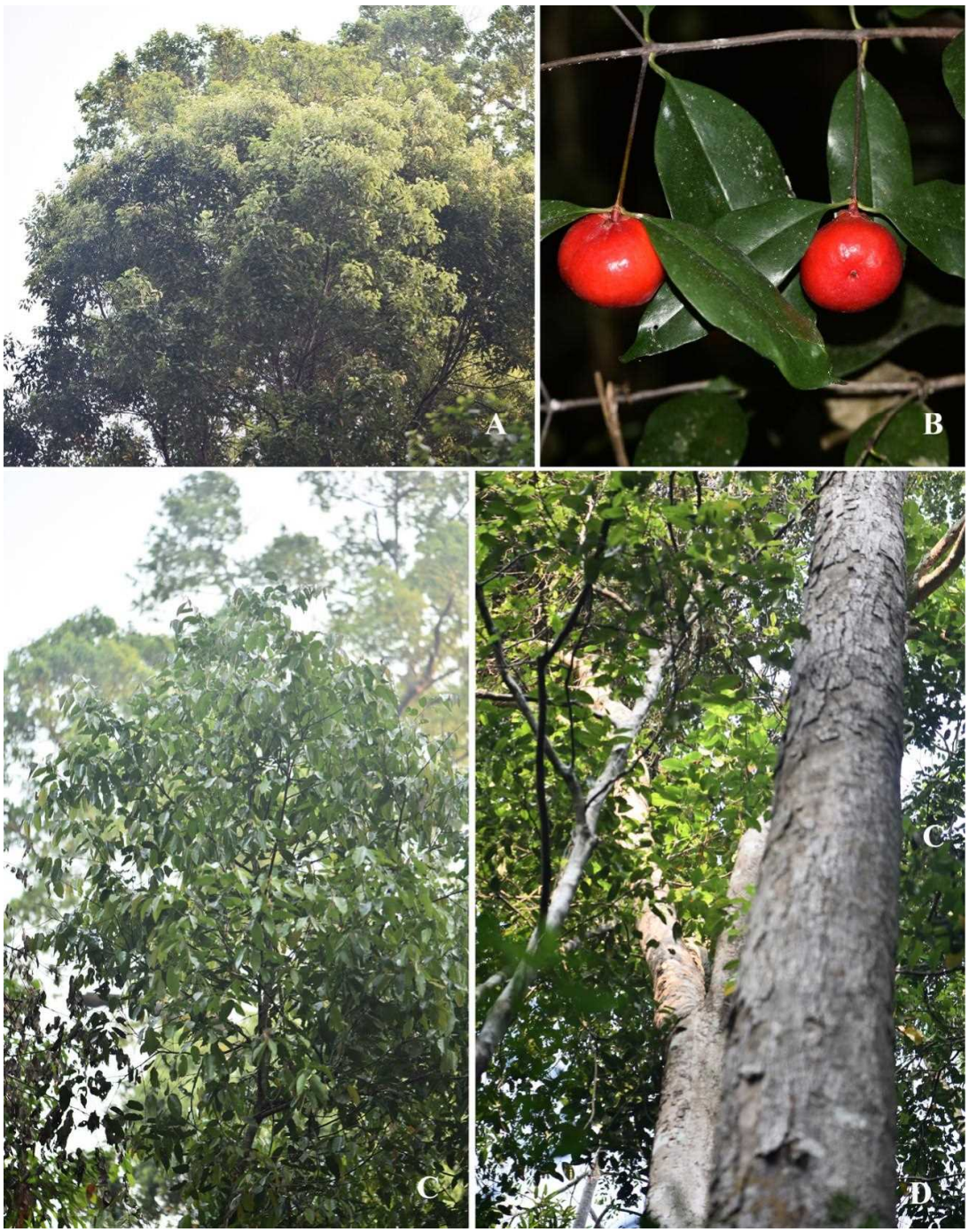

(Source) The Authors.

## Results

### *Forest habitats*

To represent the plant diversity in different forest habitats within the altitude range of 229 to 439 meters, we conducted five Transect Lines (TL) in Phou Xieng Thong National Protected Area (PXT NPA). Two TLs were placed in the dry evergreen forest of Lakhonpheng district (Figure 4), two TLs were placed in the mixed deciduous forest of Sanasoumboun district (Figure 5), and one TL was placed in the Dry Dipterocarp forest of Khongxedon district (Figure 6).

Figure 4**.** Transect Line 1 represents the dry evergreen forest in Lakhonpheng. A. canopy of *Litsea* sp. (Lauraceae); B. red fruits of *Garcinia lanceifolia* Roxb. (Clusiaceae); C. *Orophea* sp. (Annonaceae); D. tree trunk of Syzygium sp. (Myrtaceae)



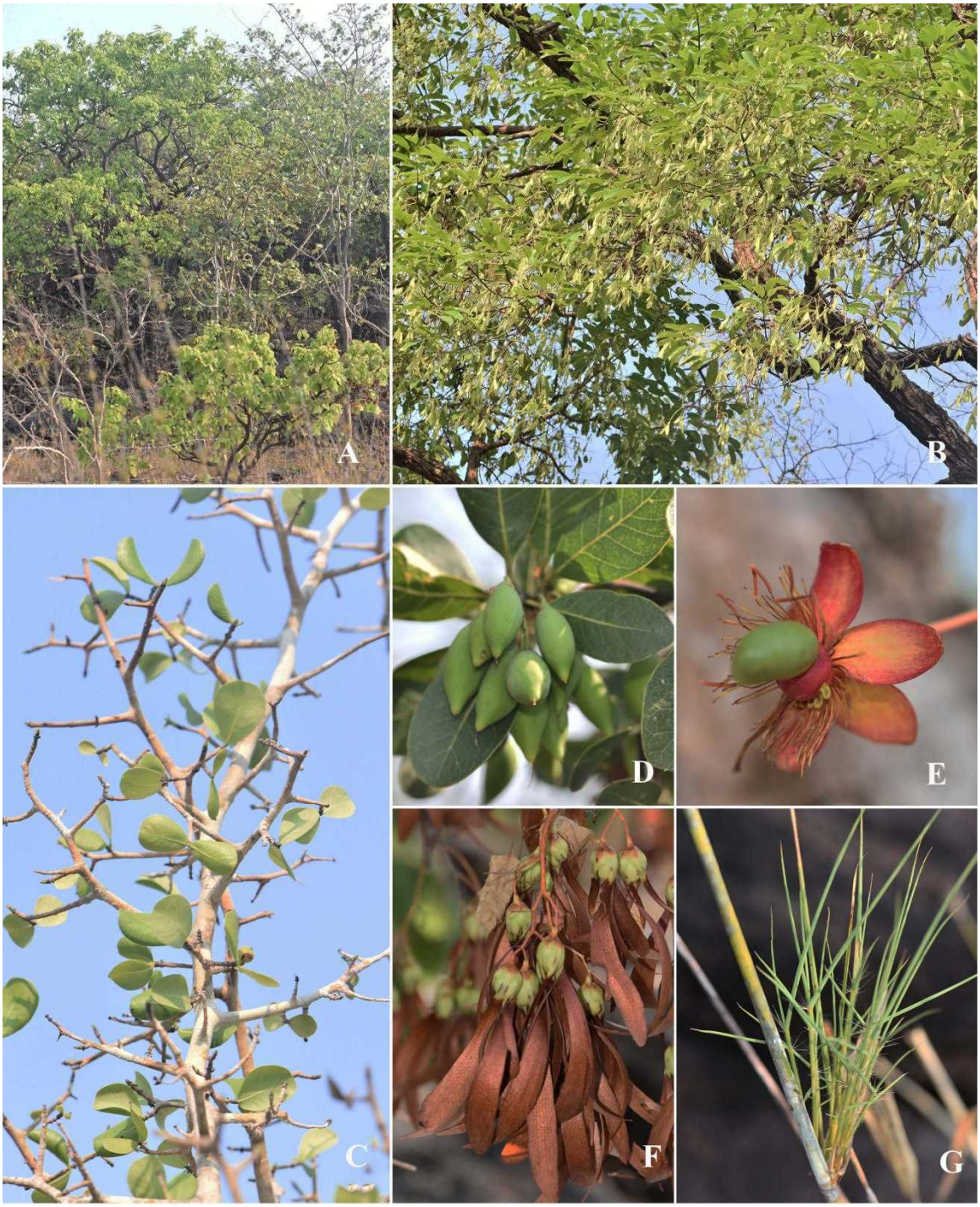

(Source) The Authors.

Figure 5. Transect Line 3 represents mixed deciduous forest in Sanasomboun. A. canopy of *Streblus monoicus* Gagnep. (Moraceae); B. canopy of *Syzygium sp.* (Myrtaceae); E. flowers of *Barringtonia macrostachya* (Jack) Kurz (Lecythidaceae); F. clump and sheaths of *Pseudoxytenanthera monadelpha* (Thwaites) Soderstr. & R.P.Ellis (Poaceae).




(Source) The Authors

Figure 6**.** Transect Line 5 represents dry dipterocarp forest in Khongxedon. A. habitat of Dipterocarps forest with dominance by *Pentacme siamensis* (Miq.) Kurz (Dipterocarpaceae); B. *Hopea* sp. (Dipterocarpaceae); C. leaves and branches s of *Gardenia saxatilis* Geddes (Rubiaceae); D. fruits of *Mimusops elengi* L. (Sapotaceae); E. fruits of *Ochna integerrima* (Lour.) Merr. (Ochnaceae); F. fruits of *Pentacme siamensis* (Miq.) Kurz; & G. leaves of *Vietnamosasa pusilla* (A.Chev. & A.Camus) T.Q.Nguyen (Poaceae).




(Source) The Authors

***Plant diversity in Phou Xieng Thong NPA***

During our survey, we recorded a total of 843 records, consisting of 253 plant species from 61 families. These included 216 Dicots, 33 Monocots, 2 Gymnosperms, and 2 Pteridophytes. It's important to note that our detailed analysis and description focused on tree and shrub species, while herbaceous plants and non-tree species were counted without detailed analysis. The dominant family observed was Rubiaceae with 20 species, followed by Fabaceae with 19 species, and Apocynaceae and Dipterocarpaceae with 11 species each (Table 1).

Table 1. List of Most Dominant Families Found in All 5 Transect Lines.

| No. | Family Name | No. of species | No. | Family name | No. of species |
|---|---|---|---|---|---|
| 1 | Rubiaceae | 20 | 32 | Annonaceae | 2 |
| 2 | Fabaceae | 19 | 33 | Celastraceae | 2 |
| 3 | Apocynaceae | 11 | 34 | Opiliaceae | 2 |
| 4 | Dipterocarpaceae | 11 | 35 | Pandanaceae | 2 |
| 5 | Orchidaceae | 10 | 36 | Poaceae | 2 |
| 6 | Lauraceae | 9 | 37 | Polypodiaceae | 2 |
| 7 | Malvaceae | 9 | 38 | Ancistrocladaceae | 1 |
| 8 | Poaceae | 8 | 39 | Araliaceae | 1 |
| 9 | Acanthaceae | 8 | 40 | Bignoniaceae | 1 |
| 10 | Zingiberaceae | 8 | 41 | Calophyllaceae | 1 |
| 11 | Anacardiaceae | 7 | 42 | Cucurbitaceae | 1 |
| 12 | Euphorbiaceae | 7 | 43 | Cycadaceae | 1 |
| 13 | Myrtaceae | 7 | 44 | Dilliniaceae | 1 |
| 14 | Sapindaceae | 7 | 45 | Elaeagnaceae | 1 |
| 15 | Clusiaceae | 6 | 46 | Elaeocarpaceae | 1 |
| 16 | Phyllanthaceae | 6 | 47 | Gnetaceae | 1 |
| 17 | Rhamnaceae | 6 | 48 | Hypericaceae | 1 |
| 18 | Arecaceae | 5 | 49 | Hypoxidaceae | 1 |
| 19 | Combretaceae | 5 | 50 | Irvingiaceae | 1 |
| 20 | Melastomataceae | 5 | 51 | Lecythidaceae | 1 |
| 21 | Meliaceae | 5 | 52 | Magnoliaceae | 1 |
| 22 | Moraceae | 5 | 53 | Menispermaceae | 1 |
| 23 | Ebenaceae | 4 | 54 | Myristicaceae | 1 |
| 24 | Lythraceae | 4 | 55 | Nyssaceae | 1 |
| 25 | Simaroubaceae | 4 | 56 | Ochnaceae | 1 |
| 26 | Vitaceae | 4 | 57 | Peraceae | 1 |
| 27 | Araceae | 4 | 58 | Sapotaceae | 1 |
| 28 | Loganiaceae | 3 | 59 | Schizaeaceae | 1 |
| 29 | Primulaceae | 3 | 60 | Styracaceae | 1 |
| 30 | Symplocaceae | 3 | 61 | Thymelaeaceae | 1 |
| 31 | Asparagaceae | 2 | | | |
| 32 | Capparidaceae | 2 | | | |

(Source) The Authors

***Globally threatened species account***

Based on the IUCN Red List Criteria of Threatened Species, we identified eleven globally threatened species (Table 2 and Figure 7). These included two Critically Endangered (CR) species: *Dalbergia cochinchinensis* Pierre and *Dalbergia oliveri* Gamble ex. Prain; four Endangered (EN) species: *Anisoptera costata* Korth., *Hopea ferrea* Laness., *Pterocarpus macrocarpus* Kurz, and *Dipterocarpus intricatus* Dyer; three Vulnerable (VU) species: Dialium cochinchinensis Pierre, *Dipterocarpus tuberculatus* Roxb., and *Shorea roxburghii* G. Don; and two Near Threatened (NT) species: *Dipterocarpus obtusifolius* Teijsm. ex Miq. and *Shorea obtusa* Wall. ex Blume.

Table 2. List of Key Plant Species Found in 5 Transect Lines.
(/) indicates the presence of tree species in each transect.

| No | Local Name | Scientific Name | Family Name | Conservation status | | Transect Lines | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | IUCN Red List | Lao Law List | 1 | 2 | 3 | 4 | 5 |
| 1 | ຂະຍຸ | *Dalbergia cochinchinensis* Pierre | Fabaceae | CR | I | | | | | / |
| 2 | ຄຳພີເຫຼືອງ | *Dalbergia oliveri* Gamble ex. Prain | Fabaceae | CR | I | | / | | | / |
| 3 | ບາກ | *Anisoptera costata* Korth.; | Dipterocarpaceae | EN | II | / | | | | / |
| 4 | ແຄນຫີນ | *Hopea ferrea* Laness. | Dipterocarpaceae | EN | I | | | / | | |
| 5 | ສະແບ | *Dipterocarpus intricatus* Dyer | Dipterocarpaceae | EN | - | | | | | / |
| 6 | ດູ່ | *Pterocarpus macrocarpus* Kurz | Fabaceae | EN | I | | / | | | |
| 7 | ເຄ້ | *Dialium cochinchinensis* Pierre | Fabaceae | VU | II | / | | | | |
| 8 | ກຽ | *Dipterocarpus tuberculatus* Roxb. | Dipterocarpaceae | VU | II | / | | | | / |
| 9 | ແຄນຄະຍອມ | *Shorea roxburghii* G. Don | Dipterocarpaceae | VU | | | | | | / |
| 10 | ຊາດ | *Dipterocarpus obtusifolius* Teijsm. ex Miq. | Dipterocarpaceae | NT | III | / | | | | / |
| 11 | ຈິກ | *Shorea obtusa Wall. ex* Blume | Dipterocarpaceae | NT | | | | | | / |

(Source) The Authors

Figure 7**.** Some key species found during the survey. A. Bark, young leaves of *Dalbergia oliveri;* B. Leaves of *Hopea ferrea;* C. Tree trunk showing fruiting of *Mammea* sp. (which need further study and could be a new species); and D. male strobilus of *Gnetum montanum.*




(Source) The Authors

**Discussion**

As our preliminary survey was conducted during the dry season, we may have missed recording several species, especially herbaceous plants that thrive in wet conditions. However, we did observe some species with flowers and fruits during this period. To obtain a more accurate count of plant species in PXT NPA, we analyzed photos and information collected during the rainy season. Further surveys during the rainy season are necessary to capture as many species as possible.

## Conclusions

This survey has significantly contributed to our understanding of the forest ecosystem by documenting a rich diversity of flora. A remarkable total of 843 individual plants were meticulously recorded, categorizing them into 253 distinct plant species across 61 families. This includes a diverse representation of 216 Dicots, 33 Monocots, 2 Gymnosperms, and 2 Pteridophytes. Within the Transect Lines, the Rubiaceae family emerged as the most prevalent, boasting 20 species, closely followed by the Fabaceae family with 19 species. Additionally, the Apocynaceae and Dipterocarpaceae families were well-represented, each with 11 species. Among the notable findings were several species of global conservation concern that were directly observed in the field. These include *Dalbergia cochinchinensis* Pierre and *D. oliveri* Gamble ex. Prain, both classified as Critically Endangered (CR); *Anisoptera costata* Korth., *Hopea ferrea* Laness., *Pterocarpus macrocarpus* Kurz, and *Dipterocarpus intricatus* Dyer, all listed as Endangered (EN); along with *Dialium cochinchinensis* Pierre, *Dipterocarpus tuberculatus* Roxb., and *Shorea roxburghii* G. Don, categorized as Vulnerable (VU). Additionally, *Dipterocarpus obtusifolius* Teijsm. ex Miq. and *Shorea obtusa* Wall. ex Blume were identified as Near Threatened (NT), highlighting the critical need for conservation efforts in these forest communities. This survey underscores the rich biodiversity and the urgent need for protective measures to safeguard these invaluable forest ecosystems and their threatened species.

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## Appendix. A checklist of Vascular plants in Phou Xieng Thong NPA

### Pteridophytes

| | | | |
|---|---|---|---|
| Polypodiaceae | 2 species | ກະຮອກກາຍວົ່ມ | Drynaria bonii Christ |
| | | ຜ້າສາດສີດາ | Platycerium wallichii Hook. |
| Schizaeaceae | 1 species | ກູດເຄືອ | Lygodium flexuosum (L.) Sw. |

### Gymnosperms

| | | | |
|---|---|---|---|
| Cycadaceae | 1 species | ຜ້າວໂຄກ | Cycas siamensis Miq. |
| Gnetaceae | 1 species | ເຄືອມ້ວຍ | Gnetum montanum Markgr. |

### Angiosperms
### Monocots

| | | | |
|---|---|---|---|
| Araceae | 4 species | ບອນຕ່ຳ | Aglaonema costatum N.E.Br. |
| | | ແຂນນາງ | Aglaonema ovatum Engl. |
| | | ພູຊ້າງ | Rhaphidophora megaphylla H.Li |
| | | ຫວາຍສະນອຍ | Pothos scandens L. |
| Arecaceae | 5 species | ຕາວ | Arenga caudata (Lour.) H.E.Moore |
| | | ຫວາຍທອກ | Calamus poilanei Conrard |
| | | ຫວາຍແຍ້ | Calamus tenuis Roxb. |
| | | ຫວາຍຫາງໜູ | Calamus tetradactylus Hance. |
| | | ຫວາຍ | Calamus sp. |
| Asparagaceae | 2 species | ຄອນແຄນ | Dracaena angustifolia (Medik.) Roxb. |
| | | ຫอ้ານເສດຖີໃບຍາວ | Ophiopogon longifolius Decne. |
| Orchidaceae | 10 species | ເອື້ອງຈ່ຳປາ | Dendrobium moschatum (Banks) Sw |
| | | ເອື້ອງຄັ່ງ | Dendrobium parishii Rchb.f. |
| | | ເອື້ອງແປງສີແຂ້ວ | Dendrobium secundum (Blume) Lindl. |
| | | ໃບລາຍ | Goodyera sp. |
| | | ນາງອົ້ວ | Habenaria sp. |
| | | ເອື້ອງດິນ | Liparis sp. |
| | | ເອື້ອງມ້າແລ່ນ | Phalaenopsis pulcherrima |
| | | ມ້າແລ່ນ | Phalaenopsis sp. |
| | | ເອື້ອງສາຍ | Rhynchostylis sp. |
| | | ໄສ້ປາຄໍ່ | Spathoglottis eburnea Gagnep. |
| Pandanaceae | 2 species | ເຕີຍສານ | Pandanus fibrosus Gagnep. |
| | | ເຕີຍ | Pandanus sp. |
| Poaceae | 2 species | ໄຜ່ | Pseudoxytenanthera monadelpha (Thwaites) Soderstr. & R.P.Ellis |
| | | ຫຍ້າ | *Vietnamosasa pusilla* (A.Chev. & A.Camus) T.Q.Nguyen |
| Zingiberaceae | 8 species | ຂ່າຕາແດງ | Alpinia galanga (L.) Willd. |
| | | ຂ່າປ່າ | Alpinia malaccensis (Burm.f.) Roscoe |
| | | ໝາກແໜ່ງ | Amomum sp. |
| | | ກะจ๋ายอขาอ | Curcuma comosa Roxb. |
| | | ກะจ๋ายอ | Curcuma sp. |
| | | ຫอ้ານตูบหมูบ | Kaempferia angustifolia Roscoe |
| | | ຂิง | Zingiber sp. |

| | | | |
|---|---|---|---|
| | | ກະເລ່ອ | Wurfbainia uliginosa (J.König) Škorničk. & A.D.Poulsen |

(Source) The Authors

**Dicots**

| | | | |
|---|---|---|---|
| Acanthaceae | 8 species | ກ້ານພອງ | Justicia procumbens L. |
| | | ຕອກມ້າແຕກ | Chroesthes lanceolata (T.Anderson) B.Hansen |
| | | ຫຍ້າຕອກແຕກ | Chroesthes sp. |
| | | ຜັກຫົມແຊງ | Phlogacanthus curviflorus (Wall.) Nees |
| | | ປີກໄກ່ແດງ | Pseuderanthemum crenulatum (Wall. ex Lindl.) Radlk. |
| | | ຫຍ້າພັນງູ | Pseuderanthemum latifolium (Vahl) B.Hansen |
| | | ຫ້ອມດົ່ງ | Sericocalyx quadrifarius (Nees) Bremek. |
| | | ຫນາມແນ່ແດງ | Thunbergia coccinea Wall. ex D.Don |
| Anacardiaceae | 7 species | ຮັກ | Buchanania arborescens (Blume) Blume |
| | | ພະເຈົ້າຫ້າພະອົງ | Dracontomelon laoticum C.M.Evrard & Tardieu |
| | | ຮັ່ງຮ້ອນ | Gluta cambodiana Pierre |
| | | ນ້ຳກ້ຽງໃຫ່ຍ | Gluta laccifera (Pierre) Ding Hou |
| | | ນ້ຳກ້ຽງ | Gluta sp. |
| | | ມ່ວງປ່າ | Mangifera caloneura L. |
| | | ກອກ | Spondias pinnata (L.f.) Kurz |
| Ancistrocladaceae | 1 species | ເຄືອຫາງກວາງ | Ancistrocladus cochinchinensis Gagnep. |
| Annonaceae | 2 species | ນົມແມວ | Uvaria vietnamensis Meade |
| | | ກ້ວຍຄ່າງ | Orophea sp. |
| Apocynaceae | 11 species | ເຄືອສົ້ມລົມ | Aganonerion polymorphum Pierre ex Spire |
| | | ຕີນເປັດ | Alstonia scholaris (L.) R.Br |
| | | ເຄືອຢາງນ່ອງ | Anodendron sp. |
| | | ມະລິເຄືອ | Epigynum auritum (C.K.Schneid.) Tsiang |
| | | ມູກນ້ອຍ | Holarrhena curtisii King & Gamble |
| | | ໂສ້ໄກ່ແຈ້ | Melodinus cochinchinensis (Lour.) Merr. |
| | | ໄພສົງ | Parsonsia sp. |
| | | ມູກເຂົາຄວາຍ | Tabernaemontana corymbosa Wall. |
| | | ພຸດປ່າ | Tabernaemontana bovina Lour. |
| | | ເຄືອໝາກຢາງ | Willughbeia edulis Roxb. |
| | | ມູກມັນ | Wrightia dubia (Sims) Spreng. |
| Araliaceae | 1 species | ເລັບມືນາງ | Heptapleurum ellipticum (Blume) Seem. |
| Bigononiaceae | 1 species | ແຄຝອຍ | Stereospermum fimbriatum (Wall. ex G. Don) A.DC. |
| Calophyllaceae | 1 species | ກົກນ | Mammea sp. |
| Capparidaceae | 1 species | ຊີງຊ/ຊາຍຊ້ | Capparis micracantha DC. |
| Celastraceae | 2 species | ຕາກວາງ | Salacia chinensis L. |
| | | ກ່ຳແພງເຈ້ດຊັ້ນ | Salacia viminea Wall. ex M.A.Lawson |
| Clusiaceae | 6 species | ຊ້າມາງ/ໂມງ | Garcinia lanceifolia Roxb. |
| | | ກະນອນ | Garcinia merguensis Wight |
| | | ສົ້ມໂມງ | Garcinia oliveri Pierre |

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| | | ກອັກ | Garcinia speciosa Wall. |
| | | ສົ້ມປ່ອງ | Garcinia xanthochymus Hook.f. ex T.Anderson |
| | | ບົ້ງນັ່ງ | Garcinia sp. |
| Combretaceae | 5 species | ກົກແຫງນ | Terminalia bellirica (Gaertn.) Roxb. |
| | | ເຄືອເບັນ | Combretum pilosum Roxb. |
| | | ແກຂາວ | Combretum quadrangulare Kurz |
| | | ເຄືອງວງຊຸມ | Getonia floribunda Roxb. |
| | | ກົກສົ້ມມໍ | Terminalia chebula Retz |
| Cucurbitaceae | 1 species | ເຄືອຫຸນ | Gynostemma pentaphyllum (Thunb.) Makino |
| Dilliniaceae | 1 species | ສ້ານ | Dillenia ovata Wall. ex Hook.f. & Thomson |
| Dipterocarpaceae | 11 species | ບາກ | Anisoptera costata Korth. |
| | | ຍາງຂາວ | Dipterocarpus alatus Roxb. ex G.Don |
| | | ສະແບງ | Dipterocarpus intricatus Dyer |
| | | ຊາດ | Dipterocarpus obtusifolius Teijsm. ex Miq. |
| | | ກຸງ | Dipterocarpus tuberculatus Roxb. |
| | | ແຄນຫີນ | *Hopea ferrea* Laness. |
| | | ແຄນເຮືອ | Hopea odorata Roxb. |
| | | ຮັງ | Pentacme siamensis (Miq.) Kurz |
| | | ຈິກ | Shorea obtusa Wall. ex Blume. |
| | | ແຄນຄະຍອມ | Shorea roxburghii G. Don |
| | | ຊີດານ | Vatica odorata (Griff.) Symington |
| Ebenaceae | 4 species | ຕະໂກ | Diospyros castanea (Craib) H. R. Fletcher |
| | | ເກືອນ້ຳ | Diospyros malabarica (Desr.) Kostel. |
| | | ໝາກເກືອ | Diospyros martabanica C.B.Clarke |
| | | ໜັງດຳ | Diospyros sp. |
| Elaeagnaceae | 1 species | ໝາກຫລອດ | Elaeagnus conferta Roxb. |
| Elaeocarpaceae | 1 species | ໝາກກອກນ້ຳ | Elaeocarpus hygrophilus Kurz |
| Euphorbiaceae | 7 species | | |
| | | ລັບແລ | Balakata baccata (Roxb.) H.-J.Esser |
| | | ປີໝີ | Cleidion brevipetiolatum Pax & K.Hoffm. |
| | | ເປົ້ານ້ຳ | Croton bifurcatus Baill. |
| | | ຕອງແຕບບ | Macaranga trichocarpa (Rchb.f. & Zoll.) Müll.Arg. |
| | | ຕອງສາມຫາງ | Mallotus garrettii Airy Shaw |
| | | ນາງແຊ່ງ | Trigonostemon reidioides (Kurz) Craib |
| Fabaceae | 19 species | ໝາກລ່ຳ | Adenanthera pavonina L. |
| | | ແຕ້ຂ່າ | Afzelia xylocarpa (Kurz) Craib |
| | | ສ້ຽວເຄືອ | Cheniella glauca (Benth.) R.Clark & Mackinder |
| | | ເຄືອເຂົ້າປູນ | Clitoria ternatea L. |
| | | ຂະຍຸງ | Dalbergia cochinchinensis Pierre |
| | | ຄຳພີ້ເຫຼືອງ | Dalbergia oliveri Gamble ex. Prain |
| | | ເຄ້ັງ | Dialium cochinchinensis Pierre |
| | | ເຄືອບ້າລີງ | Entada glandulosa Gagnep. |

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|---|---|---|---|
| | | ເຄືອໝາກບ້າ | Entada rheedii Spreng. |
| | | ຫຍ້າເກັດລິ່ນ | Flemingia sp. |
| | | ເຄືອຕຳແຍ | Mucuna sp. |
| | | ຫົວໂລ້ນ | Parkia sumatrana Miq. |
| | | ສະຜາງ/ອະລາງ | Peltophorum dasyrrhachis (Miq.) Kurz |
| | | ດູ່ | Pterocarpus macrocarpus Kurz |
| | | ເຄືອໜາມຫັນ | Pterolobium microphyllum Miq. |
| | | ແຕ້ຮໍ | Sindora siamensis Teijsm. ex Miq. |
| | | ເຄືອພັນຊ້າຍ | Spatholobus parviflorus (Roxb. ex G.Don) Kuntze |
| | | ໄມ້ແດງ | Xylia xylocarpa (Roxb.) Taub. |
| | | ໄມ້ແດງນ້ຳ | Xylia xylocarpa var. kerrii (Craib & Hutch.) I.C.Nielsen |
| Hypericaceae | 1 species | ຕ້ອສົ້ມ | Cratoxylum formosum (Jack) Dyer |
| Hypoxidaceae | 1 species | ຫຍ້າດອກຄຳ | Hypoxis aurea Lour. |
| Irvingiaceae | 1 species | ກະບົກ | Irvingia malayana Oliv.ex Bennett |
| Lauraceae | 9 species | ຈອງ | Cinnamomum curvifolium (Lour.) Nees |
| | | ສີໃຄຕົ້ນ | Cinnamomum iners Blume |
| | | ມີ່ລາງ | Litsea helferi Hook.f. |
| | | ບົງຮ້າງ | Litsea umbellata (Lour.) Merr. |
| | | ຢາງບົງຫາດ | Machilus cochinchinensis Lecomte |
| | | ຈອງເຄືອ | Neocinnamomum caudatum (Nees) Merr. |
| | | ໄພເຄືອນຫ້າ | Neolitsea chuii Merr. |
| | | ພາຍເວັ້ນ | Phoebe lanceolata Nees |
| | | ພາຍ | Phoebe sp. |
| Lecythidaceae | 1 species | ນົມຍານ | Barringtonia annamica Gagnep. |
| Loganiaceae | 3 species | ແສງເບືອ | Strychnos nux-blanda A.W.Hill |
| | | ງູມກາ | Strychnos nux-vomica L. |
| | | ຂີ້ກາ | Strychnos sp. |
| Lythraceae | 4 species | ແຕ້ນ | Duabanga grandiflora (Roxb. ex DC.) Walp. |
| | | ເບືອຍແດງ | Lagerstroemia floribund Jack |
| | | ອິນທະນິນ | Lagerstroemia speciosa (L.) Pers. |
| | | ກາກະເລົາ | Lagerstroemia sp. |
| Magnoliaceae | 1 species | ຈຳປາປ່າ | Magnolia champaca (L.) Baill. ex Pierre |
| Malvaceae | 9 species | ບ່ຫມົ່ນ | Grewia hirsuta Vahl |
| | | ບ່ຂີ້ຕຸ່ນ | Helicteres hirsuta Lour. |
| | | ໜາກຄອມກ້ຽງ | Microcos paniculata L. |
| | | ໜາກຄອມ | Microcos tomentosa Sm. |
| | | ຫ້ຳອາວ | Pterospermum megalocarpum Tardieu |
| | | | Pterospermum sp. |
| | | ຈອງບານ | Scaphium macropodum (Miq.) Beumée ex K.Heyne |
| | | ບ່ | Sterculia |
| | | ບ່ | Sterculia sp. |
| Melastomataceae | 5 species | ກົ້ນໜໍ້ | Melastoma malabathricum L. |
| | | ເອນອ້າໃຫ່ຍ | Melastoma sp. |

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| | | ໝືອດພອງ | Memecylon coeruleum Jack |
| | | ໝືອດແຂ້ | Memecylon pauciflorum Blume |
| | | ເອນອ້ຳ | Osbeckia chinensis L. |
| Meliaceae | 5 species | ຕາປູ | Aphanamixis polystachya (Wall.) R.Parke |
| | | ດ້ຳມພ້ຳ | Cipadessa baccifera Miq. |
| | | ໝາກຕ້ອງ | Sandoricum koetjape (Burm.f.) Merr. |
| | | ລ່ຳໄຍປ່ຳ | Walsura pinnata Hassk. |
| | | ແສງໝາກດາບ | Walsura robusta Roxb. |
| Menispermaceae | 1 species | ເຄືອເຂົ່າຮໍ | Tinospora crispa (L.) Miers ex Hook.f.& Thomson |
| Moraceae | 5 species | ໝາກມີ້ປ່ຳ | Artocarpus lacucha Buch.-Ham. |
| | | ຫາດ | Artocarpus sp. |
| | | ເດື່ອ | Ficus sp. |
| | | ໝາມຂີ້ແຮດ | Streblus ilicifolius (Vidal) Corner |
| | | ສົ້ມພໍ່ | Streblus monoicus Gagnep. |
| Myristicaceae | 1 species | ເລືອດຄວາຍ | Knema erratica (Hook.f. & Thomson) J.Sinclair |
| Myrtaceae | 7 species | ໂພງ | Rhodomyrtus tomentosa (Aiton) Hassk. |
| | | ເຂົ້ຳຂາວ | Syzygium acuminatissimum (Blume) DC. |
| | | ຫວ້ຳໃບໃຫ່ຍ | Syzygium grande (Wight) Walp. |
| | | ສະເມັກ | Syzygium gratum (Wight) S.N.Mitra |
| | | ຫວ້ຳດົ່ງ | Syzygium nervosum A.Cunn. ex DC. |
| | | ຫວ້ຳ | Syzygium sp. |
| | | ດู่ຄ່ຳ | Tristaniopsis merguensis (Griff.) Peter |
| Nyssaceae | 1 species | ໝາກເຖິນ | Mastixia sp. |
| Ochnaceae | 1 species | ຊ້ຳງບ້ຳວ | Ochna integerrima (Lour.) Merr. |
| Opiliaceae | 2 species | ຜັກຫວານ | Melientha suavis Pierre |
| | | | Urobotrya sp. |
| Peraceae | 1 species | ບົກຄາຍ | Chaetocarpus castanicarpus (Roxb.) Thwaites |
| Phyllanthaceae | 6 species | ເໝົ້ຳໂຄນ | Antidesma acidum Retz |
| | | ເໝືອດ | Aporosa serrata Gagnep. |
| | | ເໝືອດ | Aporosa sp. |
| | | ໝາກໄฟ | Baccaurea ramiflora Lour. |
| | | ກ້ຳງປຳ | Breynia sp. |
| | | ຂາມປ້ອມ | Phyllanthus emblica L. |
| Primulaceae | 3 species | ຕີນຈ່ຳ | Ardisia crenata Sims |
| | | ຂີ້ມອນ | Embelia ribes Burm.f. |
| | | ກ່ຳລັ້ງຊ້ຳງสาน | Maesa montana A.DC. |
| Rhamnaceae | 6 species | ເຄືອໝາກດูก | Sageratia cordifolia Tardieu |
| | | ເຄືອເຂົ່າແกบ | Ventilago cristata Pierre |
| | | ກ່ຳລັ້ງເสือโค่ง | Ziziphus attopensis Pierre |
| | | ໝາມລັ่บแมว | Ziziphus oenopolia (L.) Mill. |
| | | ໝາກมาย | Ziziphus rugosa Lam. |
| | | ລັ่บแมว | Ziziphus sp. |
| Rubiaceae | 20 species | ໝາมแห่ງน้อย | Canthium horridum Blume |

| | | | |
|---|---|---|---|
| | | ໜາມແທ່ງ | Catunaregam spathulifolia Tirveng. |
| | | ກົກໜາມແທ່ງ | Catunaregam tomentosa (DC.) Tirveng. |
| | | ງ່ຽງປ່າດຸກ | Catunaregam spinosa (Thunb.) Tirveng. |
| | | ພຸດປ່າ | Gardenia cambodiana Pit. |
| | | ອິນທະຫວາດົ່ງ | Gardenia saxatilis Geddes |
| | | ໄຂ່ເນົ່າ | Gardinia sootepensis Hutch. |
| | | ສົ້ມກົບ | Hymenodictyon orixense (Roxb.) Mabb. |
| | | ເຂັ້ມຂາວ | Ixora chinensis Lam. |
| | | ເຂັ້ມໂຄກ | Ixora cuneifolia Roxb. |
| | | ເຂັ້ມດົ່ງ | Ixora dongnaiensis Pierre ex Pit. |
| | | ເຂັ້ມແດງ | Ixora sp. |
| | | ກ່ຳລັ່ງຊ້າງ | Lasianthus sp. |
| | | ໄມ້ທົ່ມ | Mitragyna rotundifolia (Roxb.) Kuntze |
| | | ໄມ້ທົ່ມ | Mitragyna sp. |
| | | ຍໍ | Morinda angustifolia Roxb. |
| | | ຕໍກະດຸກ | Prismatomeris tetrandra (Roxb.) K.Schum. |
| | | ດູກໄກ່ | Psychotria asiatica L. |
| | | ໜາກໜັ້ນ | Rothmannia wittii (Craib) Bremek. |
| | | ພຸດດົ່ງ | Rothmannia sp. |
| Sapindaceae | 7 species | ລຳໄຍ | Dimocarpus longan Lour. |
| | | ຫອດ | Lepisanthes rubiginosa (Roxb.) Leenh. |
| | | ຫອດ | Lepisanthes sp. |
| | | ໜາກເຫຼືອ | Nephelium hypoleucum Kurz |
| | | ແດງນ້ຳ | Pometia eximia Hook.f. |
| | | ຄໍ້ສົ້ມ | Schleichera oleosa (Lour.) Merr. |
| | | ຄໍແຂວນ | Xerospermum cochinchinensis Pierre |
| Sapotaceae | 1 species | ພິກຸນ | Mimusops elengi L. |
| Simaroubaceae | 4 species | ຍົມຜາ | Ailanthus triphysa (Dennst.) Alston |
| | | ອ່ຽນດ່ອນ | Eurycoma harmandiana Pierre |
| | | ຍົກບ່ຖອງ | Eurycoma longifolia Jack |
| | | ກົນທາ | Harrisonia perforate |
| Styracaceae | 2 species | ຊ້າຍານແດງ | Styrax benzoides Craib |
| | | ຍານ | Styrax sp. |
| Symplocaceae | 3 species | ເໝືອດຫຼວງ | Symplocos adenophylla Wall. ex G.Don |
| | | ເໝືອດຄອມ | Symplocos longifolia H.R.Fletcher |
| | | ພຸງຜາວ | Symplocos paniculata (Thunb.) Miq. |
| Thymelaeaceae | 1 species | ເກດສະໜາ | Aquilaria crassna Pierre ex Lecomte |
| Vitaceae | 4 species | ເຄືອກາບ | Ampelocissus martini Planch. |
| | | ເຄືອເຂົ້າປູນ | Cissus repanda (Wight & Arn.) Vahl |
| | | ເຄືອຮູນ | Tetrastigma harmandii Planch. |
| | | ເຄືອເຂົ້ານ້ຳ | Tetrastigma sp. |

(Source) The Authors

# 4

# Quality Assessment of Glue Bond on Plywood- *Eucalyptus* Hybrid (*Eucalyptus Deglupta* and *Eucalyptus Cammaldulensis*) Based on the Length of Pressing Time

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Abstract

*This study focused on evaluating the factors affecting the quality of A-bond in plywood, specifically examining the influence of pressing time duration. The plywood used was made from Eucalyptus hybrid (Eucalyptus deglupta and Eucalyptus cammaldulensis) sourced from Burapha's Agro-Forestry Co., Ltd. The veneers were air-dried to a moisture content of 14-16 % and further dried in a steaming kiln to achieve 6% moisture content. The plywood panels consisted of 5 plies bonded with Phenol Formaldehyde (PF-402) adhesive. Pressing was done at 120°C and 23 MPa pressure for durations of 10, 12, and 14 minutes. The quality of the A-bond was assessed according to AS/NZS 2754.1(2016) standards. The results showed that wood failure percentages in the glue lines were 65.72% for 10 minutes, 57.02% for 12 minutes, and 68.90% for 14 minutes. Statistical analysis indicated no significant difference in wood failure among the different pressing times, suggesting the need for further experiments with higher temperatures and longer pressing times to improve bond quality.*

Keywords: A bond, Hot-pressing, Eucalyptus hybrid (clone-K7), Phenol Formaldehyde (PF-402).

## Introduction

Wood, a resilient and fibrous tissue, is abundantly found in numerous plant species, offering a multitude of advantageous properties. Its exceptional workability, impressive physical and mechanical attributes, pleasing aesthetics, and eco-friendly nature make it highly desirable. For centuries, humans have relied on wood for various purposes, including fuel, construction material, tools, furniture, packaging materials, artworks, and even paper (Bodig, 1982), (Lui, 2004). In addition to natural wood, engineered wood has emerged as a reliable alternative. It is produced by combining wood, adhesive, and fiber reinforcement under pressure and heat (Utai Meekum, Yumatorn Mingmongkol, 2012). Plywood, a type of engineered wood, consists of sheets of veneer called plies bonded together with an adhesive. It can be made from both softwoods and hardwoods, always constructed with an odd number of layers and alternating grain directions (Youngquist, 1999).

Structural panels, such as sheathing, siding, concrete form, or marine-grade plywood, are classified based on their intended structural application rather than the wood species used (Rubin Shmulsky, 2011).

The role of adhesive bonding in the forest products industry is becoming increasingly significant, serving as a crucial element in maximizing the efficient use of timber resources.

Adhesives are predominantly utilized in the production of building materials such as plywood, oriented strand board, particleboard, fiberboard, structural composite lumber, as well as in the fabrication of doors, windows, frames, and various factory-laminated wood products (Charles R. Frihart, 2010) Structural adhesives, designed to retain their strength and stiffness even under extreme conditions of cyclic water saturation and drying, are classified as fully exterior adhesives. On the other hand, adhesives that exhibit faster degradation than wood, especially under harsh conditions like prolonged water exposure, are categorized as interior adhesives. Bridging the gap between these two types are intermediate adhesives, which can withstand short-term water immersion while maintaining their structural integrity but tend to degrade more rapidly than wood when subjected to prolonged exposure to moisture and heat. It is noteworthy, however, that adhesives offering the highest levels of strength, rigidity, and resistance to service deterioration often show the least tolerance to variations in wood surface conditions, moisture content, and assembly parameters, including pressure, temperature, and curing conditions (Hunt, 2010). A case in point is the Technical Datasheet of Phenol-Formaldehyde (PF-402), which highlights a waterproof adhesive ideal for veneer-based products intended for exterior use. This adhesive requires curing at elevated temperatures, specifically at 120°C for 4 minutes, 130°C for 3 minutes, and 140°C for 2 minutes of hot-pressing duration (TDIC, 2011). This example underscores the intricate balance between adhesive performance characteristics and the operational conditions required to achieve optimal bonding efficacy.

Following the recommendations provided, a comprehensive experiment was conducted to evaluate the adhesive bond quality of a Eucalyptus hybrid, specifically the crossbreed of *Eucalyptus deglupta* and *Eucalyptus camaldulensis*, referred to as K7. This study focused on the performance of K7 plywood when bonded with two types of adhesives: PF-402 (referred to as A-bond) and Melamine Urea Formaldehyde (MUF, referred to as B-bond). The experiment involved the production of 7-ply plywood panels, each with a thickness of 14 mm. These panels were fabricated using a hot press machine (model BY214*4/2A-1) at a temperature of 130°C and a pressure of 25 MPa for a duration of 9.0 minutes. To assess the durability and reliability of the adhesive bonds under different conditions, the A-bond samples underwent a steaming process for 6 hours at 135°C in a pressurized vessel (autoclave) at 200kPa. Subsequently, a pressure-chisel test was employed to separate the glue lines, allowing for the evaluation of the percentage of glue failure. Conversely, the B-bond samples were subjected to boiling for 6 hours at the standard boiling temperature of 100°C. The findings from this experiment indicated that both A-bond and B-bond samples exhibited an average glue failure rate of 65%, as reported by Manychanh in 2020% (Manychanh, 2020). In a separate experiment focusing on the bond quality of Red Mahogany plywood, which was composed of 5 plies and had a thickness of 15 mm, the panels were processed at a temperature of 140°C for 11.3 minutes under a pressure of 1.3 MPa. The results from this test revealed that the A-bond samples demonstrated an average glue failure rate of 75%, according to research conducted by W.J. Atyeo, G.P. Hopewell, and R.L. McGavin (W.J. Atyeo; G.P. Hopewell; R.L. McGavin, 2008). These experiments underscore the critical role of adhesive selection and processing conditions in determining the bond quality of plywood, highlighting the need for further research to optimize these parameters for enhanced durability and performance.

Based on the guidance provided in the Technical Datasheet (TDIC, 2011), it is advised that additional research be conducted on K7 to explore its potential benefits for the plywood manufacturing industry. Specifically, there is an opportunity to enhance production value by investigating ways to decrease energy consumption and reduce pressing time.

The primary goals of this study are to evaluate the effectiveness of the adhesive bond in plywood, which incorporates four glue lines, by varying the duration of the pressing time. The pressing times under consideration are 10 minutes, 12 minutes, and 14 minutes, all conducted at a consistent temperature of 120°C. This research aims to identify the optimal pressing time that ensures a strong glue bond while potentially lowering production costs and improving efficiency.

## Materials and Methods

### *Log preparation and veneer production*

Seven-year-old Eucalyptus K7 logs were sourced from the Burapha Agro-forestry Company Limited plantation in Nongbua Village, Phonehong District, Viantiane Provinces, Lao PDR. These logs, with diameters ranging from 15 to 25 cm and lengths of 150 cm, were transported to the Wood Science and Wood Products Research Center at the Faculty of Forest Science (FFS), National University of Laos (NUOL). The debarking process was carried out using a Log Debarker machine (Model: BBP1400D), followed by peeling with a Spindleless Peeling Lathe (Model: SL1350/3, BSY Industry Company) at a rotation speed of 500-1,200 RPM. The resulting veneers measured 2.5×1,250×1,250 mm in thickness, width, and length, respectively.

### *Veneer Drying and Adhesive Application:*

Post-measurement and visual grading, the veneers were air-dried under ambient conditions and subsequently dried to a final moisture content (MC) of 6-8% using a steam kiln. A Glue Spreader machine (Model: YQ65-1200) facilitated the application of Phenol-formaldehyde adhesive (PF-402) from TOA company (Thailand), with an application rate of 160-180g/m².

### *Plywood Pressing:*

The adhesive-coated veneers were first pressed using a Cool Press machine (Model: BY814*4/3B) for 20 minutes at 19MPa. Following this, a Hot Press machine (Model: BY214*4/2A-1) was employed to treat the plywood at 120ºC with 23MPa for durations of 10, 12, and 14 minutes.

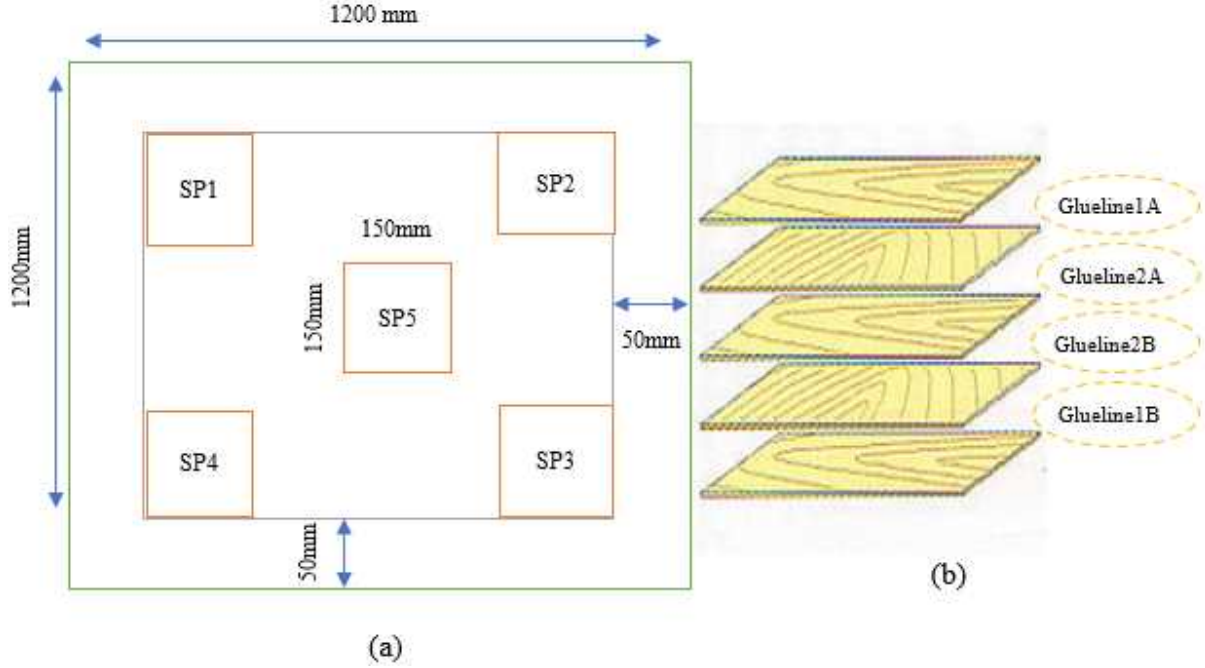
### *A-Bond Testing Preparation:*

Based on the AS/NZS 2754.1:2016 standard, samples measuring 12.5 x 1200 x 1200 mm were cut down to 12.5 x 150 x 150 mm using a circular saw (Model: BJ 6113-45), resulting in five specimens per panel. The AS/NZS 2269.0:2012 standard guided the quality assessment, emphasizing the need for varying bond classes depending on durability requirements. A total of 90 A-bond testing specimens were derived from 18 different panels, segmented into six groups based on the pressing duration (10, 12, and 14 minutes).

### *Bond Quality Assessment:*

The bond quality was evaluated using the AS/NZS 2098.2:2012 standard, which involved chiseling apart the glue lines of the specimens after steaming them for 6 hours at 135°C in a pressurized vessel (autoclave) at 200kPa. This process aimed to assess the percentage of wood failure in four glue lines: Glueline1A and Glueline1B (located at the plywood surface) and Glueline2A and Glueline2B (located inside the plywood).

Figure 6 (a) Samples Cutting Points and (b) Glueline Testing Sample




(Source) The Authors.

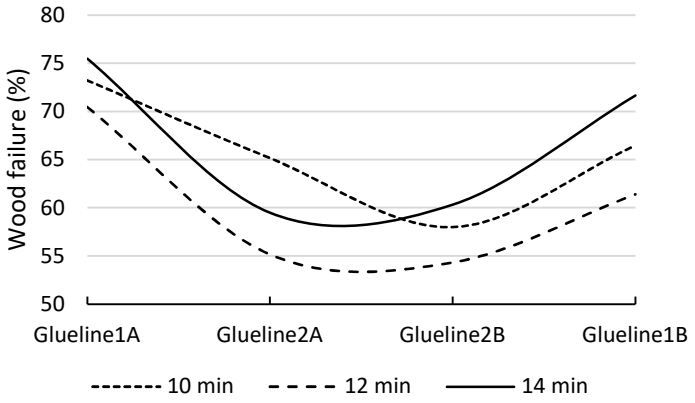
Results and Discussion

This study presents an analysis of wood failure percentages within gluelines, as depicted in Figure 2. The evaluation was conducted across three distinct pressing durations (10, 12, and 14 minutes) at a constant temperature of 120ºC. The findings revealed average glueline failure rates of 65.7% for the 10-minute treatment, 60.3% for the 12-minute treatment, and 66.7% for the 14-minute treatment. An ANOVA test was employed to compare the pressing time groups, revealing significant differences among the 10-minute, 12-minute, and 14-minute durations (P=0.03).

Notably, the highest incidence of wood failure was observed at the outer edges of the glueline (Glueline1A and Glueline1B), with failure rates ranging between 61% and 75%. Conversely, the inner gluelines of the plywood (Glueline2A and Glueline2B) exhibited lower failure rates, ranging from 54% to 60%, as illustrated in Figure 2.

The 10-minute pressing time resulted in a 65.7% wood failure rate, aligning with previous research conducted by Manychanh (2020), which utilized the same quality assessment standards. However, it is noteworthy that the hot press temperature in the current study was 10ºC lower than that of the previous study. Despite this temperature difference, the patterns of wood failure were comparable; the maximum wood failure in previous studies ranged between 85% and 95%, while the inner gluelines showed failure rates between 46% and 55%. These findings suggest that both the previous study (conducted at 130ºC with a 9-minute pressing time) and the current study (120ºC with a 10-minute pressing time) indicate a need to adjust pressing times to optimize adhesive rigidity and enhance the yield of wood failure within the plywood's gluelines.

Figure 2. Wood Failure in Glueline Based on Length of Pressing Time (10 min, 12 min, and 14 min)




(Source) The Authors.

Further analysis of between glueline comparison for each group of treatment for 10 min, 12 min, and 14 min (Table1).

Table 5 Comparison between Glueline to Gluline of Each Length Pressing Time Group

| Time (min) | Between glueline | P-*value* |
|---|---|---|
| 10 | Glueline1A and Glueline2A | 0.04 |
| | Glueline1A and Glueline2B | 0.00 |
| | Glueline1B and Glueline2B | 0.03 |
| 12 | Glueline1A and Glueline2A | 0.01 |
| | Glueline1A and Glueline2B | 0.00 |
| 14 | Glueline1A and Glueline2A | 0.00 |
| | Glueline1A and Glueline2B | 0.00 |

(Source) The Authors.

Table 6 Comparison between Length of Time of Each Glueline Group

| Glueline | Comparison between times (min) | P-value |
|---|---|---|
| Gluline1A | 10 and 12 | .522 |
| | 10 and 14 | .600 |
| | 12 and 14 | .245 |
| Glueline2A | 10 and 12 | .055 |
| | 10 and 14 | .273 |
| | 12 and 14 | .402 |

| | | |
|---|---|---|
| Glueline2B | 10 and 12 | .483 |
| | 10 and 14 | .655 |
| | 12 and 14 | .252 |
| Glueline1B | 10 and 12 | .332 |
| | 10 and 14 | .320 |
| | 12 and 14 | .051 |

(Source) The Authors.

## Conclusions

The findings revealed that the average wood failure in the glueline for the 10-minute treatment was 65.7%, 60.3% for the 12-minute treatment, and 66.7% for the 14-minute treatment. A comparison of the different pressing time groups indicated a significant difference, with a P-value of 0.03. Furthermore, the wood failure in the glueline at the outer layers was higher than that of the inner layers. Specifically, the maximum wood failure in the outer gluelines ranged from 85% to 95%, while the inner gluelines ranged from 46% to 55%.

## Acknowledgements

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# 5
# Technical Efficiency and Role of Labor in Maize Production, Evidence from Houaphanh Province, Laos

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## Abstract:

*This study evaluates farmers' perceptions and challenges in maize cultivation, focusing on Viengxay and Houamueng Districts, which lead in harvested area except for "seed variety." All participants are affiliated with maize production groups and companies, utilizing popular varieties such as LVN10, CP888, CP989, and CP999. However, the technical efficiency of farm practices, including land clearing, planting, and weeding, is notably low. Enhancing labor skills and farming techniques has shown to boost production. The primary workforce comprises individuals aged 35-60 and teenagers, with the younger generation (18-35 years old) showing little interest in maize farming. A short-term solution involves improving farming knowledge and skills across all stages, with essential training for household laborers. Additionally, limited road access impedes product transportation and market access. Financial challenges, including the absence of a guaranteed maize price, further complicate investment in maize cultivation. Lower interest rates on loans could offer financial relief. Moreover, concerns over pests, climate change, fluctuating market prices, labor costs, and alternative crops prompt reconsideration of maize as a primary income source, due to declining production and inefficiency.*

**Keyword: Maize plantation, Efficiciance Techical, Farm production, Houaphan Province, Laos.**

## Introduction

In Laos, maize production has been blooming since 2000 and cultivating in Northern provinces including Bokeo, Udomxay, Syabouly, Xiengkhouang and Houaphan province. The maize production is cultivated in the form of mono-cropping system and it was rapidly increased from 0.37 million tons in 2005 and jumped to 1.1 million tons in 2008. With such results, there are several explanations regarding to the causes of increasing of maize production. For example, the high demand of maize from both and international markets and commercial agricultural production policy of Lao government. Another reason was due to maize was successful used to produce ethanol and in the same year there was a severe drought in South America and Australia (FAO, 2011). However, it was reduced to 1.02 tons in 2010 and slightly increased to 1.21 million tons in 2013 (Agricultural Statistic Yearbook, 2013).

The maize production in northern Laos has received in low productivity and human labor base, especially in upland area human labour is the key input factor for maize production the average labour used for maize production is 62 man-day per ha (Southavilay at all., 2012) and maize productivity is generally between 1.5-2.5 tons/ha, compared to national average maize yields is 3.8 tons/h (DOPC, 2010). In order to meet markets' demand farmers were encouraged to produce maize under limited technical skill labour of commercial farming practices. Consequently, farmers were practiced their production under low productive farmland and intensive of labor uses. If the existing condition of maize production is being continued it will be brought the negative impacts to their production, especially high demand of production cost and farmers then will obtain low profit from their production.

On the other hand, maize is one of strategic crops for rural poverty reduction and it is in the list of priority cash crops in the Agricultural Development Strategy 2025 and vision 2030 of Ministry of Agriculture and Forestry. Therefore, this research will be a tool to support the strategic implementation. To do so, it requires improving technical skills labor and minimizing other factors that impediment of maize production.

This study aims to enhance maize production by enhancing the technical skills of farmers, with a focus on youth and young farmers. Additionally, the research aims to identify and mitigate any unnecessary or inefficient factors that may hinder maize production in northern Laos.

## Objectives

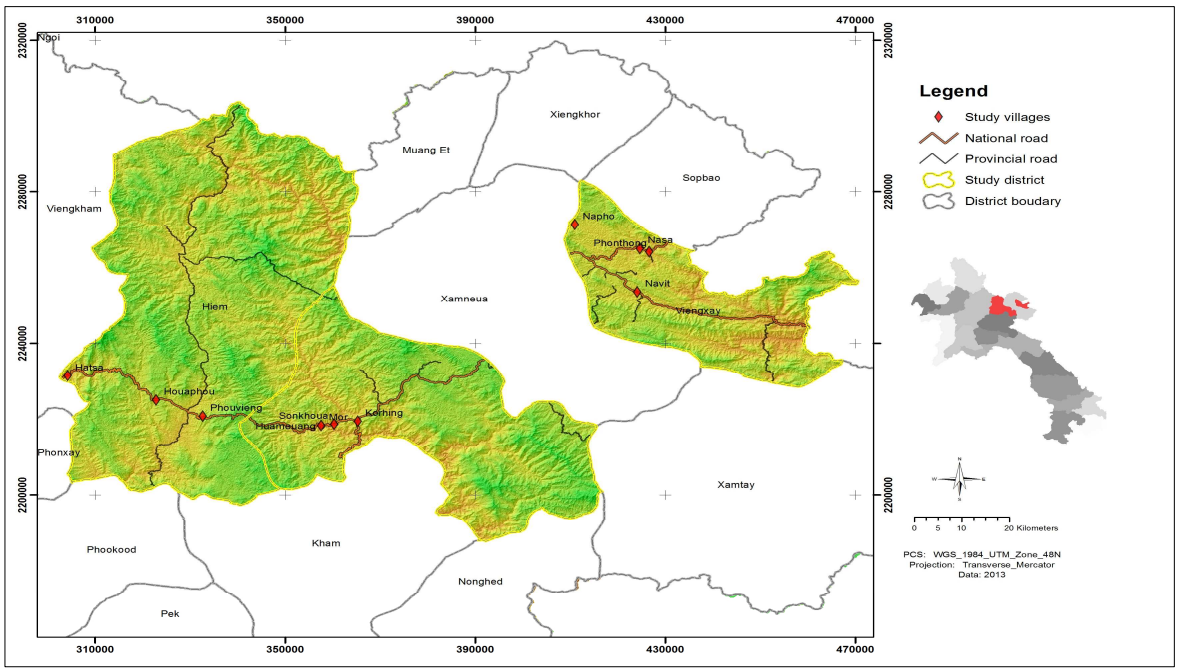
- To estimate a technical efficiency of maize farmers and identify inefficiency factors that effect on maize production.
- To explore the contribution of labor across various age groups, along with other significant factors, to maize production.
- To understand maize farmers' perceptions and identify key concerns regarding their production practices.

## Study Site

### *Study Site*

The study conducted in the main maize production districts that including Huameuang, Hiem and Viengxay district of Houaphanh province, Northeast of Laos. Viengxay district border to Vietnam. Hiem and Houameung district connect to LuanPrabang and XiengKhouang provinces. See location from figure 1:

Figure 1: Study Areas




(Source) The Authors.

## Methodology and Data Analysis

For the data will be analyzed the stochastic frontier production function and will be used to estimate the Technical Efficiency (TE) of individual maize farmers and the factors that influence inefficiency. The use of stochastic frontier production has some advantages. According to Coelli et al., (1994), the stochastic frontier production determinant is more appropriate for developing countries where data are more likely to be heavily influenced by the measurement of two-sided errors, including factors outside the control of the farmers such as weather conditions, disease, pests, etc.; and, a one-side component that accounts for inefficiency. Therefore, the stochastic frontier production function developed by Aigner et al. (1977) is used in this study.

In order to determine the effect of input factors and socio-economics to production function and efficiency estimation, Cobb-Douglas of stochastic production frontiers will be used as:

$$ln\gamma_i = \beta_0 + \sum_{j=1}^{n} \beta_{ij} lnX_{ij} + v_j - u_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, $ln$ is natural logarithm, $Y_i$ is maize production of the i-n (i= 388) farm in ton, $\beta_0$ is the intercept and $\beta_{j-n}$ are response parameters to be estimated or elasticity corresponding to each input j=n (X= 5) as shows in table below, $V_j$ is two-sided error component.

$$u_i = \delta_0 + \sum_{j=1}^{n} \delta_i lnZ_{ni} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, $\mu_i$ or Technical Efficiency (TE) is inefficiency effects, $\delta_0$ is the intercept term and $\delta_{1-n}$ are parameter for the i-th input variables (Z= 6).

Table below descripts determinant factors (inputs variables) that will be collected. The independent variables allow us to explicitly control for many other factors that simultaneously affect the dependent variable.

Table1. Variable Description of Determinant Factors to be Measured in the Model

| Variable for production function model | Description |
|---|---|
| Output (Y) | Maize production (ton) |
| Seeds ($X_1$) | Total amout of seeds (kg) |
| Farmsize ($X_2$) | Maize farmland (ha) |
| Labor1 ($X_3$) | Total labor for land clearing (cuting and burning) (Man-day) |
| Labor2 ($X_4$) | Total labor for transpanting and weeding (Man-day) |
| Labor3 ($X_5$) | Total labor for harvestation and transportation (Man-day) |
| Variable for inefficiency model | Description |
| Education ($Z_1$) | Farmer's education (school year) |
| Household size ($Z_2$) | Household member (person) |
| Female ($Z_3$ ) | Number of female in the house (person) |
| Age ($Z_4$) | Dummy variable, if farmers' age 18-35 years old is considered as youth labor which take the value of 1, 0 = otherwise |
| Credit access ($Z_5$) | Dummy variable which takes the value of 1 if the farmers loan credit from the bank; 0 = other wise |
| Main occupation ($Z_6$) | Dummy variable which takes the value of 1 if the occupation is maize farming; 0 = otherwise |

Note: the number of variables can be changed based on the result from field survey.

(Source) The Authors.

***Data collection***

Face-to-face interviews were conducted with a total of 388 maize growers who collectively managed approximately 700 hectares of land. The participants were randomly selected from 10 villages across three districts that are known for maize cultivation in the Houaphanh province. Specifically, there were 135 maize farmers from three villages in the Houameung district (Korhing, Sonkhoua, and Mor), 122 maize farmers from four villages in the Viengxay

district (Naveed, Naphoh, Nasa, and Phonthong), and 131 maize farmers from three villages in the Hiem district (Houaphou, Phouvieng, and Hadsa). The maize farmland in these districts is predominantly situated on uplands with steep slopes. Land use observations were carried out through ground surveys and transect walks in plantation fields and farm areas.

The structured questionnaires were used to extract from the selected farmers on their household and farming activities. Semi-structure method applied during discussion. Data related to farm inputs and outputs were collected. The data on farm inputs included labor, fertilizer, seed and machinery, while data on farm output includes production quantities of maize. Socio-economic variable of the farmers also collected, which include farmer`s age, farm size, level of education, household size, farming experience, source of credit and seed variety.

## Result and Discussion

### *Maize Production*

Since 1995, maize production has been introduced in Houaphanh province. However, a sharply increase in maize production was from 2005. The leading district of harvested area was Viengxay and Houamueng districts. Only seed variety is accepted in this area, and there are two main maize varieties have been planting and all of maize farmers is farmers' membership of maize production groups and companies. The most famous variety is LVN10, CP888, CP989 and CP999 which provided by maize traders and companies.

Photo1: Imported maize hybrid seed




(Source) The Authors.

Maize production in this area is based on conventional techniques with intensive human labors and non-fertilizer applied. The area of production is mainly on steep slope by slash and burn before direct seedling. After planting, the weeding activity is necessarily needed at least two

to three times before harvesting. If farmers well done in performance of weeding, they will receive in high productivity.

The basic of harvest and post-harvest technique of maize production in the study area, we observed that some farmers in let the maize dry on the stem and directly carryout to the main road (market) and wait for traders come to buy. The technique of let maize dry on the stem can help to reduce some of moisture content level before shelling. However, some farmers dry maize in a storage before selling as happened in Hiem and Houamoung district.

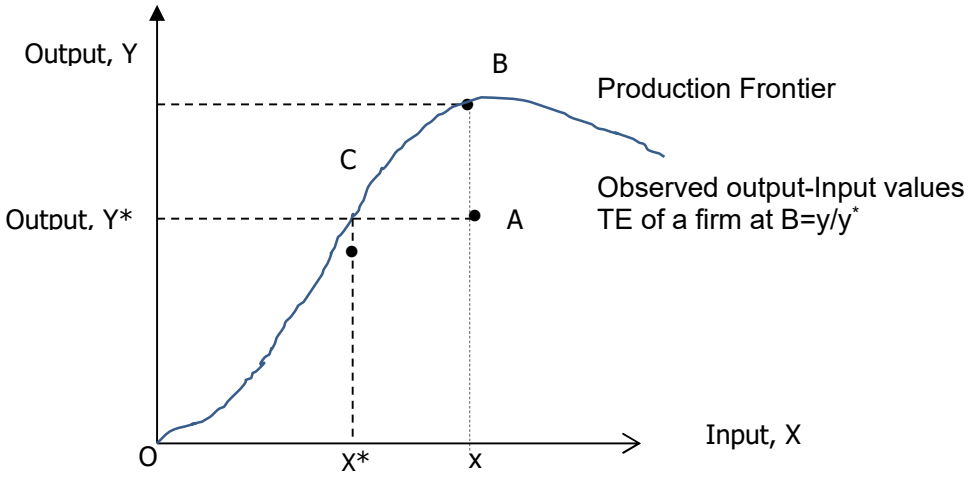
Photo 2: Maize Storage in the Farm and along Sideroad.



(Source) The Authors.

For the shelling, some farmers shell by hand, others use their own small mechanical shelling machines and mobile machines which are provided by traders and middlemen. The harvest period of wet season maize will be started from September to October. If farmers sell their maize in this period, they will get lower price than farmers who stock their maize and sell it around November to December. This is because the maize still has high moisture content and high supply during the harvest period (September to October).

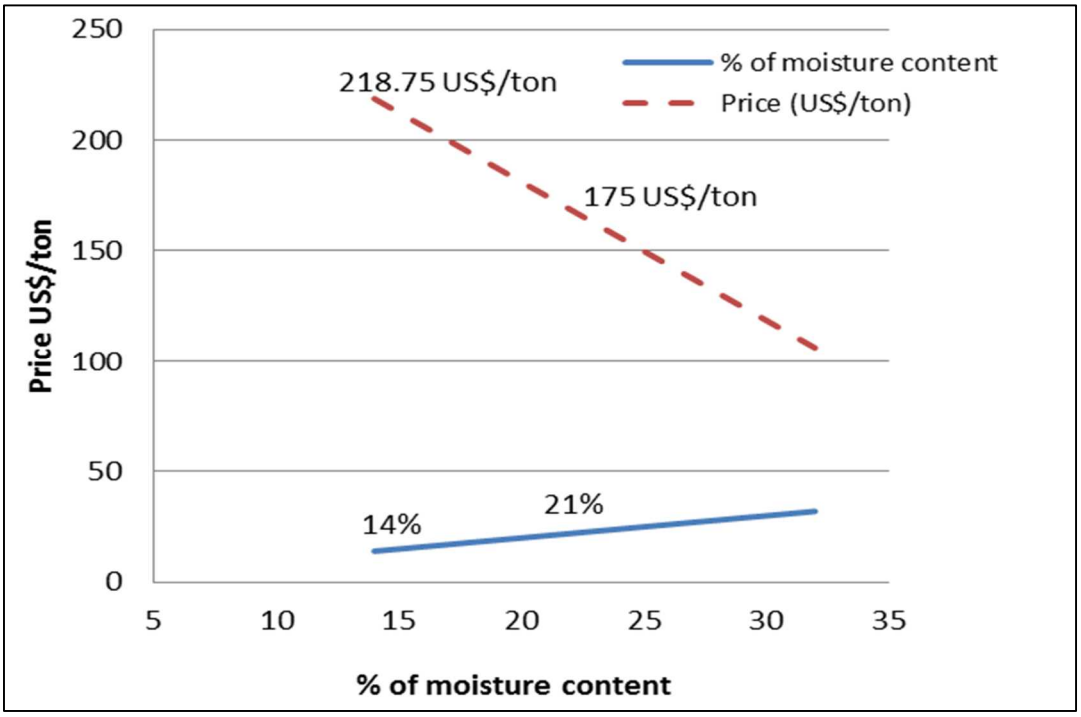
Figure 2 Technical Efficiency of a Firm in Input-Output Space




(Source) Battese, 1992.

Figure 2 shows the relationship between moisture content and price of selling maize. If moisture content increased the price will directly to decrease. This implies that the main requirement leading to the best price for maize was its moisture content, which should be 14-15.0% and the price can be achieved at US$220 per ton. According to Southavilay et al, (2012) found that Charoen Pokaphan (CP) bought maize from Laos cheaper than bought maize from Thai farmers and the differencing price was US$26 per ton because maize from Laos has high moisture, while Thai maize has moisture content was around 16-17%.

Figure 3 Relationships between Moisture Content and Price of Selling Maize




(Source) Southavilay et al (2012)

***Statistic of Output and Input Variables***

Table 2 presents data on the output-input and socioeconomic factors of maize production in Houameung district. The average yield is 4.4 tons per hectare, with production per household ranging from 0.38 to 38 tons across farm sizes of 0.3 to 6.60 hectares. Labor for land preparation, including slash and burn, planting, weeding, harvesting, and transportation, is intensive, averaging 45, 50, and 68 man-days respectively. Houameung district records the highest labor intensity at 145 man-days/ha, followed by Viengxay at 74 man-days/ha, and Hiem at 64 man-days/ha. This aligns with Southavilay et al., (2012), who reported an average of 62 man-days/ha for maize production in Bokeo, Oudomxay, and Xayaboury provinces.

In Houameung district, maize production relies heavily on manual labor due to lack of road access, leading to a higher number of laborers compared to other districts where machinery is commonly used. In provinces like Xiengkhouang, Bokeo, Oudomxay, and Xayaboury, farmers have easier access to roads and utilize machinery for land preparation, planting, and transportation. Additionally, weeding is also mechanized in some provinces like Bokeo and

Xayaboury. Educational data shows that 50% of maize farmers have completed elementary school, with only 5% having 15 years of education. The majority of maize farmers are aged between 18-35 years, with 22% engaged in maize production as their main occupation.

Table 2. Summary Statistics of Variables Used
in the Stochastic Frontier Production Function and Technical inefficiency Function.

| Variables | Units | Maximum | Minimum | Mean | Standard Deviation |
|---|---|---|---|---|---|
| Variables for production function model | | | | | |
| Output (Y) | Ton | 38.00 | 0.30 | 6.95 | 5.70 |
| Seeds ($X_1$) | Kg | 100.00 | 2.00 | 23.99 | 16.55 |
| Farmsize ($X_2$) | Ha | 11.10 | 0.05 | 1.67 | 1.26 |
| Labor1 ($X_3$) | Man-day | 360.00 | 1.33 | 45.11 | 42.33 |
| Labor2 ($X_4$) | Man-day | 261.00 | 2.10 | 48.05 | 46.39 |
| Labor3 ($X_5$) | Man-day | 316.00 | 5.32 | 67.97 | 45.61 |
| Variables for inefficiency model | | | | | |
| Education ($Z_1$) | Year | 15.00 | 0.00 | 5.79 | 3.19 |
| Household size ($Z_2$) | Person | 13.00 | 1.00 | 5.84 | 1.84 |
| Female ($Z_3$ ) | Person | 9.00 | 1.00 | 2.77 | 1.30 |
| Age ($Z_4$) | Year | 1.00 | 0.00 | 0.38 | 0.49 |
| Credit access ($Z_5$) | Dummy | 1.00 | 0.00 | 0.95 | 0.44 |
| Main occupation ($Z_6$) | Dummy | 1.00 | 0.00 | 0.22 | 0.50 |

(Source) Survey Data, 2014

***Technical Efficiency***

Table 2 presents the maximum-likelihood estimates (MLE) for the Cobb-Douglas parameters, showing that farm size, and labor for both land clearing and planting/weeding, significantly enhance maize production. Specifically, farm size and planting/weeding labor positively impact production at the 1% significance level, while land clearing labor does so at the 5% level. An increase in farm size by 1% notably boosts maize yield, suggesting that production grows with expanded cultivation area. This finding contrasts with Vanisaveth et al. (2012), who argued that larger farms, due to their complexity, are less productive than smaller ones. Field surveys indicate that farmers looking to boost maize output often prioritize expanding farm size, typically through deforestation, over increasing yield per hectare.

Table 3. Production Function

| Variables | Para. | Cobb-Douglas Production Function | |
|---|---|---|---|
| | | Coefficient | t-value |
| Constant | $\beta_0$ | -0.686 | 1.66 |
| Seed | $\beta_1$ | 0.6401 | 1.53 |
| Farm size | $\beta_2$ | 0.1932*** | 3.91 |
| Labor1 | $\beta_3$ | 0. 355** | 2.66 |

| | | | |
|---|---|---|---|
| Labor2 | $\beta_4$ | 0.1592*** | 3.42 |
| Labor3 | $\beta_4$ | 0.0889 | 1.33 |
| Sigma-squared $\sigma^2_s = \sigma^2_v + \sigma^2_u$ | $\delta^2$ | 0.400** | 2.15 |
| Gamma $\gamma = \sigma^2_u / \sigma^2$ | y | 0.791*** | 6.77 |
| No of observation: 379 | | | |

Note: *** significant at 1%, ** significant at 5%, * significant at 10%
(Source) Survey Data, 2014 (computed by Frontier 4.1)

However, the important input factors (variables) is labor1 (land clearing) and labor2 (planting and weeding). It means that 1% increase of labor for planting and weeding will lead to increase the maize production of 0.15% and 5% increase of labor for land clearing will lead to increase the maize production of 0.35%. This is expected because most of the maize production in Laos relies heavily on labor usage, particularly during clearing field, planting, weeding and harvesting. This is the line with finding of Southavilay et al (2012) who study on promotion of cash crop production in Northern Laos. According to the technique of maize production, the highest labor need is the planting period due to in this time farmers have to run to finish their planting activity in short period of 45 days after the first raining in May. For the harvesting technique is very important if a farmer low technique and limited labor, the maize will be damaged by rain and pest.

Table 4 Inefficiency Model Cobb-Douglas Stochastic Frontier Production Function

| Variables | Parameters | Coefficients | t-Value |
|---|---|---|---|
| Constant | $\delta_0$ | 1.078** | 2.142 |
| Education ($Z_1$) | $\delta_1$ | -0.175** | 2.288 |
| Household size ($Z_2$) | $\delta_2$ | -0.408 | 0.583 |
| Female ($Z_3$ ) | $\delta_3$ | 0.296 | 1.490 |
| Age ($Z_4$) | $\delta_4$ | 0.187 | 0.997 |
| Credit access ($Z_5$) | $\delta_5$ | 0.238 | 1.330 |
| Main occupation ($Z_6$) | $\delta_6$ | -0.202* | 1.835 |

***, ** and * are significant at 1%, 5% and 10% level respectively
(Source) Out of Frontier 4.1 from Field Survey Data, 2014

The study reveals that education level among maize farmers negatively correlates with inefficiency, meaning better-educated farmers are more efficient. This is attributed to their ability to grasp and implement new technologies. This aligns with findings from Shehu et al. (2007), Akhtaruzzaman (2010), and others who observed similar trends in rice farming efficiency across Nigeria, Bangladesh, and Laos. However, this contrasts with Ephraim (2007)'s study in Southern Malawi, where education didn't significantly impact maize production efficiency, attributed to traditional farming methods and the influence of policy and market factors. Interestingly, half of the maize farmers in the study had only completed elementary education.

The study also notes that household size and the presence of female family members have an insignificant impact on efficiency, suggesting that the contribution to efficiency is more about

the adult and working capacity of family members rather than sheer numbers. Age, particularly the 18-35 year bracket, also showed an insignificant effect on efficiency, with a notable portion of this age group not actively engaged in maize farming. Older farmers (35-60 years) and teenagers form the core labor force in maize production. Access to credit was seen to potentially enhance efficiency, though its impact was not significant due to limited uptake among farmers.

### *Technical Efficiency Score*

The distribution of technical efficiency scores relative to the best practice frontier scores are presented in Table 5. The mean of technical efficiency is recorded by 58%, indicating that farmers could improve technical efficiency by some 42%, on average with the current set of inputs and the given technology at that time. In the study area, there was no farmers operate their farms higher 90% technical efficiency levels, only 7% of farmers operate their farms between 71-80% technical efficiency levels. About 50% of farmers in the study area operate their farm between 51-60% and 61-70% technical efficiency levels.

Table5. Frequency Distribution of Efficiency of Maize Farmers

| Efficiency class | No. of farmers | Percentage |
|---|---|---|
| 0.10-0.30 | 8 | 2.11 |
| 0.31-0.40 | 42 | 11.08 |
| 0.41-0.50 | 67 | 17.68 |
| 0.51-0.60 | 86 | 22.69 |
| 0.61-0.70 | 109 | 28.76 |
| 0.71-0.80 | 60 | 15.83 |
| 0.81-0.90 | 7 | 1.85 |
| | | 100.00 |
| Total | 379 | |
| Mean | 58% | |
| Maximum | 89 | |

(Source) Survey data, 2014 (computed by Frontier 4.1)

The further analysis revealed that the average maize farmers would realize about 34.83% [1] in cost saving, if the farmer achieved the highest level of technical efficiency of 89% in the sampled site (Bravo-Ureta & Pinheiro, 1997, Khai & Yabe, 2011, Obare et al., 2010 and Southavilay et al 2012).

### *Concerning issues of maize farmers:*

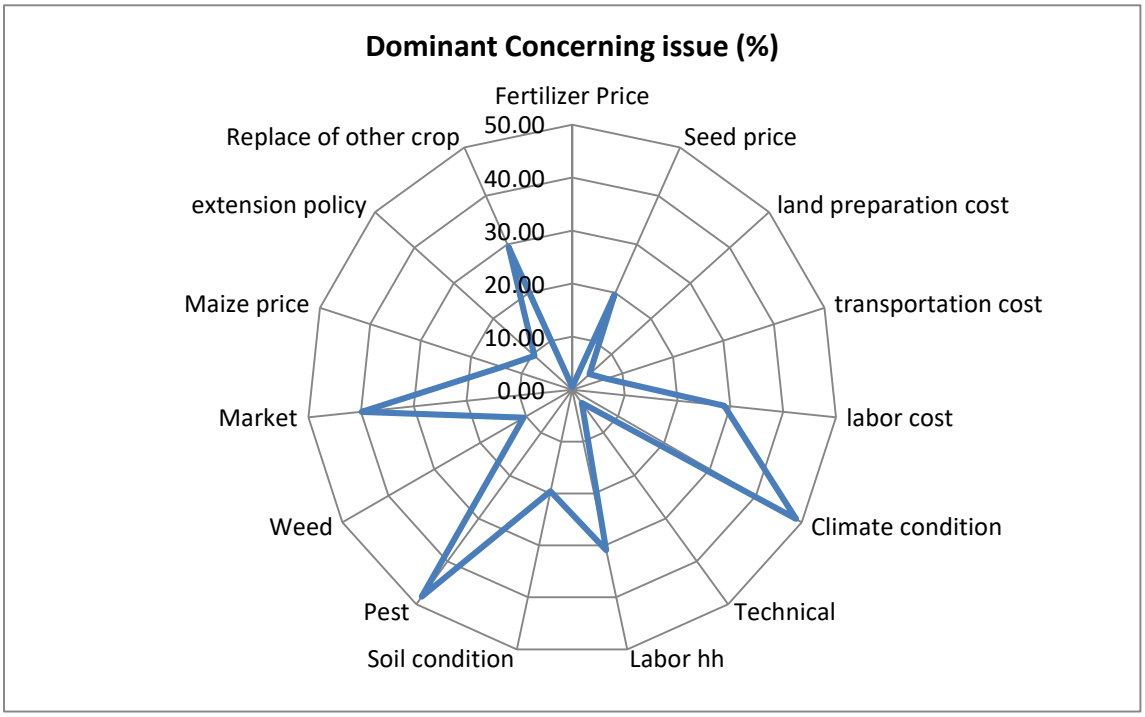
In order to understand the perception and concerning issues of maize farmers on their maize production, the questionnaire was designed by providing the list of issues and responding code 1 to 5 for extent from low to high: (1) Not at all; (2) Somewhat; (3) Relevant; (4) Significant; (5) Dominant constraint. The study found that the main issue of maize farmers concerns

[1] Calculated by {[1-(mean/max)]*100}=, {[1-(58/89)]*100}=34.83%

included of pest, climate condition, market, labor cost, family labor and replacing of other crops. This result presents very important issues of maize production due to its driven factors of maize production in this province. This indicates that maize farmers will further to continue or stop growing maize is depending on those factors. This result is in the same line with found during field survey, the maize production was damaged by mice during early plant and close to harvesting time. On the other hand, farmers are very much concern on the climate change condition as according to their experiences the maize productivity is very much upon weather conditions and rainfall, especially the first is necessarily needed after two to three days of planting.

The market is also the most concerning issues for maize farmers in this province because there are only few market places that farmers could easily access and most of them owned by Vietnamese. From the result the land preparation cost, price of maize, fertilizer and extension service issues are not significant for maize farmers in this province. The land preparation activities are only cleared and burned before planting farmers could save the cost of soil ploughing. However, we found that farmers used intensive labor for this activity. The figure below shows the dominant constraints or key issues that control maize farmers to stop and continue for growing maize in Houaphanh province.

Figure 4 Dominant Concerns of Maize Farmers on Maize Production




(Source) Survey data, 2014.

## Conclusions

In conclusion, this study analyzed the farm performance of 379 maize farmers in Houaphan province, focusing on technical efficiency and factors influencing it. The study revealed low technical efficiency in farm maintenance, with household labor being crucial for land

preparation and weeding. Harvesting labor was found to have a positive impact on maize production. To enhance maize production, it is essential to improve labor skills and techniques, particularly among farmers aged 35-60 and teenage laborers. Younger farmers should be trained to boost their knowledge and skills in maize farming. Improving road access can reduce intensive labor, and policies should be implemented to enhance basic infrastructure, such as road access, storage, and drying facilities. Providing maize guarantee prices and access to credit from local banks can help farmers overcome financial challenges. Farmers identified various risks in maize production, including pests, climate conditions, market fluctuations, labor costs, and competition from other crops. Addressing these challenges is crucial for improving the productivity and efficiency of maize farms.

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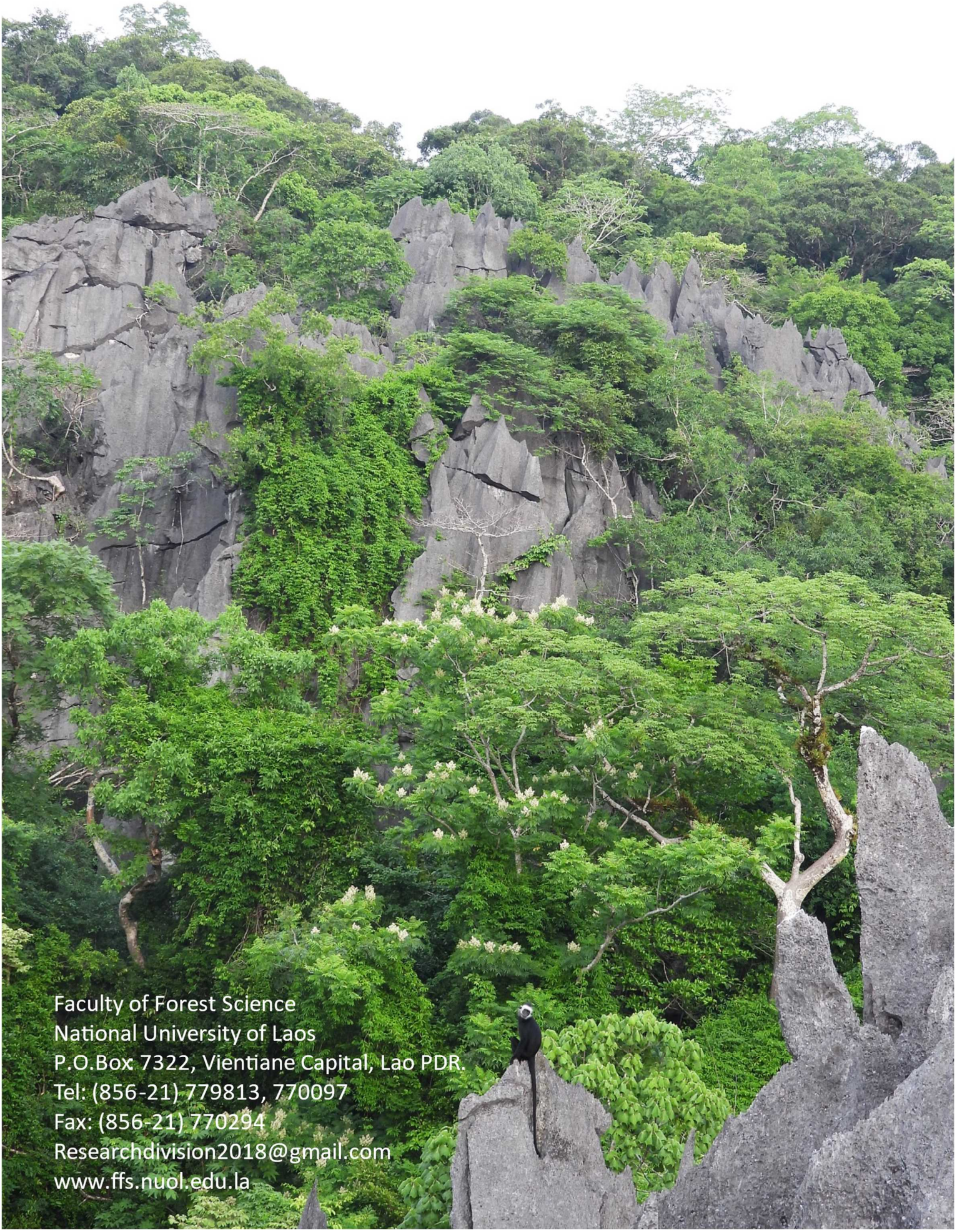
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