SOCIAL POLICY ECOLOGY RESEARCH INSTITUTE (SPERI)

TRAN THI LANH

Pilot Empirical Research

CARBON STOCK IN ABOVE-GROUND BIOMASS TROPICAL RAINFORESTS IN NORTH-CENTRAL VIETNAM

"Carbon element is a across cutting foundation of all living being, therefore, commodification of Carbon is impossible!"

VIETNAM NATIONAL UNIVERSITY PRESS, HANOI

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Acronyms

AGB	Above-Ground Biomass
ATV	Average Timber Volume
AUD	Avoiding Unplanned Deforestation
BHE	Bio-human Ecology
C_AGB	Carbon in the above-ground biomass
C_BGB	Carbon in the below-ground biomass
CF	Carbon Fraction
CHESH	Center of Human Ecological Study of Highland
CO2-e	Carbon Dioxide Equivalence
CODE	Consultancy on Development
COP26	26^{th} Conference of the Parties
DBH	Diameter at Breast Height
DW	Dry Weight
EU	European Union
GHG	Greenhouse Gass
GIS	Geographic Information System
GPS	Global Positioning System
H	Height
HEPA	Human Ecology Practical Area
IPCC	Inter-governmental Panel on Climate Change

ISO	International Organization for Standardization
IVI	Important Value Index
MARD	Ministry of Agriculture and Rural Development
MOIC	Ministry of Information and Communications
MOIT	Ministry of Industry and Trade (MOIT)
MONRE	Ministry of Natural Resources and Environment
MOPI	Ministry of Planning and Investment
MOU	Memorandum of Understanding
MRV	Measurement-Reporting-Verification
NCCC	National Center for Climate Change
NDCs	Nationally Determined Contributions
NFI	National Forest Inventory
NFI&S	Forest Inventory and Statistics
NRW	Natural Resources Wales
PPC	Provincial People's Committee
QGIS	Quantum Geographic Information System
SDGs	Sustainable Development Goals
SFMP	Sustainable Forest Management Plan
SPERI	Social Policy Ecology Research Institute
tCO_2-e	Ton of Carbon Dioxide equivalent
VCS	Verified Carbon Standard
WD	Wood Density

FOREWORD

The research reported in this publication is the first of its kind in Vietnam where indigenous peoples in both Vietnam and Laos, the legal owners of tropical rainforests, have proactively undertaken their own above-ground carbon stock measurements through the application of international and Vietnamese scientific formulas. Within 310.7-hectares of natural forest of a biodiversity conservation area (HEPA), which had been regenerated over 22 years (2002-2024) after many years of overexploitation, forest owners from upper watersheds have come together to practice, learn from experience, and uphold their own creativity in identifying standard forest plots, measuring, calculating, and recording estimated timber volumes, carbon stock in forest biomass, and carbon sequestration capacity of their own forests. Through this process, the forest owners have become familiar with the concepts of 'emission reduction' and 'carbon credit', and have gained confidence to prepare them for entering the global forest carbon credit market. In pursuing this aim, we have continued with the four key concepts that have guided all of our work from the early 1990s up to now: "Nurturing Nature", "Co-governance[1] of Rainforests", "Agroecology", and "Community Entrepreneur Development". These are the core values that guide all our strategic orientations and participatory methodologies whenever we engage with forest owners who are ethnic minority communities in the upper Mekong River watersheds.

Our "Community Entrepreneur Development" strategy plays a crucial role in the early 21st century. Community entrepreneurs have a mission to keep a balance between the market economy and the existing socialist orientation of minority communities. They are a key force,

1 Integrating community regulation, Forest Law, and Land Law in collaborative forest management among neighboring forest owners.

deeply connected to their traditional cultural heritage of environmental protection in societies that uphold the lifestyle of nurturing forests, even as technological and industrial production methods are neglecting the environmental values of the watershed ecosystem. Equipping these entrepreneurs with the skills, techniques and processes of applying global positioning technology (GPS), formulas and algorithms for identifying satellite images, and standard plots for measuring and calculating carbon stocks of tropical forests for forest owners-community entrepreneurs, is the key objective. Once the forest owners clearly realize that natural forests serve as both carbon sinks and carbon dioxide sequesters, and well understand how the carbon stock in trees can be converted into tradable carbon credits of monetary value, they will fully recognize that their forest trees are like ATMs in their forest. These four concepts - "Nurturing Nature", "Co-governance of Rainforests", "Agroecology", and "Community Entrepreneur Development" - are fundamental to a circular, green economy and a driving force to reduce carbon dioxide emissions globally.

In conducting this farmer-based participatory action research, we have been accompanied by our long-term cooperation partners NLI and SCCF, and in bringing this research to publication we have benefitted greatly from the editing done by Mr. Dam Trong Tuan, founding member and senior leader of SPERI from 1996 - 2019.

Tran Thi Lanh

Founder-social Policy Ecology Research Institute

ACKNOWLEDGEMENTS

To complete this publication on Pilot Empirical Research on Carbon Stock in Above-ground Biomass Tropical Rainforests in North-Central Vietnam located in HEPA, we SPERI, with the official mandate from Centre for Human Ecology Study of Highland (CHESH) express our sincere thanks to Professor Friedhelm Goeltenboth who on be half of NatureLife-International over many years has voluntarily taken care of our SPERI team (Mr. Le Van Ka, Mr. Dang To Kien, Ms. Nguyen My Linh và Mr. Le Hong Giang) and young grassroots farmers farming in sensitive watershed areas. He has supported our strategy and helped us in solving difficulties when we have faced them. Over the decades since 2010, Professor Goeltenboth has freely provided face-to-face teaching and online training in Rainforest Farming, Nurturing of Local Seeds, and Carbon restoration strategies for farmers.

We express our deeply felt appreciation and thanks also to the SCCF foundation for their organisational and administrative support for our philosophical-based fieldwork action in moving this case study of Pilot Empirical Research forward to become an instrument for social awareness raising and education.

To Professor Bao Huy, inventor of the Formula of Carbon Stock Calculation in Above Ground Biomass of Tropical Rainforests in Vietnam which we have chosen for this action research, we express our great respect and our appreciation for his comments on its documentation.

Finally, we give our special thanks to our volunteer friends who are artificial intelligent applied mathematics specialists who re-verified our carbon stock's calculation - Mr. Nguyen Thanh Cong, Mr. Nguyen Chi Trung and Nguyen Chi Thanh; to the anthropology student Dang Nhu Bang; to our SPERI Senior Team; to our Key Farmers – Forestland Owners and Traditional Healers from all over Northern Vietnam who have been devoted to our foundation since the 1990s; and to Ha Tinh, Huong Son, and Son Kim Local authorities; Cau Treo Border Army; Huong Son Forest and Service Company, as well as Huong Son Watershed Management Board who has been long-term partners with us from 2002 up to today.

Thank you!

FOUNDER of SPERI

Key Research Findings

The results of this research on carbon stock measurement in above-ground biomass within 310.7 hectares of tropical rainforest in the Ngan Pho River watershed (HEPA 2002-2024) after 22 years of nurturing nature and natural regeneration demonstrate the extremely crucial role of Vietnamese tropical rainforests in mitigating GHG emissions and climate change. *By July 2024, the total C-stock of the HEPA forest was calculated to be a substantial 42,475.8 tonnes. This assessment revealed a total biomass carbon (Ctb_total) of 136.71 tonnes of carbon per hectare, with a Wood Density (WD) of 0.55 grams per cubic centimetre. In terms of carbon dioxide equivalence (CO_2-e), HEPA's 310.7 ha of forest sequestrated a significant 155,886.19 tonnes of CO_2.*

This research employed a transdisciplinary approach to account for the unique terrain and the rich and diverse indigenous knowledge in North Central Vietnam's tropical rainforest. This approach not only captured the ecological richness of the watershed but also weaved in traditional knowledge from forest owners who possess a profound understanding of the forest's dynamics. By aligning with the overarching philosophy of nurturing ecosystems, this methodology emphasized the integration of local wisdom and practices into scientific endeavours. This comprehensive methodology ensures that the research is both scientifically sound and representative, while simultaneously honoring local cultural values and promoting a sustainable relationship between the community and its ecosystem.

The selection of standard plots for the research was decided by a wide-ranging set of criteria, ensuring a robust and representative assessment of the HEPA region. These criteria include uniqueness of terrain and watershed slope, vegetation cover of herbaceous and liana medicinal plants, diameter class of wood groups, canopy thickness along energy flow directions, and species diversity. Notably, the application of principles related to *Yang energy flow directions*, a crucial element in the traditional spiritual belief of 'Worshiping Nature', is emphasized. This aims to preserve the community's cultural heritage while integrating practical skills in applying technology to measure and calculate timber volume, forest carbon stocks, and carbon dioxide absorption capacity of the forest. These unique criteria are utilized for comparative analysis and serve as a foundation to assess local comparative advantages of forests in terms of economic efficiency. By applying these five key indicators, the research methodology integrated scientific consistency with cultural sensitivity, providing a holistic understanding of the ecosystem. This approach not only promotes accurate and meaningful results but also respects and incorporates local cultural practices, rendering the findings more relevant and acceptable to the local communities.

The study site, encompassing a total area of 310.7 hectares, was systematically analyzed to ensure representativeness and accuracy. Standard plots were logically established by considering factors such as direction, route, terrain and slope. To determine the most suitable calculation method, a comparative analysis of various formulas was conducted, including those proposed by Brown (1997), Chave *et al.* (2005), Natural Resources Wales, and Bao Huy (2012). The Bao Huy formula was ultimately selected due to its alignment with HEPA's ecosystem characteristics. This decision was based on its proven efficacy in similar ecological contexts, ensuring the results are both accurate and contextually relevant. The combination of these factors helps the survey and calculation method for forest carbon and biomass to ensure scientific reliability, and fully reflect the unique characteristics of the survey area, thereby improving the overall validity of the research results.

Part 1
OVERVIEW

This pilot empirical research "Application and Comparison of Methods for Estimating C-Stock (Above-Ground Biomass) of Tropical Rainforests in North-Central Vietnam," was conducted on a 310.7-hectare area of natural regenerated forest with wood groups from I to VI in the Ngan Pho River Upper Watershed, located in Huong Son District, Ha Tinh Province from 2023-2024. This comprehensive investigation contributes to shedding light on the most effective approaches for assessing C-stock in tropical rainforests in Vietnam, offering evidence-based solutions and informed policies that promote sustainable development and forest conservation in watershed areas.

This research aimed to cultivate sustainable co-governance within the upper watershed ecosystems, aligning with Vietnam's ambitious goal of achieving Net Zero emissions by 2050. By fostering collaborative decision-making and stakeholder engagement, the research contributes to enhancing the resilience and sustainability of critical upland ecosystems. Leveraging advanced techniques for measuring AGB, the research provided precise estimations of forest carbon stocks, offering invaluable data for developing effective strategies to mitigate emissions and increase carbon sequestration. Remote sensing technology and field measurements were employed to gather comprehensive data on AGB. This data can be used to identify intervention areas such as ecological agriculture and sustainable land use solutions to maintain the adaptive capacity and productivity of ecosystems, contributing to greenhouse gas (GHG) emissions reduction. Moreover, this data is concrete evidence that provides policymakers and stakeholders with a solid foundation for developing and adjusting appropriate decisions and strategies in the sustainable management and protection of highland ecosystems.

This research initiative has deepened the comprehension of rainforest regeneration and succession processes. It has also led to the refinement of methodologies for estimating C-stocks in rainforest ecosystems. The enhanced understanding of these ecological dynamics is vital for developing more accurate models of carbon sequestration and for informing sustainable forest management practices. The study's findings elucidate the intricate mechanisms underlying forest regeneration, including the roles of species diversity, topography, slope and climatic factors. By integrating advanced remote sensing technologies and ground-based measurements, the research can improve the precision of C-stock estimations. This methodological advancement is crucial for assessing the carbon sequestration potential of different rainforest types and for monitoring changes over time. Furthermore, the refined methodologies allow a more nuanced evaluation of the impacts of anthropogenic activities, such as reforestation and agroecology, on forest carbon dynamics. This, in turn, supports the formulation of evidence-based policies aimed at mitigating climate change and promoting biodiversity conservation.

Centre for Human Ecology Study of Highlands (CHESH), or the Human Ecological Practice Area, has orchestrated forest restoration across 310.7 hectares of previously devastated forest, transforming it into a diverse and sustainable ecosystem. On this area, allocated to CHESH in 2002 under Decision 1230 by the Ha Tinh Provincial People's Committee, HEPA has employed a comprehensive approach that integrates forest biodiversity protection, conservation and enrichment. HEPA acknowledged the organic interconnectedness of these strategies in cultivating the resilience of forest ecosystems. Moreover, it has fostered a deep bond between local ethnic minority communities and the natural environment, drawing upon the system of indigenous knowledge, customary laws and practices. Sustainable local practices in forest management and conservation were effectively incorporated into HEPA's strategies, ensuring that its activities are culturally relevant and sustainable. Thanks to the active participation of the community, ecological restoration has achieved significant results, not only restoring ecosystems but also improving the livelihoods of those involved in the process.

HEPA's conservation efforts are demonstrated through diverse innovative strategies aimed at restoring and protecting forest ecosystems. These included reforestation programs to augment forest cover, soil improvement measures to enhance soil health and nutrient availability, and the reintroduction of native plant species to enrich the ecosystems. HEPA has planted thousands of native trees to increase forest cover and implemented soil enrichment techniques such as composting and mulching to improve soil fertility. Native tree species have been reintroduced, supporting wildlife and strengthening the ecosystem's resilience. Notably, HEPA has implemented community-based monitoring programs, encouraging local residents to actively participate in the monitoring and evaluation of conservation activities. This co-development process has empowered local communities, enabling them to become the owners of the process of protecting and managing their natural resources. HEPA's conservation efforts, bolstered by active community participation, have led to significant improvements in the protection and sustainable management of natural resources in the Rao An watershed region.

HEPA's forest management is underpinned by solid partnerships with local stakeholders, ensuring effective and sustainable conservation efforts. The organization has forged collaborative arrangements with local authorities, including the Ha Tinh Provincial People's Committees, Son Kim 1 and 2 communes, the Cau Treo Border Guard Station, forest rangers, the Huong Son Forest Protection Management Board and law enforcement agencies. HEPA worked closely with the Cau Treo Border Guard Station and forest rangers to monitor and protect the forest from illegal acts. Collaborative efforts with the Forest Protection Management Board and local communes ensure that conservation strategies are tailored to local needs and priorities. This collaborative strategy has fostered active support and engagement from local communities as they have been directly involved in the decision-making process. By effectively balancing conservation goals with local needs, HEPA's strategies and action plans have proven to be more relevant and effective, fostering a greater sense of ownership and responsibility for the forest within the community.

The implementation of the above strategies has led to remarkable ecological restoration, transforming a once-degraded forest area into a thriving biodiversity hotspot in the region. The previously barren landscape has now become a habitat for a diverse array of native tree species, including valuable timber and medicinal plants. Additionally, the area has seen a resurgence of wildlife, with populations of various species experiencing significant growth over time. This resurgence has included increased sightings of native birds and mammals, indicating a healthy and balanced ecosystem. Ecological recovery has profound implications for ecosystem services, including carbon sequestration, water regulation, and biodiversity conservation. The revegetated lands serve as critical carbon sinks, contributing to mitigating climate change and ensuring the sustainable supply of clean water for local communities. Additionally, these forests play a vital role in soil conservation, preventing erosion and maintaining soil fertility. The HEPA's forest now serves as a vital ecological hub, benefiting both the local community and the broader environment.

HEPA has successfully implemented a seasonal approach to restoring and enriching forest ecosystems, attracting the active participation of staff and young eco-farmers from local communities across Vietnam and the Mekong region, such as Laos. These young farmers are committed to sustainable and environmentally friendly practices, embracing a holistic approach to agroecology that emphasizes ecological balance, social responsibility, and economic viability. They have undertaken actions that emphasize environmental sustainability and biodiversity by collecting seeds from valuable native timber species, such as Lim Xanh

(*Erythrophleum fordii Oliv.),* Dổi xanh (*Michelia tonkinensis*), Táu (*Vatica sp.),* Vàng Tâm (*Manglietia fordiana Oliv.),* Trâm đỏ (*Syzygium cumini*), Trám Trắng (*Canarium album (Lour.)* Raeusch), and Trám Đen (*Canarium album (Lour.) Raeusch)*. These seeds were then cultivated in nurseries and subsequently planted along forest edges to promote reforestation. Besides this, HEPA has implemented both annual training programs for its staff and local communities. These programs have focused on essential skills such as forest monitoring, fire prevention and the mitigation of mechanical and biological risks.

From 2010 to 2020, HEPA collaborated with local governments and stakeholders to develop and implement effective forest management plans, resulting in positive outcomes for conservation efforts. Joint assessments were conducted to monitor changes in forest cover, estimate C-stocks, evaluate the efficacy of conservation efforts and identify potential risks such as illegal logging, encroachment and forest fires. Based on detailed findings from these assessments, HEPA has enhanced forest monitoring efforts and implemented more effective fire prevention and control measures to protect forest resources. These actions not only mitigated immediate risks but also maintained the long-term provision of environmental services from the forest ecosystem. By aligning these strategies properly with conservation goals and local conditions, HEPA has optimized the overall effectiveness of its forest management efforts. This approach ensured that conservation initiatives were both scientifically sound and contextually relevant, ultimately contributing to the sustainable management and preservation of the region's forest resources.

By 2015, the forest within HEPA's management boundary had undergone a remarkable ecological transformation, as evidenced by significant improvements in quality, extent, biodiversity, C-stock, and overall ecosystem health. In particular, the density of trees with a diameter exceeding 10 centimetres has increased significantly, indicating a stable and highly resilient ecosystem. To further leverage these positive outcomes, HEPA organized field trips and training programs for key farmers from neighbouring communities. These training programs equipped farmers with essential technical skills such as timber measurement, species identification, and ecosystem assessment, enabling them to become effective forest protectors. This not only enhanced their capabilities but also ensured the sustainability and scalability of the initiative, laying a solid foundation for long-term ecological resilience at a larger scale.

From 2016 to 2022, key farmers across various regions of Vietnam, including Cao Quang commune in Tuyen Hoa District, Quang Binh Province, and Kon Tu Ma village in the Dak Bla River watershed of Mang Canh commune, Kon Plong District, Kon Tum Province of the Central Highlands, received practical training in measuring and calculating forest C-stocks. This training equipped them with the basic techniques and skills to accurately quantify carbon storage, one of the driving factors for sustainable forest management. These farmers learned to use standardized methodologies and tools to measure tree biomass and calculate the carbon sequestration rates of forest trees. These trained individuals are now poised to become mentors for other forest owners in the communities who have secured land use rights certificates through forest and land allocation schemes since the 1990s. These schemes, supported by SPERI/CHESH/CODE in partnership with local government agencies, aimed to promote sustainable land use and forest conservation in watershed areas. Through this learning process, these farmers can assist other forest owners in implementing effective carbon management practices, thereby enhancing the overall sustainability of forests in the region. This initiative has achieved significant success in enhancing local capacity and promoting sustainable forest management by creating a knowledge-sharing network.

From October 2023 to July 2024, CHESH, as authorized by the Memorandum of Understanding (MOU) and Authorization Letter 43, dated December 28th, 2023, commissioned a team of researchers from the Social Policy Ecology Research Institute (SPERI) to conduct this pilot empirical research. The interdisciplinary nature of the research, which integrates the specialized knowledge of various organizations with the insights of local stakeholders, ensures that the findings are both scientifically grounded and socially meaningful.

The study involved a thorough assessment of carbon stored in both Aboveground Biomass (AGB) and Belowground Biomass (BGB) within the regenerating natural forest. Through detailed measurements and analysis, the research contributed to the development of more accurate and efficient methodologies for estimating forest C-stocks. These methods enable the determination of key elements in forest carbon sequestration processes, facilitated by sustainable management and ecosystem restoration practices. This investigation aligned with Circular 28 (MARD, 2018), empowering forest owners to fulfil their societal obligation of quantifying GHG emission reductions and actively participating in carbon markets.

Image 1. The researcher team is measuring the forest trunk diameter (HEPA, 2023)

The research employed a rigorous methodology that integrated international and Vietnamese scientific standards, adhering to the Ministry of Agriculture and Rural Development (MARD) regulations and the EU's Mandatory Disclosure and Certification Rules for Carbon Credits. This requirement aims to ensure high transparency and reliability in carbon emissions reduction processes, thereby fostering trust among all stakeholders. This methodology aims to precisely identify and analyze representative standard plots, thus providing a comprehensive assessment of the forest condition in the HEPA headwater area. For each tree with a Diameter at Breast Height (DBH) exceeding 6 centimetres, meticulous measurements and data collection were conducted, encompassing local and Latin names, DBH, clear bole height, individual count and taxonomic information. Data was accurately recorded and analyzed using Excel formulas to calculate diameter, equivalent dry weight, timber volume, C-stock, and CO_2-e. All information was accurately recorded, adhering to a standardized template, and securely stored for future reference and analysis. By applying these calculations to the standardized plots, the study provides a comprehensive overview of the forest conservation and development status, especially the carbon sequestration capacity of the entire region.

The primary output of this research has been to ensure strict adherence to both national and international standards, particularly ISO 14064-2:2019 on greenhouse gases, thereby guaranteeing the accuracy, consistency and transparency of greenhouse gas emissions reduction at the project level. This research seeks to prove that HEPA's operations align with both domestic regulations and the highest international standards for carbon reduction and sequestration, ensuring transparency and reliability. By rigorously following these guidelines, the research outcomes can substantially contribute to developing optimal forest carbon accounting practices in Vietnam. The Verified Carbon Standard (VCS) under VM0015 used in this research serves as a valuable reference, particularly for the *"Methodology for Avoiding Unplanned Deforestation"* .

The research findings will provide the scientific and practical basis for HEPA to apply for ISO 14064-2 carbon credit certification, which aligns with the relevant Vietnamese legal framework, including Circular 28 (MARD, 2018), Decree 06 (Vietnamese Govt., 2022) and Circular 23 (MARD, 2023), as detailed in the following section.

The effectiveness of this research is designed to equip young, core farmers who are also forest owners with the necessary tools and knowledge to independently assess the carbon stored in their forests, thereby enabling them to make more informed forest management decisions. Through practical training activities such as workshops and hands-on training, young forest owners will be fully equipped with the necessary knowledge and skills to confidently apply carbon quantification tools in their daily forest management practices, enabling them to actively and confidently participate in carbon market activities.

This research holds significant importance in developing a comprehensive training system including a curriculum to equip local communities with the capacity to independently assess forest carbon stocks. The training program will focus on core technical skills such as establishing standard plots, data measurement and analysis, and converting biomass parameters into CO_2 emissions. An experiential learning approach will be implemented throughout the training process, encouraging active participation and input from learners. By practicing carbon assessment techniques directly in the field, participants will not only gain theoretical knowledge but also develop essential practical skills. Moreover, this training program aims to build a community network of voluntary carbon assessors. This will facilitate the sharing of experiences, knowledge, and innovative solutions, contributing to improving the effectiveness of forest management and conservation on a large scale. Equipping local communities with the ability to assess forest carbon not only contributes to biodiversity conservation and climate change mitigation but also creates an independent monitoring mechanism, enhancing transparency and accountability in forest resource management as well as carbon markets.

Part 2
REGULATORY FRAMEWORK

Vietnam is actively implementing a comprehensive strategy to address climate change. This strategy focuses on developing and implementing policies and facilitating close coordination among government levels and ministries. Additionally, the active participation of businesses, civil society organizations, and individuals is crucial to the strategy's success. A highlight of the strategy is the commitment to achieving net-zero emissions in 2050 and transitioning to a low-carbon economy, as reflected in the *Nationally Determined Contributions (NDCs)*. These efforts not only help Vietnam mitigate the negative impacts of climate change but also contribute to the global community's shared Sustainable Development Goals (SDGs).

Faced with the increasing pressure of climate change, Vietnam has set an ambitious target of reducing greenhouse gas emissions by 9% by 2030 compared to 2014. With the support of the international community, this target could be raised to 27%. To achieve that, Vietnam is focusing on the forestry and land use sectors, in addition to other sectors, to reduce 70% of emissions from related activities. Specific solutions include conserving and expanding forest areas, as well as promoting sustainable agriculture. These efforts not only help mitigate the impacts of climate change but also protect biodiversity and ensure food security.

Vietnam's NDCs emphasize the importance of multi-sectoral coordination and strong linkages among government levels. Ministries such as Natural Resources and Environment (MoNRE), Industry and Trade (MoIT), Ministry of Agriculture and Rural Development

(MARD), Planning and Investment (MoPI), and the National Center for Climate Change (NCCC) play key roles in developing and implementing policies and action plans. Additionally, local governments are tasked with adjusting these policies to suit the specific conditions of each locality. Through this close cooperation, Vietnam aims to raise public awareness, build capacity for organizations and individuals, and thereby develop and implement effective climate change adaptation and mitigation strategies

The Update National Strategy on Climate Change to 2050 is a long-term roadmap, guiding Vietnam's transition to a green and sustainable economy. The strategy sets a target of reducing greenhouse gas emissions by 50% by 2050 compared to 2010 and enhancing the adaptive capacity of vulnerable communities. To achieve this goal, the strategy focuses on solutions such as developing renewable energy, improving energy efficiency, protecting mangroves, and building resilient infrastructure. The strategy not only facilitates the development of a transparent and inclusive carbon market but also encourages the participation of all sectors of society in emission reduction activities. By creating an effective market mechanism, the strategy not only motivates businesses to invest in green technologies but also attracts investment from other sources, promoting sustainable green economic growth.

This strategy not only focuses on reducing greenhouse gas emissions but also integrates climate change considerations into the country's overall sustainable development process. By addressing challenges in sectors such as agriculture, energy, transportation, and water resources, the strategy aims for a low-carbon economy, enhances resilience, and ensures that the benefits of climate actions are equitably distributed across all segments of society. Moreover, Vietnam is committed to international cooperation to jointly address climate change through enhanced knowledge, technology, and resource sharing.

Directive 13 (2024), marks a significant step forward in Vietnam's efforts to address climate change. By focusing on strengthening carbon credit management, the Directive aims to build a low-carbon economy, fulfil international commitments, and achieve sustainable development goals. Through the establishment of a transparent and effective carbon credit management system, the Directive not only supports businesses in transitioning to clean technologies but also facilitates the development of a domestic carbon market, attracts green investment, and raises public awareness of the importance of environmental protection. The Directive requires relevant ministries and agencies, including MARD, MoIT, Ministry of Information and Communications (MOIC), and the People's Committees of provinces and centrally-run cities, to develop detailed plans to reduce greenhouse gas emissions within their respective jurisdictions. These plans should include specific strategies and actions to achieve the common goal.

Decree 06 (2022) is a significant legal document that establishes a legal framework for greenhouse gas emissions reduction and ozone layer protection in Vietnam. This Decree not only demonstrates Vietnam's commitment to fulfilling international commitments on climate change but also provides a solid legal basis for ministries, sectors, and localities to implement emission reduction measures. A new feature of the Decree is the setting of specific and clear targets for each sector, motivating organizations and individuals to participate in environmental protection efforts. Currently, the Decree is undergoing consultation with the public through electronic channels to ensure its suitability to practical needs and to finalize the regulations for implementation.

Article 4.1 of the Decree stipulates that emission reduction measures must be suitable to Vietnam's socio-economic conditions, ensuring that these measures do not negatively impact the country's development. *Article 4.3*, with its regulations on emissions trading, opens up opportunities to create a vibrant carbon market, encouraging businesses to invest in clean technologies and reduce production costs. However, for the carbon market to operate effectively, the Decree needs to clarify the criteria for determining emissions allowances, trading mechanisms, and monitoring measures.

Circular 28 ((MARD, 2018) marks a significant step forward in sustainable forest management in Vietnam. The Circular not only provides specific regulations for forest management but also establishes a legal basis for competent authorities to strengthen the inspection, monitoring, and handling of violations. However, the implementation of the Circular will require the efforts of the entire political system, businesses, and the people. To achieve the set goals, there needs to be close coordination between levels of government, capacity building for management agencies, and raising public awareness of the importance of forest protection.

The Circular plays a crucial role in realizing Vietnam's goal of achieving net-zero emissions by 2050. It promotes activities such as selective logging, afforestation, and land conservation, thereby reducing deforestation and enhancing the forest's carbon sequestration capacity. Additionally, the Circular mandates forest owners to develop sustainable forest management plans, including carbon stock assessments, providing a scientific basis for calculating and verifying carbon emission reductions.

The Circular encourages forest owners to participate in voluntary carbon markets by allowing them to accurately measure and report the amount of carbon sequestered by their forests. This not only generates income from carbon credits for forest owners but also incentivizes them to manage forests sustainably. Data collected from the implementation of the Circular will provide valuable information for the government to develop effective policies and strategies to mitigate the impacts of climate change, such as identifying priority areas for forest conservation and restoration.

Furthermore, the Circular emphasizes the critical role of forests in combating climate change. By promoting sustainable forest management and fostering participation in carbon markets, the Circular has created a mechanism to enhance the responsibility of forest owners and communities in forest protection. However, to achieve the set goals, there needs to be close coordination between government levels, capacity building for management agencies, and, especially, raising public awareness of the importance of forests in daily life.

Circular 23 (MARD, 2023) has established a comprehensive framework for measuring, reporting, and verifying greenhouse gas emissions reductions and greenhouse gas inventories in the forestry sector. This document provides specific and detailed regulations.

First, the circular has developed a unified system of standards for measuring, reporting, and verifying greenhouse gas emissions and removals in the forestry sector, ensuring scientific rigour, transparency, and comparability in climate change mitigation activities.

Second, the circular requires the implementation of independent verification and validation procedures for reported data. This aims to ensure the accuracy and reliability of information on carbon sequestration, thereby enhancing the credibility of Vietnam's climate change mitigation efforts. At the same time, independent verification also facilitates participation in international carbon markets, helping Vietnam to integrate more deeply into the global green economy.

Third, this circular provides detailed regulations on data management and reporting. Specifically, the circular requires organizations and individuals to collect, store, and accurately maintain relevant data, and to submit periodic data reports to the competent authority. Ensuring the availability of data will serve to support analysis, evaluation, and accurate decision-making.

Fourth, to ensure the effective implementation of the circular's provisions, specific regulations on training and technical support were developed, aiming to equip forestry professionals with the necessary expertise and practical skills, thereby contributing to enhancing the sustainable forest management capacity of the entire country.

Part 3
RESEARCH DESCRIPTION

3.1. Research Title

Application and Comparison of Methods for Estimating Carbon Stock in Above-Ground Biomass of Tropical Rainforests in North-Central Vietnam.

3.2. Research Objectives

- Presenting a carbon stock calculation report for regenerating natural forests 20 years after exploitation in compliance with the ISO14064-2 standard.
- Designing a curriculum on the process of approaching, analyzing, comparing, and selecting a carbon stock calculation method for tropical rainforests in Vietnam based on commonly applied formulas worldwide.
- Giving recommendations for a legal framework for carbon credit trading for forest owners in watersheds.
- Introducing a key farmers group of forest owners in watersheds, who are proficient in mapping, standard plot boundaries determination, Global Positioning System (GPS) applications, and natural forest carbon stock calculation and CO_2-e conversion in the journey of learning, understanding and recognizing the crucial values and roles of natural forests in CO_2 emission mitigation efforts that enable Vietnam to achieve the NetZero emissions 2050 commitment.

3.3. Research Location Background

CHESH, the governing entity of HEPA, operates under a Land Use Rights Certificate granted by Decision 1230 (Ha Tinh PPC, 2002). Beyond this legal framework, HEPA's operations are deeply rooted in the philosophy of "Nurturing Nature," which promotes an equal relationship between humans and the natural world. This behaviour emphasizes the necessity of respect and harmony in human interactions with nature, advocating for a more sustainable and ethical approach to environmental management, and at the same time highlighting the negative consequences of the current overexploitation of natural resources (Tran Thi Lanh, 1992). With a vision of a sustainable future, HEPA's philosophy of action focuses on implementing sustainable practices to protect and restore ecosystems while ensuring a balance between human development needs and nature's regenerative capacity. This philosophy is embodied in practical activities such as community education on sustainable actions, forest restoration, biodiversity enhancement, co-governance, leadership development, and knowledge management.

Restoration of upstream forests following natural succession

Regenerating and restoring forests while respecting the natural succession of the watershed ecosystem involves a nuanced understanding of ecological dynamics. This approach respects the natural rhythm of the ecosystem, ensuring that restoration activities occur in harmony with the growth processes of plants and animals. Aligning with the natural cycles of the ecosystem and adjusting reforestation activities according to the seasons can enhance forest recovery and resilience to environmental disturbances. This method promotes the long-term sustainability of headwater ecosystems by cultivating ecological balance and leveraging the system's regenerative potential. For example, planting native species during the rainy season not only promotes seedling growth but also contributes to biodiversity and ecosystem resilience.

Integrating traditional knowledge in forest conservation by "Teaching by learning, learning by doing"

The Mekong region's ethnic minority communities, with their respected elders and young farmers, are custodians of a rich tradition of "reverence for nature." Their knowledge and practices offer invaluable inspiration for HEPA to develop effective training programs on agroecology and forest conservation. These curricula employ a "Teaching by Learning - Learning by Doing" methodology, which fosters a culture and behaviour focused on the management and usage of natural resources ethnically. Employing a "Teaching by learning, learning by doing" approach, these programs go beyond theoretical instruction, providing hands-on experience that enables participants to develop responsible environmental behaviours. By combining the deep knowledge of village elders with the creativity of young farmers, this approach not only preserves cultural heritage but also generates innovative and flexible solutions to address climate change and other environmental challenges. For instance, village elders can share time-tested traditional farming techniques, such as selecting crop varieties suitable for different soil types and creating compost and mulching, while young farmers can introduce new knowledge about improved crop varieties and water-saving irrigation technologies. This combination fosters a sustainable agricultural system that preserves tradition while adapting to modern conditions.

Promoting Forest Co-governance

HEPA's co-governance strategy fosters collaboration among various stakeholders in forest management, ensuring that decisions are informed by diverse perspectives and address the needs of all involved parties. This inclusive approach involves key stakeholders such as the local Forest Ranger Unit, Cau Treo Border Gate Border Guard Station, Huong Son District Protection Forest Management Board, Son Kim 1 and 2 Commune People's Committee, and Commune Police. The Forest Ranger Unit provides regulatory oversight, while the Border Guard Station ensures security and protection against illegal activities. The Huong Son District Protection Forest Management Board focuses on conservation efforts, and the Commune People's Committees represent the interests of residents. The Commune Police play a crucial role in maintaining law and order within the forest areas. Moreover, key farmers, also known as lead farmers, are indispensable in agroecological communities. They share advanced skills and knowledge related to agroecology and forest conservation, serving as mentors by demonstrating and sharing best practices. These farmers are directly involved in managing forest areas, utilizing their valuable local knowledge to maintain and expand the impact of sustainable initiatives. By integrating the insights and expertise of these stakeholders, HEPA's co-governance strategy not only promotes effective forest management but also ensures that the needs and perspectives of the community are fully considered in the decision-making process. This collaborative approach has contributed to positive results, leading to more sustainable forest ecosystems with greater resilience, thereby benefiting both the environment and local communities.

Promoting agroecology-based ecosystem conservation

To enhance forest management effectiveness and sustainable land use, organizing regular study tours to HEPA is a practical and effective solution. These visits serve as dynamic platforms for exchanging and enriching agroecological practices. Agroecology, which integrates ecological principles into agricultural systems, is key for promoting sustainable farming that works in harmony with natural ecosystems.

One of the key components of these visits is the replication of local native plant varieties. This practice goes beyond preserving biodiversity; it safeguards the local genetic heritage that underpins resilient agricultural systems. As evidenced by their remarkable adaptability to harsh natural conditions, native plant species are key to building sustainable ecosystems and ensuring long-term food security.

A special highlight of these trips is the chance to immerse oneself in and safeguard the unique spiritual rituals and festivals of ethnic minorities that celebrate the sacredness of forests. Cultural practices intertwined with nature-based practices form the foundation for sustainable forest management and land use, particularly in upland areas. Through active involvement in traditional practices, HEPA contributes to preserving the distinct cultural heritage of ethnic minorities while strengthening community spirit and promoting responsible stewardship of natural resources.

The successful blending of traditional community knowledge and scientific practices in HEPA's projects has led to substantial improvements in forest management and conservation. This approach not only enhances ecological sustainability but also strengthens community bonds and preserves cultural heritage. Integrating the profound knowledge of traditional medicine practitioners about medicinal plants with modern scientific analytical methods will facilitate the accurate determination of carbon content in individual plant species, thus enabling the development of region-specific forest management plans.

The above approach provides a new framework for forest management, fostering a sustainable future where humans and nature thrive together. By harmoniously blending traditional knowledge with cutting-edge solutions, HEPA is driving a sustainable transformation that balances the protection of natural resources with community development.

Young leadership development through agroecology networking

The young leadership development strategy, underpinned and nurtured by agroecology networking and the marketing of ecological products, is a transformative force. This program aims to cultivate a dynamic and responsible community of young agricultural entrepreneurs. HEPA believes that by combining specialized knowledge with a deep understanding of local culture and communities, these young entrepreneurs can significantly contribute to building a sustainable future for upland regions. Training activities will focus on developing management, business, and innovation skills, while also encouraging community participation in sustainable agricultural production and consumption.

By strengthening the capacity of agroecological practice networks, HEPA not only equips young leaders with sustainable farming skills but also creates a supportive community, helping them successfully start their businesses and scale up sustainable initiatives. Post-harvest processing and marketing of agricultural and forestry products is a critical aspect of this strategy. By adding value to raw agricultural products, young eco-farmers not only generate additional income but also enhance their competitiveness and adaptability to the market. This process requires not only post-harvest processing techniques but also marketing, and business skills, which are crucial for the success of any enterprise.

Furthermore, this approach not only nurtures a new generation of leaders but also deeply connects them to their cultural heritage and practices. These young leaders not only understand but also cherish traditional values, while demonstrating a strong commitment to sustainable management and protection of natural resources. By harmoniously combining traditional values with agroecological practices, they can contribute positively to the sustainable development of the community, ensuring a balance between socio-economic benefits and environmental protection.

Sustainable ecological landscape management

Sustainable ecosystem landscape planning and management within the HEPA forest area are essential for creating self-sustaining livelihoods for its staff and local farmers. This activity involves the design and implementation of agroecological farming models that harmonize with the natural environment, ensuring long-term ecological balance and economic viability.

By implementing ecological landscape planning, HEPA has developed plans for the rational use of agricultural land, integrating various forms of agriculture while maximizing the potential of the production system. This approach involves the conservation and restoration of forests, ensuring a balance between economic growth and environmental protection. The process includes carefully selecting suitable crop varieties, harmoniously combining agriculture and forestry practices, and prioritizing soil improvement and water conservation. This has led to increased crop yields, improved product quality, and a healthier ecosystem

Another crucial aspect of HEPA's activities is the development and implementation of detailed management plans for agricultural models, aiming to enhance agroecological practices, minimize negative environmental impacts, and maximize resource efficiency. This includes promoting biodiversity through diversified farming systems and reducing dependency on external inputs, fostering a more effective and self-reliant agricultural system.

In addition to creating detailed management plans, HEPA is committed to fostering a supportive environment for its staff and local communities to develop their skills and capabilities. Through training and practical experiences, HEPA has equipped communities with the necessary knowledge and skills to manage resources effectively and sustainably. This has not only contributed to environmental conservation but has also enhanced the quality of life for local communities.

HEPA - A knowledge centre for agroecology practices and education

Image 2. Carbon Measurement Practice Training for the Research Team (HEPA, 2023)

Maintaining ecological monitoring records and developing practical agroecological training materials are core activities in HEPA's sustainable livelihood development strategy. These activities not only help track the effectiveness of interventions but also contribute to building a strong knowledge base for future sustainable agricultural development.

Ecological monitoring provides valuable data, enabling HEPA staff and farmers to better understand the characteristics and trends of ecosystem changes. This allows them to make effective management decisions to optimize agricultural productivity and enhance ecosystem resilience to climate change and other environmental factors.

Developing agroecological training materials tailored to local conditions plays a crucial role in raising awareness and knowledge of sustainable farming methods. These materials, specifically designed to meet the practical needs of farmers, have created a solid foundation for training and knowledge transfer. These educational programs have been instrumental in equipping local farmers with the necessary knowledge and skills to adopt sustainable farming practices, contributing to environmental protection and increased productivity.

Collaborations with educational institutions have facilitated the application of theoretical knowledge to real-world practices, while simultaneously enhancing the quality of education by providing students with internship and research opportunities. Conversely, these internship and research programs not only contribute to the academic and professional development of students but also introduce innovative solutions and positively contribute to the sustainable development of the HEPA community.

This approach can potentially generate income and enhance livelihoods by capitalizing on the intellectual capital and ecological products within the HEPA region. The knowledge and skills acquired through ecological monitoring and agroecology education can be translated into tangible economic benefits. Ecological products derived from forests or farms within the HEPA region, including agroecological produce, herbal remedies, and nature-based crafts, possess significant potential for generating supplementary revenue streams through targeted marketing efforts.

3.4. Research Location

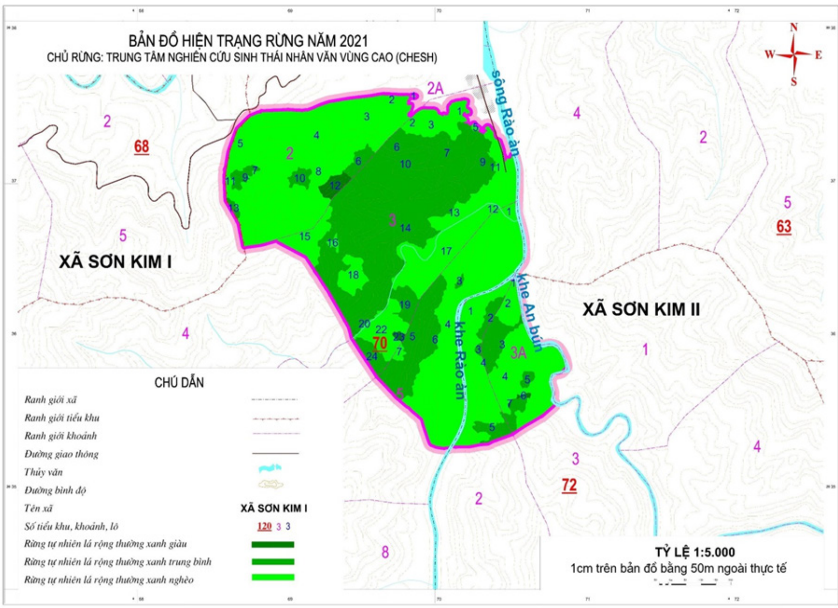

Figure 1. Location and forest status of HEPA in 2021, recognized by the Ha Tinh Provincial People's Committee, under the 2031 Sustainable Forest Management Plan

The Human Ecology Practice Areas (HEPA), managed by CHESH, exemplifies successful forest revitalization efforts initiated in the 2000s. Covering 310.7 hectares, HEPA is managed and run by Decision 1874 of the Ha Tinh Provincial People's Committee (Ha Tinh PPC, 2022), which approved CHESH's sustainable forest management plan for 2022-2031. This decision marked a significant milestone in safeguarding the sustainable management and preservation of the HEPA's forest. Situated at Huyen Vi Peak, HEPA is strategically located 499 meters above sea level, within the trans-border economic area, along National

Highway 8A, leading to the Cau Treo International Border Gate between Vietnam and Laos. This location serves as a crucial ecological corridor, linking the study area to a vast transboundary natural forest ecosystem, highlighting HEPA's importance in regional ecological conservation efforts. The coordinates (X: 468718.17; Y: 20333336588.90 on the VN-2000 Mapping System) further pinpoint its exact location, emphasizing its accessibility and strategic significance (see Figure 1). HEPA has divided its forest area into 39 sub-pilots for effective management, protection, regeneration and enrichment. Table 1 provides the precise GPS coordinates for each of these sub-pilots.

Table 1. GPS coordinates covering the HEPA forest land boundary marks, Projection VN2000

No.	X	Y
M01	470358	2037599
M02	469745	2037635
M03	470127	2038074
M04	469676	2038328
M05	469526	2038369
M06	468945	2037991
M07	468758	2037785
M08	468386	2037963
M09	468253	2037626
M10	466953	2037498
M11	467248	2037281
M12	468346	2036716
M13	468657	2036513
M14	469415	2035970
M15	469416	2035649
M16	469609	2035729
M17	470125	2035550
M18	471111	2035244
M19	471459	2035794

No.	X	Y
M20	470492	2036433
M21	470308	2037584
M22	470372	2037385
M23	470411	2037294
M24	470476	2036915
M25	470444	2036807
M26	470530	2036764
M27	470297	2037369
M28	470226	2037444
M29	470134	2037492
M30	470081	2037441
M31	469982	2037360
M32	469899	2037492
M33	470092	2037529
M34	468355	2037189
M35	468704	2037487
M36	468947	2037484
M37	469940	2037204
M38	469474	2037087
M39	469215	2036749

The study area is a highly biodiverse ecosystem that is very sensitive to environmental changes, particularly due to its diverse topography and microclimatic conditions. Located at the gateway to a natural transboundary forest, HEPA is a vital watershed providing essential ecosystem services to hundreds of thousands of people in the region, including clean water, food, medicinal plants, and firewood. Its proximity to a border economic zone makes the area highly susceptible to the direct impacts of economic activities, placing significant pressure on the environment and ecosystem. The ecosystem's vulnerability necessitates appropriate management and conservation measures to maintain its biological integrity and ensure the continued provision of ecosystem services. To protect and maintain the health of this unique ecosystem, the strict enforcement of land use regulations and the promotion of community-based conservation initiatives are essential sustainable management measures.

Before 2000, the forest area of HEPA suffered severely from overexploitation, leading to significant degradation. The primary cause was identified as poor management by the Huong Son Forestry Services Enterprise. This degradation led to a dried-up riverbed, habitat decline and serious ecosystem degradation. In 2002, CHESH took over management and initiated the "Nurture Nature" mission, recognizing the urgent need for sustainable forest management. HEPA adopted agroecology as its guiding principle, promoting practices that complement and enrich natural ecosystems. For example, agroecological methods such as intercropping with legumes and mulching were implemented to restore soil health and biodiversity, improving agricultural productivity and resilience. This task aims not only to restore and enhance the quality of degraded forests but also to ensure the long-term ecological sustainability of the upland ecosystem. The success of these measures has clearly demonstrated the crucial importance of integrating ecological principles into forest management. This not only benefits the environment but also contributes to sustainable economic and social development.

One of the core principles in HEPA's activities is a community-based approach, particularly mobilizing the active participation of the younger generation of ecological farmers to ensure sustainability and effectiveness in conservation efforts. This principle emphasizes the importance of proactive community involvement in decision-making processes related to forest resource planning and management, ensuring that local knowledge and experience are fully integrated. HEPA has proactively built and developed a network of cooperation with neighbouring forest owners and local management agencies. This network plays a crucial role in promoting sustainable land and forest management on a large scale. HEPA has actively organized exchange activities, including regular meetings, workshops, and training programs, to facilitate knowledge sharing and build cooperative relationships among stakeholders. These efforts have enhanced community participation and raised awareness about the importance of forest protection. Through transparent and comprehensive information sharing, stakeholders have built a high level of consensus, contributing to the success of sustainable forest management activities.

Since 2002, HEPA's strategy and measurements of restoring natural forests by learning and applying the unique characteristics of the ecosystem have yielded remarkable results. The forest has shown accelerated growth, a denser canopy, and increased biodiversity. Water levels in streams and the Rao An River have significantly risen, indicating an improved watershed ecosystem. Additionally, the C-stock in HEPA's forests has steadily increased. As of June 5^{th}, 2024, the entire forest area within HEPA absorbed a total C-stock of 155,886.19 tonnes of CO2-e, with the AGB estimated at 136.71 tonnes of carbon per hectare. This success in forest ecosystem restoration has attracted growing interest from young farmers from neighbouring countries in the Mekong region like Laos. The growing interest of stakeholders in HEPA's model demonstrates the effectiveness of sustainable practices. The application of HEPA's best practices has significantly contributed to the restoration and enhancement of the ecological value of the Ngan Pho watershed, while also creating a ripple effect at the regional level.

3.5. Strategies of HEPA in Leakage Management for Forest Protection and Management

HEPA has proactively developed a comprehensive risk management system, incorporating feasible measures based on a scientific assessment of potential threats to forests. These measurements were designed to enhance forest resilience, safeguard biodiversity and enrich the provision of ecosystem services. By integrating technical, social and economic solutions, HEPA has created a sustainable, adaptive and climate-resilient forest co-management model. These measurements encompassed the adoption of advanced technologies, the establishment of extensive collaborative networks and investments in human capital.

Through these efforts, HEPA has not only managed forests effectively but also contributed to improving the livelihoods of local communities.

HEPA's co-management approach with local stakeholders including neighbouring forest owners, local government, forest agencies and functional offices has been instrumental in preventing uncontrolled forest fires. This approach has enabled the prompt identification and resolution of pressing issues, such as illegal logging and forest fires, thereby safeguarding the forest ecosystem. Regular meetings and information-sharing sessions ensure that stakeholders are well-informed about the status of the forests, fostering a sense of shared responsibility and trust. Through training and outreach programs, local communities have developed a strong sense of awareness, responsibility, and technical skills in forest fire prevention and control. Collaborative efforts, coupled with regular monitoring and risk assessment, have substantially improved the effectiveness of forest fire prevention initiatives.

Deforestation, driven by agricultural production, illegal logging and infrastructure development, is the primary cause of tropical forest loss in Vietnam and global scale. This destruction leads to habitat fragmentation, wildlife displacement, and degradation of ecosystem services. The conversion of forested land into agricultural fields diminishes the forest's capacity to support biodiversity. HEPA has implemented comprehensive regulations, including functional zoning to manage agricultural activities and protect forests, and has prohibited activities that lead to deforestation. These regulations are promoted through awareness campaigns and educational programs to encourage local community participation in forest protection. It has established collaborative mechanisms with local authorities, stakeholders and communities to facilitate coordinated efforts and address violations promptly. The use of advanced technologies in regular forest inventory and monitoring, with the participation of stakeholders, allows for prompt responses to violations and risks. In cases of violations, HEPA works closely with local authorities to enforce regulations, take legal action and implement restorative measures.

Typhoons and floods pose significant threats to tropical forests, causing severe damage that can lead to widespread deforestation, habitat loss, and biodiversity decline. These natural disasters disrupt the natural recovery and succession of forest ecosystems, resulting in disrupted ecological processes and reduced environmental services. To mitigate these risks, HEPA has implemented a strategic zoning plan that delineates spiritual zones, buffer zones, and livelihood zones. The spiritual zones are strictly protected to preserve their ecological integrity and cultural significance. In the buffer zones, HEPA has taken proactive measures to enhance biodiversity and resilience, including enrichment with native plant species and silvicultural practices. The livelihood zones are managed with a focus on sustainable land use with active community involvement, ensuring that both ecosystem sustainability and local livelihoods are prioritized. This integrated approach, combining conservation, restoration, and community involvement, strives to create a resilient tropical forest ecosystem that can adapt to the challenges posed by climate change, including frequent typhoons and floods.

Biological risks including invasive species and insect outbreaks pose significant threats to forest ecosystems. Introduced through human activities, these organisms can rapidly spread, outcompeting native species and causing widespread native tree death. This disruption can have cascading ecological consequences, including reduced biodiversity, altered forest structure, and diminished forest environmental services. HEPA has implemented a multifaceted strategy to manage these risks. This strategy includes clear regulations to prevent the introduction of invasive species, promoting ecological farming practices to reduce the susceptibility of forest vegetation to insect outbreaks, and prohibiting the planting of non-native species such as acacia and eucalyptus, especially in buffer zones. HEPA also actively engaged local communities, raising awareness about the dangers of invasive species and encouraging sustainable practices such as agroecology. Regular monitoring of forest areas allows for early detection of risks, from which timely intervention measures can be taken.

Beyond these technical initiatives, HEPA has provided support to enhance the livelihoods of staff and farmers, fostering their commitment to sustainable forest management and land use. HEPA's establishment of a seasonal regeneration space with diverse native plants has significantly promoted biodiversity, ecological balance, and sustainable agricultural practices while supporting local farmers' livelihoods. This space includes a variety of native plants such as wild banana, betel leaves, mugwort, perilla, wild pineapple leaves, wild conical leaf plants, and other herbs. These plants can be harvested by farmers and HEPA staff during the off-season, providing them with additional income opportunities. They also harvested wild banana and betel leaves for food and medicinal purposes, while wild conical leaf plants can be used for traditional crafts. The enhancement of plant diversity, multi-purpose, and multi-layered canopy has also been implemented. HEPA's off-season harvesting program stabilizes farmers' and staff's incomes, safeguarding their livelihoods against market volatility and impacts of climate changes such as floods and droughts. This fosters their long-term commitment to forest management and sustainable land use practices.

Moreover, HEPA's annual training workshops play a crucial role in fostering collaboration, knowledge exchange, and continuous improvement in co-governance among neighbouring forest owners. These workshops bring together a diverse group of stakeholders, including local authorities, environmental experts, and community leaders, to ensure a comprehensive and inclusive approach to forest co-governance. The focus is on practical, actionable outcomes, with hands-on activities, case studies, group discussions and field visits. This approach helped to enhance learning by ensuring that the knowledge gained can be directly applied in the field. Additionally, the workshops serve as a platform for developing and updating plans, ensuring that the co-governance model remains effective and adaptable to changing conditions. By regularly reviewing and updating their plans, forest owners can proactively respond to new challenges and opportunities, ensuring the long-term sustainability of their businesses.

Furthermore, these workshops foster a sense of community and collective responsibility, building strong networks of support and cooperation among stakeholders. This collaborative environment not only strengthens the co-governance model but also promotes a shared commitment to sustainable natural resources management.

3.6. Risk Assessment of the Research's Result

The research team conducted a comprehensive review of existing studies from various countries that have estimated C-stocks in the aboveground biomass (AGB) of tropical rainforests, particularly focusing on the risks identified therein. This review was undertaken to ensure the reliability and accuracy of the research being conducted at HEPA. Based on this extensive literature review, the team found no instances of risks that could potentially compromise the research at HEPA.

Firstly, Petrokofsky et al.'s (2012) study, "Comparison of Methods for Measuring and Assessing Carbon Stocks and Carbon Stock Changes in Terrestrial Carbon Pools: How Do the Accuracy and Precision of Current Methods Compare? A Systematic Review Protocol" highlighted the potential for significant errors in biomass estimation due to inaccurate measurements of variables such as tree diameter, height and wood density. These inaccuracies could lead to substantial errors in estimating C-stocks, which are crucial for understanding and mitigating climate change. Instrument and calibration errors can further exacerbate this uncertainty, making it challenging to obtain accurate measurements.

Secondly, the study also emphasized that the size of the study sample area and the sampling design are critical factors for the reliability of biomass estimates. For example, small or poorly designed sample areas may not accurately represent the diversity and structure of the forest, leading to skewed results. This underscores the importance of using reliable and well-calibrated methods for measuring and assessing C-stocks.

Thirdly, the selection of "Allometric" models, which is used to estimate the biomass of a single tree or a tree population based on easily measurable parameters such as diameter at breast height (DBH), tree height, or crown area, can significantly influence the accuracy of carbon stock estimates. Aabeyir et al.'s (2020) research on "Allometric" models for estimating aboveground biomass in the tropical woodlands of Ghana, West Africa, highlighted the importance of using locally developed models with unique characteristics. The study found that employing inappropriate or generalized models can introduce substantial errors in biomass estimation. For instance, using a generalized model developed for a different region may not account for the specific characteristics of the local tree species and forest structure, leading to inaccurate biomass estimates. This highlights the necessity of developing and utilizing "Allometric" models tailored to the local context. By using locally developed models, researchers and forest managers can ensure more reliable and precise estimates.

Fourthly, human activities such as deforestation, logging, and land-use changes significantly alter forest structure and composition, complicating the estimation of C-stocks. These activities can drastically change the density and diversity of tree species, which are critical factors in biomass assessments. Sharma et al.'s (2020) study on aboveground biomass estimation and C-stock assessment along a topographical gradient in the forests of Manipur, Northeast India, revealed the importance of accounting for these changes. Accurately estimating C-stocks requires careful consideration of the effects of human activities on forest ecosystems. By incorporating these factors into biomass assessments, researchers can obtain more reliable data, ensuring that the estimates reflect the true state of the forest, accounting for both natural and anthropogenic influences.

Fifthly, tropical rainforests, with their high diversity and dynamic nature, present significant challenges in accurately estimating biomass and C-stocks. These ecosystems are characterized by a wide range of species composition, tree ages, and growth rates. Salunkhe et al. (2018) pointed out that this inherent variability can lead to significant disparities in biomass and C-stock estimates. For instance, different species have varying capacities for carbon storage, and trees of different ages contribute differently to the overall biomass. Additionally, growth rates can fluctuate based on environmental conditions, further complicating the estimation process. This variability underscores the complexity of accurately assessing C-stocks in such diverse and ever-changing ecosystems. It necessitates tailored approaches that account for local ecological conditions. By considering these factors, researchers can develop more accurate and reliable methods for estimating forest biomass and C-stocks.

Lastly, variability in nutrient levels can lead to significant differences in how carbon is distributed within the forest ecosystem. Sullivan et al. (2015) emphasized that changes in nutrient levels can alter the growth patterns and carbon storage capacities of different plant species. For instance, in areas with high potassium availability, plants may allocate more carbon to above-ground biomass, enhancing their growth and carbon storage capacity. Conversely, in nutrient-poor areas, plants might allocate more carbon to root systems to enhance nutrient uptake. This variability in nutrient dynamics can affect the accuracy of under-ground biomass estimates. Understanding and accounting for these nutrient dynamics are essential for improving the precision of biomass and C-stock assessments.

3.7. The legal validity of the research

HEPA's operations and this research are fully compliant with Vietnamese legal documents and the latest regulations from local authorities and relevant agencies. HEPA is moreover dedicated to educating key farmers and forest owners on carbon emissions reduction and actively collaborates with the relevant government agencies to achieve a neutral carbon ambition by 2050 as committed by the Vietnamese government.

CHESH's Scientific and Technological Activities

The activities of the CHESH Center are carried out based on Registration Certificate No. A374, issued by the Ministry of Science and Technology (MOST, 2023). The centre conducts research in human ecology, addressing poverty causes and developing sustainable solutions for highland ethnic minority communities. It applies and develops programs, projects and initiatives for sustainable community development, and engages in the production of products from scientific research and technological development. Additionally, CHESH offers scientific and technological services, including consulting, scientific critique, document production, organisation of scientific conferences and workshops, professional training and dissemination of knowledge related to human ecology, poverty causes and sustainable community development. The centre collaborates with individuals and organisations both nationally and internationally to fulfil its functions and missions.

Sustainable Forest Management as Circular 28

The Updated Sustainable Forest Management Plan (SFMP) for 2022-2031, developed by the Highland Human Ecology Research Center (CHESH), outlines a comprehensive strategy for managing 310.7 hectares of forest land in Son Kim 1 and Son Kim 2 communes, Huong Son district, Ha Tinh province. This plan, established under Decision 1874 by the Ha Tinh Provincial People's Committee (Ha Tinh PPC, 2022), includes 179.4 hectares of protective forest land and 131.3 hectares of production forest land. The area was allocated to CHESH under Decision 1230 by the Ha Tinh Provincial People's Committee (Ha Tinh PPC, 2002). The protective forest land is designated to preserve biodiversity and prevent soil erosion, while the production forest land is managed for sustainable timber and non-timber forest products. The SFMP strikes a balance between conservation and production, thereby preserving ecological integrity and sustaining local livelihoods. The plan's comprehensive scope, encompassing a substantial forest area, addresses multiple local needs, showcasing a strong commitment of CHESH to sustainable forestry.

Following the land allocation, CHESH developed a zoning plan for the forest area, ensuring compliance with forest regulations and Circular 28 (MARD, 2018). This ensures sustainable forest management, ecological balance and biodiversity conservation. Key measurements include protecting existing forest cover and promoting reforestation, preserving biodiversity through measures to protect plant and wildlife species, implementing sustainable natural resources management, and actively engaging the local community throughout the process.

The HEPA's forestry plan prioritized improving forest quality, delivering environmental services, and creating economic opportunities for the local community. By planting high-value trees, promoting sustainable harvesting, and safeguarding genetic diversity, the plan aims to enhance the forest's ecological and economic value. This contributes to the economic development of the forest owners and supports the local economy while sustaining the forest's resilience to environmental changes.

HEPA's forest management results as of the forest survey conducted by the Ha Tinh Provincial Department of Agriculture and Rural Development

The SFMP by CHESH including a logical database demonstrates significant improvements in forest management, adhering closely to government provisions and local regulations. This adherence was evidenced by the Ha Tinh Department of Agriculture and Rural Development's Report 1562/SNN-KL, dated August 5th, 2022, which presents the inspection results and approval submission for the SFMP by CHESH for the period 2022-2031.

Effective management and protection of the forest area in HEPA over time have increased species diversity and forest biomass. The forest primarily consists of natural broadleaf evergreen forests with varying levels of richness and density. The total timber volume is 30,678 m^3 / ha, averaging 99 m^3 per hectare. Specifically, the rich forest areas have a timber volume of 582 m^3, averaging 212 m^3 per hectare. Medium forests have a volume of 19,954 m^3, averaging 175 m^3 per hectare, while poor forests have a volume of 10,142 m^3, averaging 52 m^3 per hectare. These figures illustrate the varying productivity and biomass across different forest types. Rich forests, with their higher timber volume, contribute significantly to the overall biomass and biodiversity. Medium and poor forests, while less productive, still play crucial roles in the ecosystem by providing habitat and maintaining ecological balance.

Image 3. Stand-Level Forest Inventory in HEPA (HEPA, 2023)

HEPA currently promotes the 3R model, namely Rung (Forest), Ray (Upland Farm), and Ruong (Valley Rice Field) within the livelihood functional area to support the sustainable livelihoods of its staff and local farmers. The 3R model, a traditional farming practice used by many highland indigenous communities in the uplands of Vietnam and the Mekong Region, incorporates agroecology principles. The model integrates various activities such as agroecology and resource management to ensure both economic viability and environmental sustainability. These ecosystem-based practices have proven their value in enhancing soil health and deepening the arable layer. The following seven key activities within the 3R model shall be carried out by HEPA in the current and coming years.

Forest and ecosystem management: Implement comprehensive forest and ecosystem management plans under Article 37 of the 2017 Forest Law and associated regulations. This plan prioritizes safeguarding forest ecosystems, promoting sustainable forest management practices, and ensuring the long-term health and vitality of forests. Additionally, HEPA will consolidate its existing forest protection plan to create a more cohesive and effective framework of action for forest conservation.

Biodiversity conservation: Develop and implement plans for biodiversity conservation and the protection of endangered, valuable and rare forest flora and fauna, including endemic species, following Article 38 of the 2017 Forestry Law and associated regulations. These plans prioritize the identification and protection of high-conservation value forests, ensuring targeted conservation efforts to safeguard the region's biodiversity effectively.

Forest fire prevention and control: Carry out forest fire prevention and control plans by Article 39 of the 2017 Forestry Law and associated regulations. These plans also include proactive measures to prevent forest fires, such as creating firebreaks, conducting public awareness campaigns, and Page 43 restricting activities that could ignite fires.

Harmful organisms prevention: Implement measures for the prevention and elimination of harmful organisms affecting forests, under Article 40 of the 2017 Forestry Law and associated regulations. These measures also include the identification and control of pests, diseases and other harmful organisms that threaten the growth and development of the forest.

Silvicultural measures and forest development: Identify specific locations, areas and tree species for the implementation of appropriate silvicultural measures and special use forest development initiatives, as outlined in Articles 45 and 46 of the 2017 Forestry Law and associated regulations on silvicultural measures. These initiatives will prioritize optimizing forest management practices, promoting the development of special-use forests, and ensuring the sustainable utilization of forest resources.

Scientific research, training, and practice: Prepare comprehensive scientific research, training and practice plans under Clause 1 of Article 53 of the 2017 Forestry Law and associated regulations. These plans focus on conducting applied research, providing effective training, and facilitating practical learning opportunities related to forest management, conservation and sustainable development.

Curriculum development and implementation on sustainable rainforest management: Develop comprehensive curriculums, allocate time and space for hands-on training, demonstration and awareness-raising activities on forest ecosystems, and foster a learning environment that inspires young people towards agroecology. These include summer camps, training in system planning, detailed design of the 3R landscape ecosystems and courses on the circular economy. HEPA will position itself as a reliable destination for domestic and international students seeking internships, research opportunities and practical experience in applying methods for calculating C-stocks, and water storage capacity of tropical rainforests, and upper watershed areas. These efforts can help unlock the full potential of forests and contribute to sustainable development, under Clauses 2, 3, 4, and 5 of Article 53 of the 2017 Forestry Law and associated regulations.

Avoiding unplanned deforestation is an important strategy outlined in the HEPA's strategy for forest protection, considering the multistakeholder processes and local-led development approach. As described in Section 3.5, by embracing the philosophy of 'nurturing nature' and prioritizing the engagement of young key farmers, HEPA, in collaboration with local authorities and relevant stakeholders, especially forest owners in the Huong Son district, has successfully mitigated the risks of unplanned deforestation for over two decades since 2002. This co-management approach has proven effective in preventing illegal logging activities and preserving the integrity of forest ecosystems.

3.8. Checklist for research approval

This research has completed nine of the ten tasks required for approval by the Ministry of Science and Technology (MOST), as outlined in Table 2 below.

Table 2. Checklist of documents for research approval

No.	Documentation and activity	Progress by June 2024
1	HEPA/CHESH legal status and forestland rights	Complete
2	Assessment of substantial risks to the research's result	Complete
3	Mapping systems of HEPA's forest and land use planning	Complete
4	Inventory report on HEPA's forest biomass	Complete
5	HEPA's sustainable forest management plan, 2022 – 2031	Complete
6	Assessment of leakage management areas	Complete
7	Forest C-stock measurement and calculation	Complete
8	Approval of Ha Tinh Provincial People's Committee	Complete
9	Approval of authorized organisations (CODE-SPERI)	Complete
10	Approval by MOST	In the process

Part 4
RESEARCH METHODOLOGY

4.1. Methodology for Avoided Unplanned Deforestation

Information and databases of this research were accurately recorded and securely stored, complying with strict adherence to EU and Vietnamese regulations. This documentation serves as a basis for carbon credit certification, demonstrating the research's commitment to high standards of environmental stewardship and sustainable development.

The methodologies employed for calculating emission sequestration in this research were grounded in the Methodology for Avoiding Unplanned Deforestation (AUD), specifically VM0015 - version 1.1, which is designed to estimate and monitor GHG emissions from areas where unplanned deforestation occurs. This methodology provides a comprehensive set of tools for analyzing both frontier and mosaic deforestation patterns to establish the baseline deforestation rate, monitor emission reductions, and assess leakage. It is part of the Verified Carbon Standard (VCS), which aims to ensure the integrity of GHG accounting for individual projects.

Secure storage and management of research data facilitated HEPA's ongoing forest monitoring and evaluation, enabling the timely refinement of conservation strategies. This approach ensures the transparency and accountability of the research while supporting the broader goal of integrating scientific accuracy into HEPA's strategies and practices in forest management.

4.2. Standard plot measurement protocol

The data collection methodology employed in the research ensured accurate measurements and documentation, providing a robust basis for subsequent analysis. Specialized tools, such as the NLI tape measure that incorporates both circumference and diameter values, were utilized to enhance precision. Detailed data sheets were categorized into two distinct types: one for recording timber values of trees, further subdivided into trees with a Diameter at Breast Height (DBH) greater than 6 cm and those between 1 cm and 6 cm, and another for documenting herbal plant species within the standard plots. This methodical approach, involving the use of 22 tools, aligns with best practices in environmental research, ensuring the data collected is both accurate and verifiable (see Figure 2).

Image 4: Tools used for measurement in each standard plot (HEPA, 2023-2024)

*Note:

No.	Item	No.	Item
1	Map	12	Acrylic paint
2	Monofilament wire	13	Notebook
3	50-meter tape	14	Pen
4	20-meter tape	15	Staple
5	Sticks for plot centre and corner sign	16	Scissors
6	GPS handheld	17	Knife
7	Battery	18	Safety helmet
8	1.3-meter reference stick	19	First aid kit
9	5-meter tape measure (for diameter and circumference)	20	Black fabric
10	Laser height gauge (not used in this phase)	21	Camera
11	Compass	22	Clear bag

The data sheets were designed to capture comprehensive information for each standard plot, aligning with the forest auditing procedures outlined in Article 11.2(b) of Circular 33 (MARD, 2018).

For the natural evergreen forests in HEPA, this research applied the standard plot area set at 500 m² (rectangular size 20 m x 25 m). To accurately locate the standard plots in the field, we mapped pre-designed routes and calculated the VN2000 grid coordinates for each plot based on the distances between the routes and the plots. These coordinates were then input into a GPS device to precisely locate each plot in the forest. The randomized plot selection method was also employed, and the Geographic Information System (GIS) was used to convert the standard plot coordinates into GPS coordinates for accurate field identification. Each plot was spaced 50 to 200 m apart according to the identified routes. Trees with a DBH of 6 cm or greater were measured, and the standard plots were marked with acrylic paint. This included geo-data and GPS coordinates for the four corners of each plot, as well as an additional coordinate at the centre. Key parameters recorded for each tree included DBH, height (H), and both local and Latin names. The geo-data files were stored and managed in compliance with CHESH's protocol, ensuring data integrity and regulatory adherence.

Image 5. The field team conducting measurement in a standard plot (HEPA, 2023-2024)

Practically, H can be challenging to calculate accurately, even with laser equipment, and is time-consuming, especially for forest owners who are local people. Therefore, for each standard plot, five trees of different diameter classes were selected and carefully measured. The collected data from all standard plots was then used to develop an H/DBH model, from which the height of each tree in each standard plot could be estimated.

This thorough data collection and management process underscored the research's commitment to the precision and accuracy of collected data and information. By capturing detailed geo-data and tree parameters, the research ensured that each plot was correctly mapped and each tree was precisely measured. The inclusion of both local and Latin names results in the data's utility for various stakeholders, including local communities and researchers. Moreover, adhering to

CHESH regulations, the secure storage and management of geo-data enhanced the credibility and reliability of the research. This data was not only accurate and reliable but also protected and accessible for future analysis. This rigorous data management process contributed to the broader objectives of transparency, accountability and continuous improvement in environmental research.

The study focused on individual trees with a diameter at DBH exceeding 6 cm, as these were considered to be the primary contributors to the area's carbon stock. This decision aligns with international standards for carbon stock assessment, ensuring the accuracy and reliability of the results.

To gain a more comprehensive understanding of the forest structure, the study also conducted a census and calculated mean parameters (diameter, height) for trees with a DBH less than 6 cm. However, due to their relatively small contribution to total biomass, these trees were not directly included in the total carbon calculation.

Data collected from measurements of smaller trees provided valuable information for developing more accurate forest biomass estimation models. This contributes to effective forest management and conservation, especially in the context of climate change.

4.3. Spatial Distribution of Standard Plots (October 2023 - June 2024)

The mapping of 37 standard plots' GPS coordinates during the two forest C-stock assessments in HEPA was conducted using both structured and systematic approaches (see Figure 7).

The selection of the standard plots was carried out in two distinct phases: December 2023 and April 2024. In December 2023, 21 standard plots were selected, followed by an additional 16 plots in April 2024. This phased approach allowed for a comprehensive and methodical survey process.

4.4. Using Remote Sensing Method

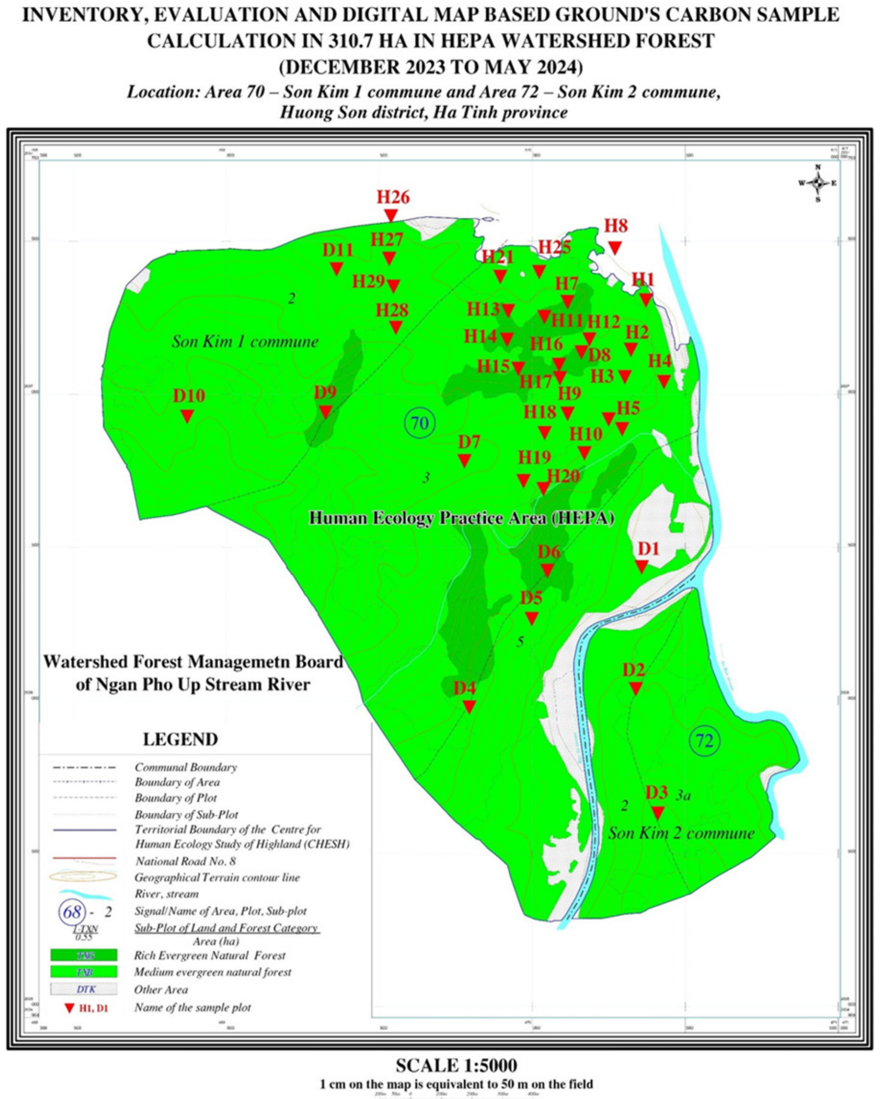

Figure 2. 37 standard plots' GPS coordinates during the two forest C-stock surveys in HEPA (2023 - 2024)

The selection process was planned, with standard plots chosen based on predetermined routes and directions. This ensured that the plots were evenly distributed and representative of the forest area. The active participation of key farmers from different communities, alongside HEPA staff, was instrumental in this process. Their local knowledge and expertise contributed significantly to the accurate selection and mapping of the plots.

MAP OF ESTIMATING C-STOCK (AGB ONLY) FROM HEPA FOREST (310.7 HA) AFTER ANALYZING PLANET SATELLITE IMAGES 3-M RESOLUTION (2023 CALCULATION)

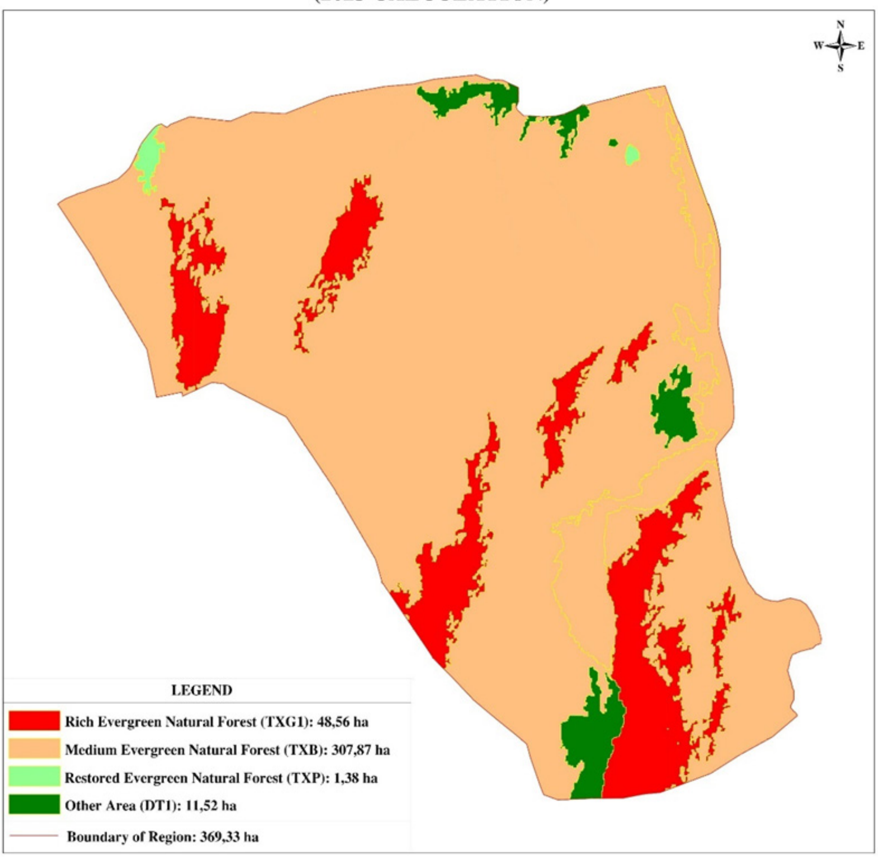

Figure 3. Estimating C-stock (AGB only) of HEPA forests after analysing Planet Satellite Images 3-m resolution (2023 calculation)

GPS technology was integral to the mapping process. VN2000 grid coordinates for each plot were calculated in advance, based on the distances between the routes and the plots. These coordinates were then inserted into GPS devices to precisely locate each plot in the forest. The randomized plot selection method was also employed, and GIS was used to convert the standard plot coordinates into GPS coordinates for accurate field determination.

Satellite imagery as an effective tool for biomass measurement

In 2023, the research team faced the difficulty of selecting a reliable and accurate method for measuring overall biomass within financial constraints. After a thorough evaluation of various technological innovations, satellite imagery emerged as the most suitable option. The research team's decision to use satellite imagery was confirmed by its potential to provide accurate and consistent data, even in remote or inaccessible areas.

The selection and acquisition of satellite data

To ensure the highest quality data, the research team conducted a comprehensive comparison and analysis of different satellite imagery providers. Ultimately, they engaged a Vietnamese technical company to procure satellite images from Planet. The team selected Planet's 3-meter resolution satellite images due to their high spatial resolution, which is essential for accurate biomass estimation.

Data acquisition and processing

The satellite images were acquired in May 2023, on a clear day to minimize cloud cover and ensure optimal data quality. Once the images were obtained, the research team carefully selected the most suitable ones for analysis. The Planet satellite image from May 2023 successfully captured the entire HEPA forest, providing a comprehensive view of the forest area.

Using QGIS for data analysis

Leveraging the power of QGIS software, the research team analyzed the high-quality satellite data to assess the current state of the forest land. By examining the images, they were able to accurately determine the actual area corresponding to the latest forest land type classification. This analysis provided valuable insights into the forest's composition and distribution.

Leveraging global and national data sources

To ensure consistency and comparability, the research team harmonized the identified forest classifications within the research site into 17 distinct types. This process involved integrating 12 forest types from the National Forest Inventory (NFI) map, a valuable source of secondary data. The NFI map is updated annually, guaranteeing that the forest classifications remain current and accurately reflect the prevailing forest conditions. The research team utilized the average values representing the 12 forest categories from the NFI results table. This secondary data provided valuable insights into the biomass stock within the study area. By focusing on biomass stock data from NFI Cycle IV (2006-2010), the National Forest Inventory and Statistics (NFI&S) (2013-2016), and the NFI (2016-2020), the research team was able to analyze trends in forest biomass over time.

Part 5

MEASUREMENT, CALCULATION AND ANALYSIS OF STANDARD PLOTS' RESULT

5.1. Results Following Measurement and Analysis

The standard plot in the research site - a fundamental unit in watershed analysis - represented three key interrelated elements: the direction of Yang energy flows including Sun, Water and Wind according to the theory and practices of Bio-human Ecology (BHE) by CHESH in diverse geo-ecosystems from 1999 to 2019, elevation representation (Peak, Slope, Valley), and the location of watershed terrain features. These features are important for understanding the biogeochemical processes operating within the Forest-Upland Farm-Valley Rice Field ecosystem.

The biogeochemical process in the above ecosystems determines the quality and content of carbon, oxygen and hydrogen in the micro-circulation systems of organisms, which are essential for the life and sustainability of tropical rainforests in the watershed region. This process involves the cycling of nutrients and elements through various components of the ecosystem, including soil, water, plants and animals.

The direction of Yang energy flows influences the distribution and movement of carbon, oxygen and hydrogen, while the elevation representation helps in understanding the topographical influences on water flow and nutrient distribution. The location of watershed terrain features provides insights into the spatial arrangement and connectivity of different ecosystem components.

The above analysis serves as a key basis for determining the carbon quality within the ecosystem, which can be categorized into different monetary values such as Diamond, Gold, Silver, etc. This categorization reflects the economic value of the carbon stored in the ecosystem, which is influenced by factors such as carbon sequestration capacity, biodiversity and ecosystem services provided by the tropical rainforest.

The study encompassed a total of 37 plots, each measuring 500 square meters (25m x 20m). These plots were strategically distributed across all four cardinal directions and various elevations within the watershed, including peaks, hills, and valleys. In total, these plots covered an area of 18,500 square meters.

This holistic spatial distribution ensured that the analysis captured a wide range of environmental conditions and topographical variations within the watershed. By including plots from different directions and elevations, the study could account for the diverse influences of sunlight, wind patterns, and water flow on the ecosystem. This diversity is essential for understanding the biogeochemical processes that govern the cycling of carbon, oxygen and hydrogen within the Forest-Upland Farm-Valley Rice Field ecosystem.

The data collected from these standard plots provided a robust foundation for assessing the health and sustainability of the tropical rainforest. The detailed measurements allowed for precise calculations of biomass, carbon sequestration, and nutrient cycling, which are critical for evaluating the ecosystem's functionality and resilience. Furthermore, the spatial arrangement of the plots facilitated the identification of patterns and trends in the distribution of biogeochemical elements, offering insights into the underlying processes that sustain the watershed.

Combining this detailed spatial analysis with the broader context of biogeochemical processes allowed the research team to gain a comprehensive understanding of the watershed's ecological dynamics. This understanding is also vital for informing conservation strategies, sustainable land use management practices, and policy decisions aimed at preserving the integrity and sustainability of tropical rainforest ecosystems in the watershed region.

5.1.1. Standard plot analysis by energy flows

The entire HEPA forest for biodiversity conservation was planned, taking into account the unique characteristics of the Ngan Pho River watershed ecosystem and the worldview of ethnic minority groups in the Mekong region. This comprehensive planning approach ensures that the conservation efforts are not only ecologically sound but also culturally respectful and inclusive. By integrating traditional knowledge and practices with modern conservation methods such as community-based conservation, ethnobotany, traditional ecological knowledge and participatory monitoring, HEPA has created a sustainable and harmonious environment that preserve both biodiversity and the cultural heritage of the local communities. This holistic strategy highlights the necessity of preserving the natural landscape while honouring the deep-rooted connections that ethnic minority groups have with their land.

The peak zone within HEPA is a designated spiritual area, believed to be the dwelling place of the Spirits of Heaven, Earth, Wood, and Waterfall. This sacred space, known as Huyen Vi Peak, is considered the harmonious convergence of the natural elements and the critical point for maintaining ecological balance. This is where Spirits are believed to deliberate on matters of Heaven, Earth, and the mortal realm. Within the peak zone, eight standard plots are strategically located to represent the four directions: East, West, South and North of the entire watershed. This arrangement signifies the interconnectedness of the natural world and the importance of honouring all aspects of the ecosystem. HEPA recognizes the profound spiritual significance of the peak zone and is committed to preserving its integrity and sanctity. By designating this area as a sacred space, HEPA underscores its respect for the natural world and its belief in the harmonious coexistence of humans and nature. Beyond its spiritual significance, the Huyen Vi plays a crucial role in maintaining the ecological balance of the watershed. Its location at the highest point of the area influences water flow, soil erosion, and biodiversity. By protecting this zone, HEPA helps to safeguard the overall health and well-being of the ecosystem.

Table 3. Spatial distribution of standard plots by Yang energy flows

No	Direction	Number of standard plots	%
1	Multi-direction[1]	8	21.62
2	East	6	16.22
3	West	1	2.70
4	South	4	10.81
5	North	18	48.65
	Total	***37***	***100***

The buffer zone surrounding Huyen Vi Peak plays a crucial role in preserving the sanctity and tranquillity of the peak zone, ensuring that the spiritual activities and natural harmony within remain undisturbed. The buffer zone acts as a shield, protecting the Huyen Vi Peak from external influences that could disrupt its spiritual significance. By maintaining a buffer around the peak, HEPA helps to ensure that the sacred space remains a place of peace and contemplation. In addition to its spiritual role, the buffer zone also plays a vital function in maintaining the ecological balance of the area. As a transition zone between the peak and surrounding areas, the buffer zone can help prevent activities that could harm the spiritual and ecological integrity of the entire region.

Further down is the enrichment zone, a core of ecological and cultural significance that harmoniously connects people and the highland environment. This is where respected elders and their younger generations meet regularly and seasonally to share and practice their knowledge of traditional herbs, natural dyeing techniques, and the identification of various plants and their uses. This area is a living

1 This is situated at the Huyen Vi peak with coordinates: X 468657, Y 2036513, H 49

repository of native medicinal plant varieties, thriving under the forest canopy. It serves as an essential ecological livelihood space for ethnic minority groups in the highlands. The continuous transmission of ancestral knowledge in this area ensures that traditional practices and ecological knowledge are preserved and adapted for future generations. With a deep understanding of the natural world, the elders guide younger community members, fostering intergenerational connections and respect for their cultural heritage.

Situated between the mountain peak and surrounding areas, the enrichment zone serves as a buffer, safeguarding the ecosystem. Its strategic location not only prevents the encroachment of human activities but also maintains natural balance. Conservation and sustainable management practices are implemented here to protect biodiversity, maintain water resources, and prevent soil erosion. Moreover, this area facilitates the growth of native plant species, contributing to the conservation of rare species and the unique ecosystem of the entire region.

Additionally, this area serves as a vital livelihood center, providing essential natural resources for the local community and staff. These resources include clean water, timber, medicinal plants, and agricultural products, helping to maintain and improve the quality of life. The exploitation and utilization of these resources are carried out sustainably, ensuring their continued availability for future generations.

5.1.2. Results of standard plot analysis by spiritual functions

Table 4 reveals a significant imbalance in the distribution of standard plots across the spiritual and enrichment zones within HEPA. The data demonstrates that the spiritual zone houses a substantially larger number of standard plots, accounting for over half (56.76%) of the total. This predominance suggests that the spiritual zone is considered a more important or valuable area of ecology and culture within HEPA.

Table 4. Distribution of standard plot analysis by spiritual functions

No	Functional zoning	Standard plot density	%
1	Spiritual zone	21	56.76
2	Enrichment zone	16	43.24
	Total	**37**	**100**

5.1.3. Result of standard plot analysis by elevation

Table 5 reveals a distinct trend of increasing standard plot density with elevation within HEPA. The highest elevation range (150-395 meters) boasts the highest number of plots, accounting for nearly half of the total.

Table 5. Distribution of standard plots by elevation

No	Elevation (m)	Standard plot density	%
1	63-90	4	10.81
2	90 -150	15	40.54
3	150-395	18	48.65
	Total	**37**	**100**

5.1.4. Results of standard plots by topographic features

Table 6 shows a clear pattern in the distribution of standard plots across the three topographic features within HEPA: mountain peaks, mountain slopes, and mountain foothills. The data indicates a significant concentration of plots on mountain slopes, which account for over half (51.35%) of the total.

Table 6. Distribution of standard plots by topographic features

No	Location	Standard plot density	%
1	Mountain peak	8	21.62
2	Mountain slope	19	51.35
3	Mountain foot	10	27.03
	Total	**37**	**100**

5.2. Analysis Results by Diameter Category and Timber Volume

5.2.1. By diameter class

The provided data in Table 7 shows the distribution of trees across four diameter classes: 6-20 cm, 20-40 cm, 40-60 cm, and >=60 cm. The majority of trees (65.95%) fall within the smallest diameter category (6-20 cm), indicating a relatively young and immature stand structure. As diameter categories increase, the number of individuals decreases significantly. This pattern suggests that mortality rates or selective harvesting practices may be higher for larger trees. Only a small percentage of trees (1.66%) belong to the largest diameter class (>=60 cm), suggesting a lack of mature, old-growth individuals.

Table 7. Forest tree classification by diameter category

No	Diameter class	Population size	%
1	6 - 20 cm	916	65.95
2	20 - 40 cm	382	27.50
3	40 - 60 cm	68	4.90
4	>=60 cm	23	1.66
	Total	**1389**	**100**

Figure 4 illustrates the positive correlation between DBH and H of forest trees. As DBH increases, tree height tends to increase as well. This suggests that larger trees are generally taller. While there is a general trend of increasing height with increasing diameter, there is also some scatter around the trendline. This indicates that other factors besides DBH may influence tree height, such as species, age, and environmental conditions. A few data points may be considered outliers, falling significantly off the general trend. These could represent unusual trees or measurement errors.

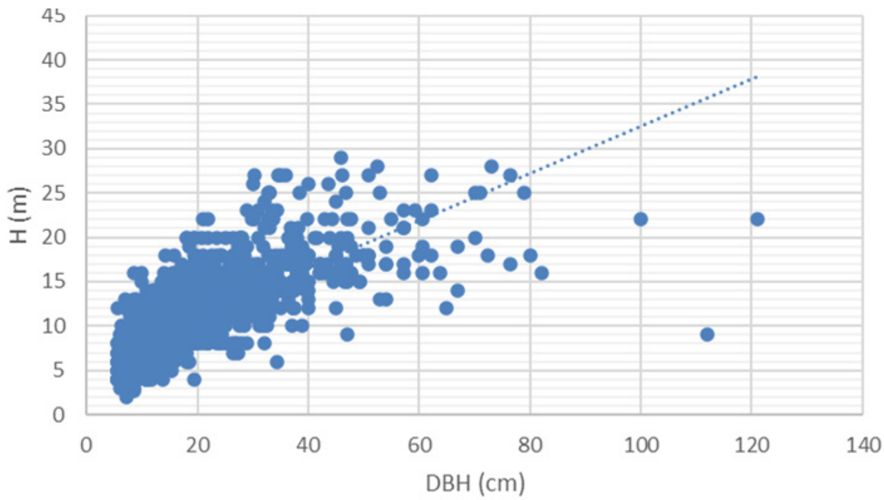

Figure 4. Correlation between DBH vs. H in 37 HEPA Plots (Jan 2023 - Apr)

5.2.2. By Timber Volume

Figure 5, classified by Vietnamese Standard, illustrates the differences between forest statuses in terms of timber volumes. The TXG (rich evergreen broadleaf forest) category demonstrates the highest average timber volume, approximately 269.350 m^3 per hectare, indicating a denser and more productive forest type. Conversely, the TXN (poor evergreen broadleaf forest) category exhibits the lowest average timber volume, around 99.515 m^3 per hectare, suggesting a less productive forest type.

Article 8 in Circular 16 (MARD, 2023), and amended by Circular N33 (MARD, 2018), outlines the regulations for the investigation, inventory, and monitoring of forest development. The categories for wooden volume-based forests are specified as follows: Very rich forests have a volume of 300 m^3/ha, rich forests span from 201-300 m^3/ha, average forests range from 101-200 m^3/ha, and poor forests contain volumes between 10-100 m^3/ha. Forests that are not yet measured for volume have a volume of less than 8 cm to 10 m^3/ha. For bamboo forests, the classification criteria include bamboo species, density and diameter.

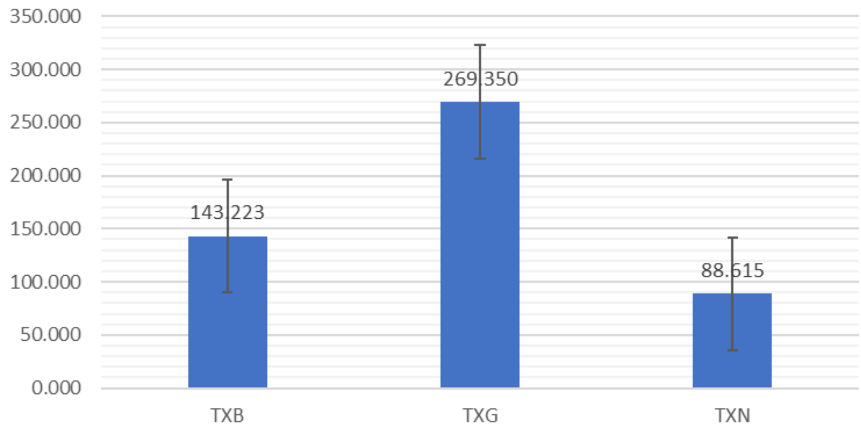

Figure 5. Average Timber Volume (m^3) by Forest Type in HEPA (Vietnamese Standard)

Therefore, the average timber volume per hectare, as measured and presented in Figure 7 at HEPA, has been adjusted accordingly, as shown in Table 8. According to Circular 33, medium forest is classified as TXB, rich forest as TXG, and poor forest as TXN. Forest status is categorized into four metrics: average value, minimum value, maximum value, and standard deviation.

Table 8 shows the adjusted figures on timber volumes by forest classes in HEPA. The average timber volume per hectare for medium forest (TXB) is 143.22 m^3, with a standard deviation of ±27.34 m^3. The minimum and maximum values for TXB are 28.48 m^3 and 198.48 m^3, respectively.

Table 8. Average Timber Volume (m^3) by Forest Type in HEPA adjusted as Circular 16

No	Forests status	Medium-forest (TXB)	Rich-forest (TXG)	Poor-forest (TXN)
1	Average Value	143.22	269.35	88.62
2	Standard Deviation	+/- 27.34	+/- 64.54	+/- 7.89

3	Minimum value	28.48	214.54	80.14
4	Maximum value	198.48	382.10	99.07

For rich forest (TXG), the average timber volume per hectare is 269.35 m³, with a standard deviation of ±64.54 m³. The minimum value recorded for TXG is 214.54 m³, while the maximum value is 382.10 m³.

In contrast, the poor-forest (TXN) category has an average timber volume of 88.62 m³ per hectare, with a standard deviation of ±7.89 m³. The minimum and maximum values for TXN are 80.14 m³ and 99.07 m³, respectively.

5.3. Forest Tree Biodiversity Analysis

Table 9 provides a comprehensive analysis of the most abundant forestry trees, categorized by family and evaluated based on individual population size and percentage. Among 37 standard plots, a total of 1,389 individuals belonging to 39 families and 52 genera have been measured. The top three dominant families are Fabaceae, represented by Dẻ, with a population size of 204, comprising 14.69% of the total; Dipterocarpaceae, represented by Dầu, with 112 individuals, accounting for 8.06%; and Cannabaceae, represented by Gai dầu, with 101 individuals, making up 7.27%. These three families are the most abundant, significantly contributing to the overall population. The following families are Myrtaceae, represented by Sim, with 76 individuals, or 5.47%; Lauraceae, represented by Nguyệt quế, with 75 individuals, constituting 5.40%; Apocynaceae, represented by Trúc đào, with 66 individuals, or 4.75%; and Fagaceae, represented by Đậu, with a population size of 58, accounting for 4.18% of the total.

Table 9. Most abundant forest tree families

No	Forest tree families	Population size	%
1	Dẻ (*Fabaceae)*	204	14.69
2	Dầu *(Dipterocarpaceae)*	112	8.06
3	Gai dầu *(Cannabaceae)*	101	7.27
4	Sim *(Myrtaceae)*	76	5.47
5	Nguyệt quế *(Lauraceae)*	75	5.40
6	Trúc đào *(Apocynaceae)*	66	4.75
7	Đậu *(Fagaceae)*	58	4.18

5.4. Important Value Index (IVI)

The Importance Value Index (IVI) of each species is calculated using the formula: IVI = RD + RF + RBA, as established by Mishra in 1968. In this formula, RD represents Relative Density (%), RF stands for Relative Frequency (%) and RBA[1] denotes Relative Basal Area (%). Additionally, N refers to the number of individuals, D indicates density and F signifies frequency. This comprehensive metric provides a holistic view of a species' ecological significance within a given area.

The analysis of the data in Table 10 reveals that, despite these seven tree species having the highest IVI values, the IVI values are relatively low, ranging from 10 to 18.38. This low range suggests that no single species exerts dominance within the ecosystem. As a result, the ecosystem shows a balanced distribution of species, which is indicative of a diverse and stable environment.

1 Refer to Annex 3 for the calculation of RD, RF, and RBA values.

Table 10: Species with the highest Importance Value Index (IVI)

No.	Tree species	Latin name	N	D	RD	Standards plot frequency	F	RF	BA	RBA	IVI
1	Lim xanh	*Erythrophleum fordii* Oliv.	71	1.919	5.112	26	0.703	3.741	5.445	9.525	18.378
2	Ngát	*Gironniera subaequalis* Planch.	100	2.703	7.199	32	0.865	4.604	3.344	5.851	17.655
3	Táu	*Vatica sp.*	110	2.973	7.919	28	0.757	4.029	3.217	5.627	17.576
4	Dẻ	*Castanopsis sp.*	54	1.460	3.888	21	0.568	3.022	2.513	4.396	11.306
5	Trâm	*Syzygium cinereum*	67	1.811	4.824	20	0.541	2.877	1.822	3.187	10.888
6	Ràng ràng	*Ormosia sp.*	35	0.946	2.520	17	0.460	2.446	3.224	5.641	10.607
7	Mức	*Wrightia annamensis*	66	1.784	4.752	14	0.378	2.015	1.872	3.276	10.042

5.5. Species diversity index - H (Shannon index) and Concentration of Dominance index – Cd

The research used the Shannon index to determine species diversity and the Concentration of Dominance of forest tree species within the surveyed area. The species diversity index, denoted as H (Shannon index), is calculated using the formula:

$$H = \sum_{i=1}^{n} \frac{N_i}{N} * Ln(\frac{N_i}{N})$$

In this formula, H represents the Biodiversity index or Shannon index; Ni-number of individuals of species i; N-total number of individuals of all species in the field. This index provides a quantitative measure of species diversity, reflecting both the richness and evenness of species distribution within the ecosystem.

Additionally, the study employs the Concentration of Dominance index (Cd) to assess the frequency of particular species. The Cd is calculated using the formula:

$$Cd = \sum_{i=1}^{n} \left(\frac{N_i}{N}\right)^2$$

Here, Cd represents the Concentration of Dominance index; Ni-number of individuals / IVI of species i; N - total number of individuals/ IVI of all species in the field, as described by Simpson in 1949. This index helps in understanding the extent to which certain species dominate in the ecosystem.

The results of the above calculations for the two indices in HEPA's forests are detailed in Table 11. The species diversity index (Shannon) of the standard plots fluctuated around 2.64 ± 0.4, indicating an average level of biodiversity. This suggests that the species diversity among the standard plots is relatively even, reflecting a balanced distribution of species within the ecosystem.

The Cd fluctuated around 0.1 ± 0.09, which indicates an inter-dependent relationship among species within the community. This low Cd value suggests that no single species is overly dominant, allowing for a more harmonious coexistence among species. This result demonstrates that the watershed ecosystem, covering the entire area of assessment, is growing harmoniously and stably. The balanced biodiversity and low dominance concentration are indicative of a healthy and resilient ecosystem, capable of sustaining its ecological functions and services over time.

Table 11: H and Cd indices of 37 standard plots

Stt	Standard plot	Number of species	Total individuals	H	Cd
1	H29	24	48	2.962	0.063
2	H16	23	39	2.953	0.064
3	D2	21	28	2.948	0.059
4	D6	22	55	2.913	0.062
5	H7	25	51	2.910	0.075
6	H13	22	34	2.909	0.069
7	H17	21	31	2.906	0.066
8	D4	23	43	2.853	0.078
9	D7	22	36	2.844	0.079
10	H20	21	42	2.843	0.069
11	H3	22	45	2.828	0.080
12	H4	21	37	2.825	0.074
13	H25	21	43	2.822	0.076
14	H2	20	37	2.819	0.069
15	H18	21	42	2.776	0.082
16	H21	21	43	2.761	0.088
17	H19	18	32	2.751	0.072
18	H26	20	49	2.744	0.081
19	D1	20	43	2.739	0.082
20	D8	22	48	2.726	0.092
21	D9	20	43	2.713	0.085

Stt	Standard plot	Number of species	Total individuals	H	Cd
22	H14	19	34	2.654	0.095
23	H12	20	41	2.651	0.103
24	H1	17	29	2.644	0.089
25	H6	17	30	2.627	0.091
26	H27	17	34	2.617	0.090
27	D10	18	52	2.603	0.092
28	D5	19	44	2.566	0.104
29	H15	16	30	2.561	0.093
30	H11	14	27	2.531	0.086
31	H10	16	28	2.511	0.110
32	D3	14	29	2.435	0.106
33	H9	13	25	2.391	0.107
34	D11	14	25	2.332	0.142
35	H5	17	40	2.301	0.174
36	H28	12	33	2.144	0.152
37	H8	2	19	0.576	0.612
Average		18.78	37.54	2.64	0.10
SD		4.26	8.66	0.40	0.09
Max		25.00	55.00	2.96	0.61
Min		2.00	19.00	0.58	0.06

5.6. Formulas applied to measure and calculate biomass and carbon stock

The research employed four different formulas from various sources to calculate biomass and C-stock for 37 standard plots, representing the entire assessed forest area. This document will detail these formulas, including the methods of analysis, comparison, screening and application. The analysis method utilizes practical data and applications to assess biomass and C-stock. The comparison method evaluates the results from different formulas to determine their accuracy and feasibility. The screening method filters out the most suitable formulas based on practical data and applications. Finally, the application method implements the screened formulas in practice to calculate biomass and C-stock.

5.6.1. Brown's Equation for Above-Ground Biomass Estimation in Tropical Rainforests

Brown (1997) developed a function to calculate the biomass of standing trees above ground for tropical rainforests with an average annual rainfall of 1,500 - 4,000 mm as follows:

$$AGB = \exp(-3{,}1141 + 0{,}9719 \times \ln(DBH^2 \times H))$$

Where:

- AGB is the AGB of each tree (kg/tree)
- exp is a function that returns the value of the exponent of the base e
- DBH is the diameter at breast height (cm)
- *H* is the clear bole height

○ **Determine the total AGB in each standard plot (kg):**

$$AGB_{OTC} = \sum_i AGB_i \ \ (kg)$$

Where:

- AGB_{OTC} is the total AGB for each standard plot (kg)
- i is the total number of trees in the standard plot

○ **Convert average above-ground biomass for each standard plot (t/ha):**

$$AGB_{OTC}\, tb = (AGB_{OTC} \times 10{,}000/S_{otc})/1{,}000 \ (ton/ha)$$

Where:

- AGB_{OTC} tb is the average AGB for each standard plot (t/ha)
- AGB_{OTC} is the standard plot's area. In HEPA, the value of is 500m^2
- 10,000: Conversion from hectare to m^2
- 1,000: Conversion from ton to kg

- **Calculate average AGB (t/ha)**

$$AGB_{tb} = (\sum_n (AGB_{otc} tb)_n) / n$$

Where:

- AGB_{tb} is the average AGB (t/ha)
- n is the number of calculated standard plots

- **Calculate the average carbon content in the AGB (t/ha)**

$$C_{AGB} = AGB_{tb} \text{ x } CF$$

Where:

- C_{AGB} is the average carbon content in the AGB (t/ha)
- CF is the default coefficient between carbon content and AGB
- According to the Inter-governmental Panel on Climate Change (IPCC) in 2006, CF = 0.47

5.6.2. Chave et al.'s Allometric Equation for Tropical Forest Biomass

In 2005, Chave et al. compiled data from a dataset of 2,410 trees with diameters of 5 cm or more, gathered from 27 study sites across the tropical regions of the Americas, Asia, and Oceania. This comprehensive dataset was used to develop allometric equations for estimating AGB in tropical forests in various types of tropical forests. For moist tropical forests, the most suitable equation is:

$$AGB = \exp\{-1.499 + 2.148 \ln(DBH) + 0.207(\mathrm{Ln}(DBH))^2 - 0.028(\mathrm{Ln}(DBH))^3 + \mathrm{LN}(WD))\}$$

Where:

- AGB is the AGB of each tree (kg/tree)
- exp is a function that returns the value of the exponent of the base e
- DBH is the diameter at breast height (cm)
- H is the clear bole height (m)
- WD is the wood density of the tree species. In this calculation, WD (g/cm^3) is taken as the average wood density of tree species in Southeast Asia, which is 0.574[1] (±0.151) (Chave et al. 2009).

1 0.55 is chosen in this research

○ **Determine the total AGB in each standard plot (kg):**

$$AGB_{OTC} = \sum_i AGB_i \text{ (kg)}$$

Where:

- AGB_{OTC} is the total AGB for each standard plot (kg)
- i is the number of trees in the standard plot

○ **Convert the average AGB for each standard plot (t/ha):**

$$AGB_{OTC}\,tb = (AGB_{OTC} \text{ x } 10{,}000/S_{otc})/1{,}000 \text{ (ton/ha)}$$

Where:

- AGB_{OTC} tb is the average AGB for each standard plot (t/ha)
- S_{otc} is the standard plot's area. In HEPA, the value of S_otc is 500m^2
- 10,000: Conversion from hectare to m^2
- 1,000: Conversion from ton to kg

○ **Calculate the average AGB (t/ha)**

$$AGB_{tb} = (\sum_n (AGB_{otc}\,tb)_n)/n$$

Where:

- AGB_{tb} is the average AGB (t/ha)
- n is the number of the calculated standard plots

○ **Calculate the average carbon content of AGB (t/ha)**

$$C_{AGB} = AGB_{tb} \text{ x } CF$$

Where:

- C_{AGB} is the average carbon content in the AGB (t/ha)
- CF is the default coefficient between carbon content and AGB
- According to the Inter-governmental Panel on Climate Change (IPCC) in 2006, CF = 0.47

5.6.3. NRW's Method for Estimating Tree Biomass

The calculation method is provided by Natural Resources Wales (NRW), the government-funded agency responsible for managing natural resources in Wales, Australia. NRW's duties include licensing, assessing, and enforcing regulations as necessary to ensure sustainable management of natural resources. NRW offers details in Table 12 that illustrate the relationship between the breast height diameter (centimetre) of trees and their estimated Dry Weight (DW) in kilograms per tree. This table serves as a valuable tool for accurately estimating the biomass of trees based on their DBHs, facilitating more precise calculations in forest management and research.

Table 12. Relationship between DBH and Estimated DW

DBH (cm)	Estimated DW (kg/tree)
1.5	0.009
2.5	0.04
5	0.23
10	1.40
20	9
30	27
40	82
50	106
75	310
100	668
125	1,208
150	1,964
175	3,253
200	4,221

As previously described, linear interpolation can be used to estimate the DW of each tree based on its DBH using the NRW's reference. The assumption that dry weight is approximately equal to above-ground biomass allows us to calculate the total AGB directly from the total DW.

- **Total AGB is equal to total dry weight within each standard plot (kg), and is calculated as follows:**

$$AGB_{OTC} = DW_{OTC} = \sum_i DW_i \text{ (kg)}$$

Where:

- AGB_{OTC} is the total AGB for each standard plot (kg)
- DW_{OTC} is the total DW for each standard plot (kg)
- i is the total number of trees in the standard plot

- **Convert average AGB for each standard plot (t/ha):**

$$AGB_{OTC}\ tb = (AGB_{OTC} \text{ x } 10{,}000/S_{otc})/1{,}000 \text{ (ton/ha)}$$

Where:

- AGB_{OTC} tb is the average AGB for each standard plot (t/ha)
- S_{otc} is the standard plot's area. In HEPA, the value of S_{otc} is $500m^2$
- 10,000: Conversion from hectare to m^2
- 1,000: Conversion from ton to kg

- **Calculte average AGB (t/ha)**

$$AGB_{tb} = (\sum_n (AGB_{otc}\ tb)_n)/n$$

Where:

- AGB_{tb} is the average AGB (t/ha)
- n is the number of the calculated standard plots

- **Calculate average carbon content in AGB (t/ha)**

$$C_{AGB} = AGB_{tb} \text{ x CF}$$

According to the Natural Resources Wales's guidebook, the carbon content of trees is approximately half of their DWs. Here, to maintain consistency with the remaining methods, the research team adopted the Carbon Fraction (CF) value of 0.47 as recommended by the IPCC in 2006.

5.6.4. Bao Huy's Model for Estimating Forest Biomass and Carbon in Evergreen Broadleaf Forests

In 2012, Bao Huy developed a model for directly estimating AGB carbon content in evergreen broadleaf forests of the Central Highlands of Vietnam using the felling method. The model is:

- **Determine carbon in AGB for each tree by applying the formula:**

$$C_{AGB} = \exp(-3.40031 - 0.819475 \times \ln(DBH) + 0.787115 \times \ln(H \times DBH^2) + 0.673237 \times \ln(WD \times DBH^2))$$

Where:

- C_{AGB} is the carbon in the AGB for each tree (kg/tree)
- exp is a function that returns the value of the exponent of the base
- DBH is the diameter at breast height (cm)
- H is the clear bole height (m)
- WD is the wood density of the tree species. In this calculation, WD (g/cm^3) is taken as the average wood density of tree species in Southeast Asia, which is 0.574[1] (±0.151) (Chave et al. 2009)

- **Determine total carbon in AGB in each standard plot (kg):**

$$C\_AGB_{OTC} = \sum_i C\_AGB_i \ \text{(kg)}$$

Where:

- C_AGB_{OTC} is the total carbon in AGB for each standard plot (kg)
- i is the number of trees in the standard plot

1 0.55 is adopted in this research.

○ **Convert average carbon in AGB for each standard plot OTC (t/ha):**

C_AGB_{OTC} tb = (C_AGB_{OTC} x 10,000/S_{otc})/1,000 (ton/ha)

Where:

- C_AGB_{OTC} tb is the average carbon in AGB for each standard plot (t/ha)
- S_{otc} is the standard plot's area. In HEPA, the value of Sotc is 500m^2
- 10,000: Conversion from hectare to m^2
- 1,000: Conversion from ton to kg

○ **Calculate average carbon content in AGB (t/ha)**

$$C\_AGB = (\sum_n (C\_AGB_{otc}\ tb)_n)/n$$

Where:

- C_AGB is the average carbon content in AGB (t/ha)
- n is the number of the calculated standard plots

Table 13. Results of average C_AGB (t/ha) from the above four formulas

Formula	**Brown (1997)**	**Chave et al. (2005)**	**NRW**	**Bao Huy (2012)**
Average C_AGB (t/ha)	97.36	151.00	133.54	110.25
Standard deviation (t/ha)	40.87	71.51	54.01	48.26
Min (t/ha)	43.76	64.25	58.14	49.37
Max (t/ha) C	249.19	420.97	332.11	297.11

BGB is estimated using the ratio of AGB to root biomass, as specified by the VM0015 method. The formula used is:

$$BGB_{tb} = AGB_{tb} \text{ x } R$$

where R is the ratio of the root biomass and AGB. According to IPCC, the ratio for tropical forests is:

- R = 0.20 when AGBtotal < 1 25 t/ha
- R = 0.24 when AGBtotal > 125 t/ha
- Applying the default coefficient between carbon content and above-ground dry biomass C_AGB = AGB x CF with the CF value of 0.47
- R = 0.20 when C_AGB total < 58.75 t/ha
- R = 0.24 when C_AGB total > 58.75 t/ha

The average total carbon stock Ctb_total (t/ha) is calculated by:

$$Ctb\_total = C\_AGB + C\_BGB$$

The results of the calculated average C_AGB, C_BGB (below-ground biomass carbon), and Ctb_total (total C-stock) in tonnes per hectare (t/ha) are as follows:

Table 14. Average C_AGB, C_BGB, and Ctb_total

Formula	**Brown (1997)**	**Chave et al (2005)**	**NRW**	**Bao Huy (2012)**
Average C_AGB (t/ha)	97.36	151.00	133.54	110.25
Average C_BGB[1] (t/ha)	23.37	36.24	32.05	26.46
Average Ctb_total (t/ha)	120.73	187.24	165.58	136.71

1 Corresponding to carbon biomass in the roots of timber trees

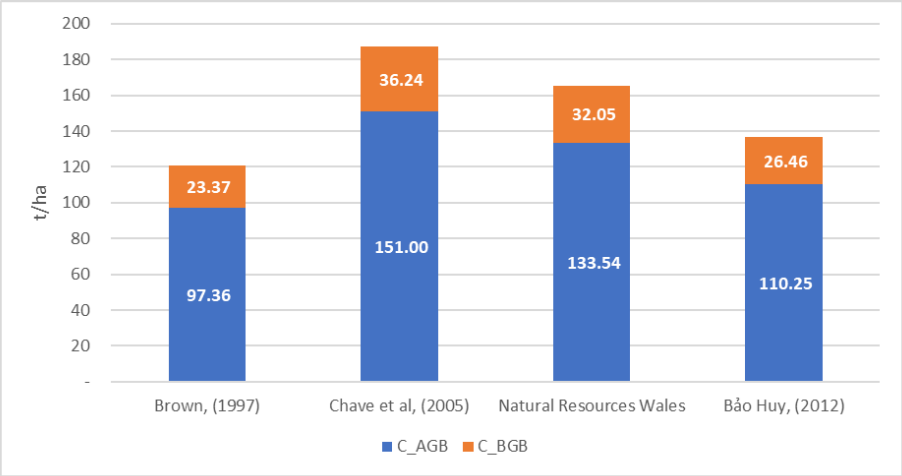

Figure 6. Average carbon biomass C_AGB, C_BGB (t/ha)

The comparison of the Brown (1997) and Chave et al. (2005) methods in Table 14 and Figure 12 underscores the significant influence of allometric equations on biomass and carbon stock estimates. It shows that the method yielding the lowest values is Brown (1997), with a C_AGB value of 97.36 t/ha and a Ctb_total of 120.73 t/ha. Conversely, the method producing the highest values is Chave *et al.* (2005), with a C_AGB value of 151.00 t/ha and a Ctb_total of 187.24 t/ha. The substantial variation in the calculated values highlights the importance of carefully selecting appropriate equations for specific forest types and conditions.

The Brown (1997) method, which consistently produces lower estimates, is likely more conservative in its approach. This may be due to factors such as the specific tree species included in the model, the range of forest types considered, or the assumptions made about biomass allocation patterns. While providing lower estimates, the Brown (1997) method may be suitable for certain forest management practices where a more cautious approach is desired, such as in areas with sensitive ecosystems or where carbon sequestration targets are being set.

In contrast, the Chave *et al.* (2005) method, which yields higher estimates, may be more applicable in scenarios where a comprehensive assessment of biomass and carbon stock is required. This method is likely based on a broader dataset encompassing a wider range of tree species and forest types, allowing for more accurate predictions. It may be particularly useful in areas where there is a need to quantify carbon stocks for reporting or verification purposes.

Part 6
COMPATIBILITY OF THE APPLIED FORMULAS

Table 15 evaluates the suitability of various formulas including Brown (1997), Chave et al. (2005), Natural Resources Wales and Bao Huy (2012) for biomass and C-stock calculations, emphasizing their input variables, advantages and limitations.

Table 15: Analysis of appropriateness among the applied formulas

No	Formula	Input variable	Appropriateness	Inadequacies
1	Brown (1997)	DBH (cm) and H (m)	• Two basic inputs are widely used in carbon calculations globally	• It has not been used for biomass and carbon stock calculations in Vietnam. • It has low reliability in practical applications. • It only analysed 168 tree species and excluded those found in Vietnam. • The data source is limited.

No	Formula	Input variable	Appropriateness	Inadequacies
2	Chave et al (2005)	DBH (cm), WD (g/m^3)	• The data source is varied, covering Asia, the Pacific, and Latin America	• No representation of the data source in Vietnam. • No basis for assessing the appropriateness and reliability of tropical forests in Vietnam. • Low reliability in practical applications.
3	Natural Resources Wales	DBH	• Simple and suitable for guiding forest owners who are farmers	• Unclear research method, location and data source • Low practical reliability
4	Bao Huy (2012)	DBH (cm), H (m), WD (g/m^3)	• Tailored for Central Highlands evergreen broadleaf forests, considering local conditions and timber. • Enhances biomass estimation, especially for mixed forests, using DBH, H and WD	• The modelling data source is unavailable in the study ecosystem, despite similarities in ecology and species composition between the modelling region and the research area.

No	Formula	Input variable	Appropriateness	Inadequacies
4	Bao Huy (2012)	DBH (cm), H (m), WD (g/m^3)	• Offers direct carbon estimation, improving accuracy over indirect methods. • Provides more accurate carbon estimates compared to Brown (1997) and Chave et al. (2005, 2014), which only estimate biomass and indirectly estimate carbon using CF=0.47 of IPCC (2006)	

Between 2000 and 2015, the tools for measuring biomass stock and tree height were not yet advanced, which limited the accuracy of estimating the tree's clear bole height. As a result, using tree diameter to estimate AGB became a practical and straightforward solution. This method simplified the calculations by reducing the number of variables needed, making it easier to apply in various research contexts.

However, Chave *et al.* (2005) argue that for tropical forests, a multi-species regression model, such as that proposed by Chambers et al. (2001b), is essential for accurately estimating above-ground tree biomass, rather than relying solely on DBH. Bao Huy (2012) further supports this by demonstrating that an estimation function incorporating DBH, H and WD yields the highest reliability. This comprehensive approach ensures more precise biomass estimations, reflecting the complex interactions among these variables in tropical forest ecosystems.

The research team's decision to apply Bao Huy's (2012) formula for calculating C-stock in AGB within the HEPA research site is based on two key factors: the forest type and the number of variables included in the formula.

- ***Alignment with forest type:*** The HEPA research site is classified as an evergreen mixed forest, which closely aligns with the target forest type for Bao Huy's (2012) formula. This formula is specifically designed for evergreen broadleaf forest areas in the Central Highlands of Vietnam, making it particularly suitable for the HEPA conditions. The alignment between the formula's intended use and the actual forest type enhances the reliability of the results obtained.
- ***The advantage of a three-variable function:*** Bao Huy's (2010) formula incorporates a three-variable function: DBH, H and WD. This multi-variable approach provides a more comprehensive and accurate estimation of AGB compared to the one-variable and two-variable formulas discussed earlier in the report. By considering these three variables, the formula can better account.

Therefore, calculating the total C-stock in the above-ground and below-ground biomass of the entire HEPA forest area using Bao Huy's (2012) formula is the most suitable approach for implementation.

Total C-stock of the entire HEPA Forest area:

$$C\_total = Ctb\_total \times A$$

Where:

- C_total is the total carbon stock over the entire area (t)
- A is the total project area (ha)
- C_total = 136.71 x 310.7 = 42,475.8 (t)

Total CO_2-equivalent (CO_2 eq) over the entire area is calculated by:

CO_2_eq = C_total x 44/12 = 42,475.8 x 3.67 = 155,886.19 (ton).

Where:

- CO_2 eq_total is the total CO_2-equivalent captured by the entire HEPA forest area (t)
- 44/12 is the conversion rate from C to CO_2

In sum, the total C-stock within the 310.7-hectare HEPA forest area, as of the research period, is 42,475.8 tons. This is equivalent to the absorption of 155,886.19 tons of CO_2 by the forest.

Part 7
THE UNIQUENESS OF THE RESEARCH

The research on C-stock calculation was conducted in the watershed biodiversity conservation area (HEPA) This area, located in the Ngan Pho River watershed, is characterized by a unique rainforest ecosystem with specific terrain, climate and annual rainfall patterns. These factors provided a practical basis for identifying, analyzing, and comparing carbon quality, stock and sequestration potential, which are key aspects for financial analysis and carbon credit benchmarking strategies.

The participatory methodology was employed for the forest assessments, integrating experts from diverse domains to facilitate comprehensive data collection and analysis. This interdisciplinary consortium, comprising specialists in cadastre, cartography, forestry, herbal medicine and carbon sequestration, collaborated synergistically with forest owners and young eco-farmers from various watersheds, such as the Ngan Pho River in Huong Son District, Ha Tinh Province, the Nan River in Tuyen Hoa District, Quang Binh Province, the Chay River in Sapa District and Bao Yen District, Lao Cai Province, and the Da River in Ba Vi District, Ha Tay Province (now part of Hanoi since 2008). Forestry experts, in conjunction with local farmers, meticulously mapped forest areas and assessed biodiversity, while herbalists identified valuable plant species and their traditional uses. This collaborative approach ensured the collected data was not only accurate but also aligned with the specific needs of the local communities. By incorporating a diverse range of perspectives, the research findings were enriched, enhancing their applicability and impact at a larger scale.

The hands-on practice with five essential skills was conducted in groups of six members, rotating among the groups after each fieldwork session across a total of 37 standard plots. The professional functions crucial for these field trips included:

- Utilizing cadastral, planning, forest current status and classification maps, as well as understanding forestry and energy flow directions (sun, water, wind)
- Measuring, counting, staking, routing, pulling ropes and positioning standard plots
- Using GPS devices to read and interpret displayed information
- Writing information from the GPS into a field notebook according to templates and double-checking the information by reading aloud clearly and slowly for the group to cross-check before using a laser to measure tree height
- Taking photos of mother trees, sacred trees, trees listed in the Red Book and medicinal herbs, as well as specimen photos. This function remains consistent throughout the field research period.

During each session, participants utilized GPS devices to delineate standard plots, meticulously recording the data in their field notebooks and subsequently cross-verifying the information through a collective reading. Distinctive plant species that require special attention were photographed to document alongside the survey results. This structured methodology ensured all participants acquired practical proficiency in essential fieldwork techniques. Rotating group assignments allows members to learn new skills and expand their knowledge base through exposure to a variety of tasks.

The training utilized a rotational and reciprocal learning methodology, effectively integrating four critical competencies and tasks to bolster forest owners' knowledge and confidence. Through immersive field experiences in standardized plots, participants honed their ability to identify tree age, diameter, height and wood classification, all of which are essential for precise biomass and C-stock assessment. Forest owners engaged in practical exercises to estimate timber volume and C-stock using appropriate allometric equations and measurement techniques. They acquired proficiency in converting sequestered CO_2-e into monetary value through hands-on practice with trees and standard plots. This practical experience is paramount to comprehending the economic viability of forest carbon sequestration. By mastering these competencies, forest owners are empowered to make accurate assessments of the carbon storage value of their forests, which is becoming increasingly significant in the context of climate change mitigation strategies and carbon trading markets locally and globally.

The participation of eco-farmers, dedicated to nurturing nature via agroecological practices, alongside traditional women herbal healers-elders from various northwestern ethnic minority groups[1] in Vietnam introduced unique perspectives and ancestral wisdom to the fieldwork, enriching the overall research result. These participants contributed their traditional knowledge and skills to the fieldwork while simultaneously benefiting from the structured training methodology of the research. This approach fostered their confidence in modern forestry practices, such

1 Ms. Trieu Thi Khang: A traditional herbal healer from the Dao minority in Ba Vi district, Hanoi (Da River watershed). Her expertise in medicinal herbs adds significant value to the identification and documentation of plant species during the field trips.

Ms. Hoang Thi Lien: From the Tay minority in Bao Yen district, Lao Cai province (Red River watershed). Her background likely provides insights into sustainable forestry practices and community-based resource management.

Ms. Ly May Chan: A community entrepreneur from the Dao minority in Sapa, Lao Cai province (Chay River watershed). Her entrepreneurial skills can contribute to understanding the economic aspects of forestry, including the potential for eco-tourism and sustainable product development.

Ms. Cao Thi Thiu: From the Ma Lieng minority in Ke village, Lam Hoa Commune, Tuyen Hoa District (Gianh River watershed). Her participation highlights the importance of integrating indigenous knowledge with modern forestry techniques.

Mr. Nguyen Van Su and Ms. Mai Thuy Huyen: From Cao Quang commune (Nan River watershed). Their involvement underscores the collaborative nature of the field trips, bringing together diverse experiences and expertise.

as utilizing GPS devices, measuring tree dimensions, and estimating timber volume and C-stock. For instance, an elderly participant might leverage her traditional knowledge to identify valuable medicinal plants while concurrently learning to employ a GPS device to accurately map their locations. The integration of traditional and advanced practices cultivated a holistic understanding of sustainable forest management. By synergizing their traditional wisdom with modern techniques, these forest owners are empowered to make informed decisions that benefit both their communities and the environment.

The research emphasized the necessity of integrating indigenous knowledge with scientific expertise to address discrepancies in tree nomenclature, taxonomic classification, and wood groupings. These discrepancies arise because forest owners belong to different ethnic groups, each with its own language, and come from various watersheds across the country. A significant challenge was the forest owners' limited proficiency in scientific nomenclature. In the standardized plots, up to 762 individuals (54.8%) remained incompletely identified by scientific names, while 171 individuals (12.31%) lacked identification at the family level. The Latin names employed in this research report have been meticulously collated and verified by senior experts from CODE and SPERI. While indigenous names and traditional knowledge are invaluable, the standardization of data through scientific nomenclature is indispensable for broader applicability and accuracy in research. This approach ensures the collected data is both comprehensive and reliable. The collaboration between forest owners and scientists facilitates a more profound understanding of the biodiversity within these tropical rainforests, leading to enhanced forest conservation and management practices.

This research presented a unique opportunity for forest owners to convene, engage, learn and share experiences, leverage technology, and directly identify the forest C-stocks via standardized plots. This participatory approach not only fortified the confidence and practical skills of the forest owners but also possessed broader implications.

Primarily, by collaborating in data collection, forest owners fostered a sense of community and shared purpose. They exchanged invaluable traditional wisdom and practices, which, when combined with modern technological tools and insights, such as the estimation of the value of each forest tree based on age, circumference, height, and wood classification, therefore led to a deeper understanding of the intricate relationships within ecosystems. This enhanced their capacity to restore and enrich natural forests, increase productivity in agroecological systems, and make informed decisions regarding sustainable forest management and conservation.

Secondly, the practical experience gained through this research empowered forest owners to make more informed and effective decisions regarding land management and utilization. They acquired the skills to accurately measure and monitor C-stocks, a crucial step in comprehending the ecological and economic value of the forests. This knowledge is particularly significant in the context of the escalating impacts of climate change and the global trends toward carbon markets, and greenhouse gas emissions reduction towards sustainability.

The benefits of natural forests extend far beyond their immediate economic value. The forest owners recognized the invaluable contributions of these ecosystems to their daily sustenance. Natural forests provide essential resources such as food, medicinal plants and materials for traditional crafts, which are integral to the cultural and economic tapestry of their communities. Forests act as natural water filtration and regulation systems, ensuring a consistent supply of clean water for daily life and agricultural production. Moreover, natural forests play a pivotal role in ensuring annual seasonal food security. By preserving biodiversity and supporting various plant and animal species, forests can contribute to a stable and resilient food supply, a particularly significant aspect in regions where agriculture is closely intertwined with forest ecosystems.

In addition to these above ecological and livelihood benefits, forest owners were increasingly cognizant of the potential for household economic development through carbon credit trading. By accurately measuring and monitoring forest C-stocks, they can be more confident to participate in carbon markets, generating income while contributing to national and global efforts to mitigate climate change. This dual benefit of environmental conservation and economic gain underscores the importance of integrating traditional knowledge with modern scientific practices.

The practical applications of this research are fully consistent with the Vietnamese government's goal of net-zero emissions. By involving forest owners in hands-on research, especially field surveys, this initiative has built a strong, evidence-based foundation for sustainable forest management and conservation strategies, particularly in watershed areas. This grassroots approach is instrumental in attaining national and international climate objectives, as it capitalizes on the local expertise and stewardship of those who possess the most intimate connection to the forest and land resources.

Part 8
LIMITATIONS OF THE FIELD RESEARCH

The biomass and C-stock calculation results remain incomplete in Latin names due to the identification challenges faced by forest owners. Specifically, some trees have been identified by local names, but their common and scientific names persist unknown. Additionally, the absence of professional taxonomists in species identification contributes to this issue. One of the primary motivations and objectives of this applied research was to build capacity for forest owners in the watersheds. However, the presence of professional taxonomists could cause confusion and a lack of confidence among forest owners. To address this issue, HEPA has planned to organize training sessions to enhance the capacity of forest owners. These training sessions will focus on correlating local names with scientific names, empowering forest owners to confidently identify tree species and participate in data collection. By bridging the gap between local knowledge and scientific nomenclature, the research can improve the accuracy of biomass and carbon stock assessments.

The comparison between the three-variable formula (DBH, H and WD) and the other formulas presented in Table 15 demonstrates the clear advantage of using a multi-variable approach for C-stock estimation. The Bao Huy (2012) formula, incorporating all three variables, provides more accurate results than formulas relying solely on DBH or a combination of DBH and H. The inclusion of WD as a variable in the Bao Huy (2012) formula is particularly significant for mixed-species forests. WD can vary considerably among different tree species, and incorporating this factor into the calculations helps to account for the differences in biomass and carbon content between species.

The lack of complete Latin names for tree species in the HEPA forest has severely impacted biodiversity assessments. This omission hinders the accurate determination of key indices like WD, IVI, H, and Cd, complicating timber and carbon stock evaluations. Consequently, this incomplete information restricts understanding of the forest's biodiversity and limits informed decision-making for sustainable forest management and conservation efforts.

Part 9
OVERVIEW OF FOREST MANAGEMENT IN VIETNAM (2001-PRESENT)

Vietnam witnessed a substantial depletion of natural forest cover between 2001 and 2023, driven by several salient factors. This situation reflects the complex contrast between economic development and environmental conservation. According to Global Forest Watch data and research conducted by Golman and Carter (2024), one of the primary catalysts for this loss was the displacement of natural forests by industrial plantations, such as rubber, acacia, cassava, etc. This trend was closely intertwined with Vietnam's national industrialization strategy, which prioritized economic growth and development. The encroachment of industrial plantations is a major cause of the dramatic reduction in natural forest cover. Another major factor contributing to this situation is the conversion of natural forests into small and medium-scale hydropower projects. These projects, designed to modernize the country's energy infrastructure, often require the clearance of significant forest areas to construct hydropower dams and reservoirs.

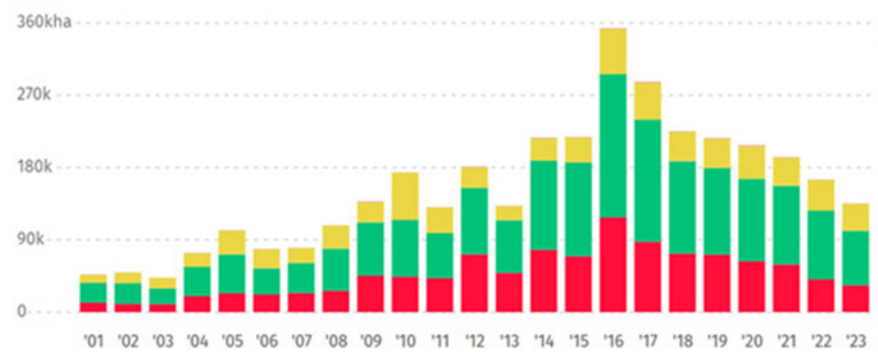

Figure 7. Annual global forest cover (Global Forest Watch data)

Figure 13 provides a visual representation of global deforestation trends from 2001 to 2023, highlighting the primary drivers of forest loss. Green denotes deforestation due to forestry activities, red signifies commodity-driven deforestation, and yellow represents deforestation caused by shifting agriculture. The extent of deforestation has fluctuated over the years, with periods of significant deforestation followed by intervals of relative stability.

The clearing of natural forests for rural urbanization and transportation infrastructure development was another major factor. The expansion of urban areas and the development of rural infrastructure have led to the clearing of natural forests for housing, roads and other development projects. The conversion of natural forests into monoculture high-tech agricultural areas, such as rubber plantations, has also contributed to deforestation. These practices often involve the clearing of forests to create large-scale agricultural fields. The need for mineral resources to support industrialization has driven deforestation in some areas. Mining operations often require the clearing of forests to access mineral deposits. Forest fires, both natural and human-caused, have played a significant role in the reduction of forest cover in Vietnam. These fires can cause extensive damage to forests, leading to loss of biodiversity and carbon stocks.

The dearth of high-accuracy natural forest data in Ha Tinh has impeded the comprehensive assessment and monitoring of changes in forest cover and composition throughout the province. However, continuous observations spanning 22 years have unveiled substantial alterations in the natural forest stock within the Ngan Pho River watershed. One of the most evident changes is the gradual replacement of natural forests with acacia plantations. This transformation has been driven by wood processing companies located in Son Truong Commune, Huong Son District. Although acacia plantations offer economic benefits, their widespread cultivation has led to numerous environmental problems. Acacia forests typically consist of a single species, lacking the diversity of natural forests, resulting in the loss of habitat for many plant and animal species. If not managed properly, the soil in acacia plantations is susceptible to erosion, causing issues such as floods and landslides. Acacia cultivation can also contaminate water sources, affecting aquatic life and human health.

Compared to other provinces in Vietnam, Ha Tinh has achieved significant milestones in forest protection and development. Despite facing numerous challenges, the province has remained committed to implementing sustainable forest management practices. Thanks to these continuous efforts, Ha Tinh has successfully preserved a substantial area of forest. As of 2023, forests covered an impressive 52.58% of the province's total area (MARD, 2024). This is a remarkable figure and demonstrates the success of the province's forest conservation policies. HEPA serves as an exemplary model for sustainable forest management and protection within the province's collective efforts.

Part 10
CONCLUSION

This pilot experimental research on "Application and Comparison of Methods for Estimating Carbon Stock in Above-Ground Biomass of Tropical Rainforests in North-Central Vietnam" was conducted in a regenerating forest with timber groups I-VIII within the Human Ecology Practice Area (HEPA), a biodiversity hotspot in the Ngan Pho River watershed, Huong Son district, Ha Tinh province.

This study successfully integrated indigenous knowledge with modern technology, pioneering a new approach to ecosystem assessment and forest biomass measurement. This was achieved through interdisciplinary collaboration, bringing together experts from SPERI, CHESH, and CODE, as well as the active participation of forest owners and traditional healers from watersheds of both Central and Northern Vietnam. This endeavour also empowered forest owners and young ecological farmers with the necessary knowledge, skills and tools to confidently quantify their forest carbon assets, thereby proactively engaging in carbon markets and enhancing the economic value of their forests.

The systematic selection of standard plots based on diverse criteria laid a solid foundation for the entire study, ensuring the representativeness and reliability of the collected data. This deepens the understanding of the structure and function of forest ecosystems and provides a crucial scientific basis for sustainable forest management and conservation.

Identifying the most suitable biomass estimation formula provides accurate information on carbon stock and forest biomass and contributes to a more precise assessment of the forest's carbon sequestration capacity. Furthermore, this discovery opens up new avenues of research, such as evaluating the impact of climate change on forest biomass, developing models to predict future forest changes, and creating decision-support tools for sustainable forest management.

The study convincingly demonstrated the significant role of HEPA forests in sequestering a substantial amount of carbon, contributing to Vietnam's international commitments to reducing greenhouse gas emissions. This achievement is the result of over two decades of relentless efforts by CHESH in regenerating, protecting and enriching forests sustainably, based on learning from natural succession, enhancing biodiversity and harmoniously combining indigenous knowledge with modern science.

This research lays the foundation for the application and expansion of the "nurturing nature" philosophy in the conservation and sustainable development of natural forest ecosystems in the watersheds of Vietnam and the wider Mekong region, placing natural forest ecosystems and local communities at the centre, with co-management as the key strategy to create multistakeholder platforms for learning, cooperation and equitable sharing of rights and responsibilities among forest owners, government and stakeholders in forest conservation and development.

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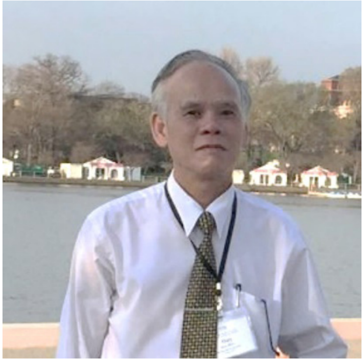
KEY REMARKS ON THIS RESEARCH

PROF. DR. BAO HUY



The sequestration or emission of forest carbon serves as an indicator of whether forest management is sustainable. Therefore, measuring forest carbon over time provides insight into sustainability and can facilitate the creation of carbon credits if the forest is well managed. This, in turn, opens up economic opportunities for local communities dedicated to preserving customary forests.

Effective forest carbon management will promote the conservation of forest biodiversity and the invaluable ecological and socio-cultural functions of forests, such as mitigating climate change, regulating weather, preventing erosion and landslides, improving soil, protecting and balancing hydrological systems, safeguarding watersheds, preventing floods, and contributing to livelihood development while preserving the traditional culture of indigenous communities.

In this context, a protected area for biodiversity conservation and watershed forest protection of the Ngan Pho River, located in North Central Vietnam and covering 311 hectares, has been experimentally measuring forest carbon in 2024. This task is new and quite complex for the forestry sector, requiring professional expertise. However, in this instance, the work is being conducted with the active involvement of local residents.

A participatory forest carbon measurement method has been developed, where the community utilizes its local ecological knowledge-expertise that professional technical staff do not possess. This includes understanding the location, terrain, and topography of the forest to identify and establish forest boundaries, locate sample plots, provide important information about the ecological and cultural functions of each forest block, identify tree species and their value, and effectively use forest measurement tools after receiving training. Combined with the professional expertise of technical staff in applying remote sensing and GIS to map changes in forest cover, and forest status, design sample plot system measurement, and calculate forest carbon stocks.

The focus of this investigation is to find the most effective and reliable formula for calculating accumulated carbon in forest aboveground biomass. Various formulas from international and domestic scientists have been tested. The results identified a suitable formula because it incorporates all relevant input factors, and aligns with local forest characteristics - such as ecological similarities, environmental conditions, and tree species composition - to provide highly reliable carbon estimates.

Participatory forest carbon monitoring and measurement have been effectively designed and implemented. Repeated measurements and calculations in subsequent years will help generate carbon credits for trade. More importantly, the involvement of the community, alongside their local ecological knowledge, has affirmed their role as an integral part of the forest's socio-ecological system. They will live and develop alongside the forest, ensuring a sustainable coexistence with nature.

September 6, 2024

Prof. Dr. Bao Huy

DR LE XUAN NGHIA

This book is a report on meticulous and innovative field research on carbon sequestration in watershed forests that have naturally regenerated and recovered thanks to the extraordinary efforts of local forest owners and authorities in forest nurturing.

The method for determining the carbon absorption index was selected by a team of experts from the Social Policy Ecology Research Institute (SPERI), Key Farmer who are the forest owner under the supervision of Professor Goeltenboth of NatureLife-International (NLI) in collaboration with leading domestic and international scientists is based on the renowned research work by Professor Bao Huy (2012).

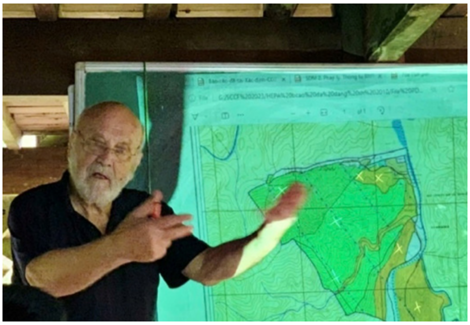
The uniqueness of this research is its: 1) innovative method of selecting random and representative standard plots based on directions (East, West, South, North) of Yang energy flows (Sun, Water, Wind), topography, elevation, slope, biodiversity, and tree diameter class; 2) application and comparison of four globally recognized formulas, ultimately choosing Bao Huy's (2012) formula as the most optimal for estimating carbon sequestration in the above-mentioned regenerating forests, a choice endorsed by the scientist Bao Huy himself; and 3) active involvement of local key farmers, the very owners of the watershed forests, and ethnic minority women with deep indigenous knowledge of medicinal vegetation in the field research for data collection, calculation, and global positioning (GPS). This unique approach has made a creative breakthrough in actively contributing to the process of understanding and empowerment among local communities regarding the application of GPS technology and formula for estimating carbon stock and carbon dioxide equivalent sequestration of each tropical forest tree in the North Central region of Vietnam.

This research paves the way for a transparent co-governance model, involving forest owners, investors, consultants, and local authorities. Accordingly, a digital and GPS-based co-governance model for each forest tree, which is directly verified and implemented by forest owners, ensures transparency, fairness, and efficiency in the public online management of the carbon stock of each tree in a strategy towards accessing the carbon credit market and carbon finance on the exchange.

Last but not least, the research's uniqueness also lies in its community-based approach, involving local forest owners in identifying standard plots, measuring and counting trees, and inputting field data into the formula for calculating carbon stock and carbon dioxide equivalent absorption.

I would like to extend my sincere gratitude and admiration to all key farmers, and authors, particularly Professor Friedhelm Göltenboth from the NLI organization, Professor Bao Huy and SPERI Founder, Tran Thi Lanh.

PROFESSOR FRIEDHELM GOELTENBOTH



The Pilot Empirical Research for estimating the Carbon Stock in Above Ground Biomass of the Tropical Rainforest in the area of the Human Ecology Practice Area (HEPA) in North-Central Vietnam unfolds, in a unique way, the research findings on 87 pages with an additional 31 pages of key remarks and annexes.

According to the Sustainable Forest Management Plan 2021-2031 of CHESH the forested area of 310,7 ha, composed of 179,4 ha of so-called protected forest and 131,3 ha of so-called production forest, is part of the efforts of CHESH to preserve the integrity of the forest ecosystem since 2002. This means the economic viability and the environmental sustainability have been. In a very impressive way, seven very important factors are combined: Forest and ecological management, biodiversity conservation, forest fire prevention and control, prevention of harmful organisms, silviculture measurements and special forest developments, scientific research, practical training, curriculum development and implementation.

The integration of traditional knowledge with cultural heritage in all modern conservation methods and the dynamics of an important watershed underlines the holistic strategies applied. The comparison of four methods to calculate the biomass and C-stock of the forested area revealed as a result of a C-stock of 42,475.8 t in July 2024 and therefore the CO_2 equivalent can be given with 155,886.19 t for the HEPA forested areas.

DR. KEITH BARBER

This publication of Pilot Empirical Research provides not only a model for the estimation of carbon stocks in the above-ground biomass of tropical rainforests in North-Central Vietnam but also a model of rainforest co-governance - an inclusive approach that ensures that forest management is informed by multiple perspectives and addresses the needs of all stakeholders. It is also a wonderful example of participatory research involving indigenous farmers, professional scientists and civil society organizations, integrating local indigenous knowledge with the latest scientific techniques to demonstrate an effective way forward in addressing one of the major problems facing the world today - climate change caused by excessive greenhouse gas emissions.

Dr Keith Barber - A Social Anthropologist, from the University of Waikato who has been engaging in the social, cultural, ecological, and livelihood impacts of industrial agriculture on indigenous ethnic minority communities in Southeast East Asia over 10 years from 2007-2019.

MSC. KEES DE RUITER

Since 2002, ICCO has provided support to HEPA, transforming a once-exhausted forest landscape into a thriving centre for carbon restoration. With ICCO's backing, HEPA has been able to pioneer ecological restoration practices, breathing new life into the degraded forest ecosystems of North-Central Vietnam. This area, which was once severely impacted by deforestation and over-exploitation, has now emerged as a focal point for sustainable forest management and biodiversity conservation. Through its "Nurturing Nature" philosophy, HEPA has integrated local traditional knowledge with modern ecological practices, ensuring the forest's regeneration aligns with natural rhythms.

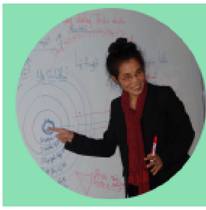
HEPA's work has not only restored the biodiversity of the area but also positioned it as a significant player in global climate change efforts. The 310,7 hectares of forest now sequester a substantial amount of carbon, playing a vital role in mitigating greenhouse gas emissions. HEPA's success in transforming the land into a carbon-rich ecosystem has earned it the title of a "Princess of Carbon Restoration," symbolizing its critical contribution to climate resilience. This transformation was made possible through ICCO's financial and strategic support, highlighting the powerful impact of long-term partnerships in environmental restoration efforts.

Mr Kees de Ruiter holds a 1985-1991 IR in Tropical Engineering at Wageningen University & Research 1985-1991. He worked for ICCO from 1995 as Field Representative in Vietnam focus on Indigenous Community's Wisdom and Knowledge-Based Poverty Alleviation (1995-1999); Coordinator of Community Based Organizational

& Institutional Approach toward Livelihood Security, South East Asia (2002-2007); Learning facilitator Democracy and Peace (2008-2009); Regional manager South East Asia on Rights Based Approach Community Small Scale Business Capacity Building & Development (2009- 2019); Head of Strategy and Program Support (2019 to 2021), and is now Director program unit, for Cordaid-ICCO (2021-now). In 2002, Kees de Ruiter was instrumental in arranging long-term funding for the development of HEPA as a forest restoration and preservation site and Eco-Farming School.

DR. JOHN QUAYLE BVSC. LLB.

The combination of traditional beliefs and knowledge with adequate methodologies to calculate the respective carbon stored in this area and the presentation of these findings in accordance with the legal framework of Vietnam makes this publication a very valuable contribution to both biodiversity protection and climate change mitigation. The method of estimating carbon stock in biomass of tropical rainforests is very important. Having been closely associated with SPERI for many years and I have seen their dedication to project development and accurate information recording. As a recent international observer at HEPA, I was able see first-hand on location as SPERI undertook these recent carbon stock calculations in the rainforests of HEPA. Their attention to detail in recording information collected by the onsite teams in the HEPA rainforest and then the computer calculations done by the SPERI team to determine the carbon stock was done with care and caution. These carbon credits calculated at HEPA will provide a valuable source to offset carbon for any company wishing to mitigate their carbon footprint.



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HUMAN ECOLOGY APPROACH IN LAND USE FARMING ON SLOPPING LAND, BUFFER ZONE OF BA VI NATIONAL PARK
(1992 - 1997)
Vice PhD - Hanoi university

SHIFT UP TO PhD *(1997 - 1998)*
Academic Reforming Policy in Vietnam

LANGUAGES

Vietnamese (Mother tongue)
French (Fluent speaking & writing)
English (Fluent speaking & writing)

INTELLECTUAL & LEGAL RESPONSIBILITY

TOWARD ETHNIC WOMEN - TEW
Founder (1994)
Focus on Women's Wisdom & Endogenous Energy in empowering their traditional organization and institution in development; connecting women in different identities and locality for enriching their local customs law and knowledge in practicing their traditional land use farming in order to sustaining their Ecological Livelihood Identity and Wellbeing.

CENTER FOR HUMAN ECOLOGY STUDY OF HIGHLAND - CHESH
Founder (1999)
Focus on Community Landscape of "3R" (Rừng - Rẫy - Ruộng) in Agro-Ecology in the Mekong region.

CENTER FOR INDIGENOUS KNOWLEDGE RESEARCH & DEVELOPMENT-CIRD
Founder (2000)
Comparative Research Analysis of customary law and state law in Watershed Forestland Co-Governance in the Mekong region.

SOCIAL POLITICAL ECOLOGY RESEARCH INSTITUTE - SPERI
Founder (2006)
Interdependence between social, political, ecological capital research analysis in development in the Mekong region.

CONSULTANT ON DEVELOPMENT INSTITUTE - CODE
Founder (2007)
Transparency and justice in extractive industry management concerning ecological livelihoods identity, community solidarity economics, and watershed rain-forest co-governance in the Mekong region.

COMMUNITY ENTERPREUNER DEVELOPMENT INSTITUTE - CENDI
Founder (2015)
Focus on community leadership networking toward agro-ecology enterprise and niche markets in the Mekong region

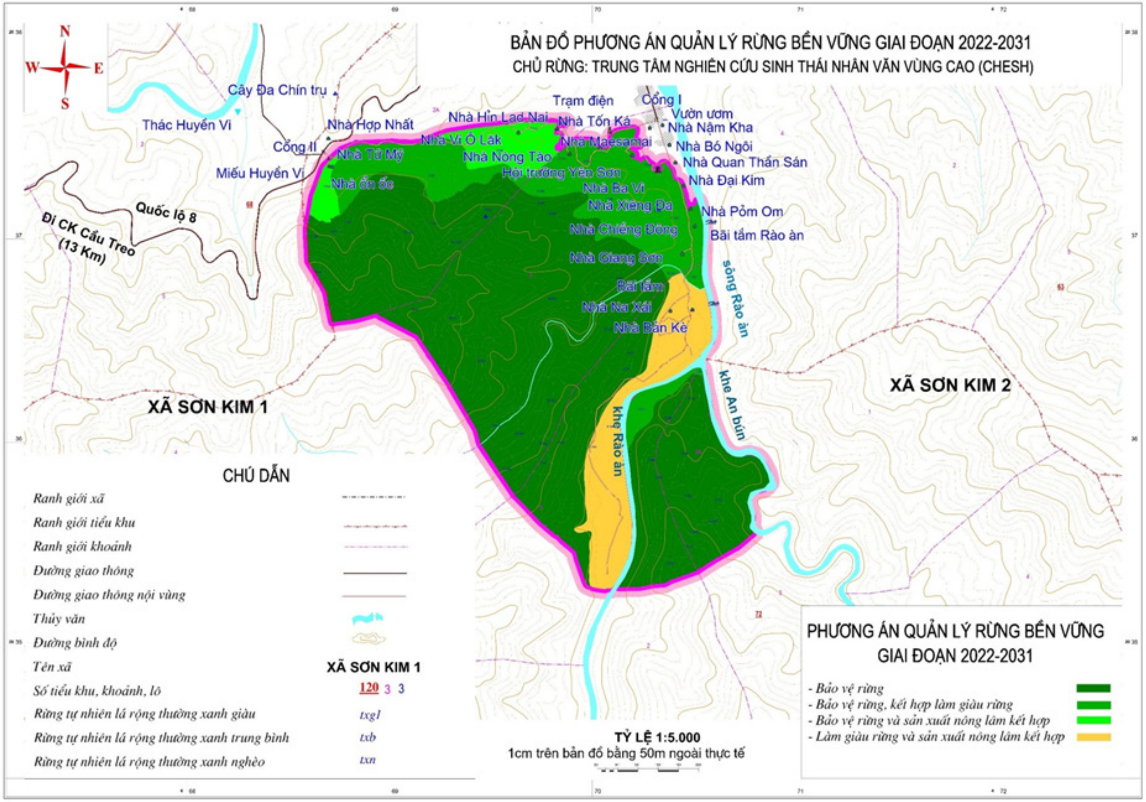
CONCERN

Indigenous Customary Law Based Watershed Rainforest Co-Governance and Endogenous Capacity of IP[1] for Community Solidarity Economy and Self-determination toward C02justice and Biodiversity Enrichment in Mekong Region.

[1] Indigenous People

ANNEXE

ANNEX 1. MAP OF HEPA'S SUSTAINABLE FOREST MANAGEMENT PLAN 2022-2031



ANNEX 2: LOCATION OF EACH STANDARD PLOT AND DETAILED COORDINATES (PROJECTION VN2000)

*Note: Enrichment zone (EZ); Spiritual zone (SZ); Mountain foot (MF); Mountain slope (MS); Mountain peak (MP)

No	Date of measurement	Standard plot	Coordinate x (center)	Coordinate y (center)	Elevation (m ASL)	x1	y1	x2	y2	x3	y3	x4	y4	Functional zoning	Position	Direction of plot
1	2023-12-12	H1	470371	2037309	79	470365	2037299	470352	2037318	470366	2037333	470376	2037323	EZ	MF	East
2	2023-12-13	H2	470322	2037148	153	470326	2037131	470311	2037125	470308	2037144	470323	2037149	SZ	MS	East
3	2023-12-13	H3	470302	2037059	164	470288	2037062	470308	2037053	470316	2037059	470299	2037082	EZ	MP	Multi-Direction
4	2023-12-15	H4	470430	2037043	94	470436	2037051	470444	2037034	470438	2037032	470420	2037053	EZ	MF	East
5	2023-12-16	H5	470293	2036889	117	470288	2036899	470301	2036898	470292	2036877	470277	2036883	EZ	MF	South
6	2023-12-16	H6	470249	2036921	154	470243	2036915	470250	2036940	470268	2036941	470257	2036912	EZ	MS	East
7	2023-12-18	H7	470115	2037304	119	470097	2037307	470111	2037287	470125	2037310	470120	2037318	EZ	MS	North
8	2023-12-18	H8	470270	2037479	89	470275	2037497	470290	2037496	470279	2037476	470265	2037475	EZ	MS	North
9	2023-12-21	H9	470115	2036939	164	470115	2036930	470106	2036942	470125	2036949	470132	2036934	SZ	MS	Multi-Direction
10	2023-12-21	H10	470170	2036810	116	470180	2036823	470194	2036807	470161	2036827	470171	2036817	EZ	MF	North
11	2023-12-22	H11	470039	2037255	159	470036	2037244	470049	2037227	470059	2037246	470047	2037257	SZ	MS	North
12	2023-12-22	H12	470186	2037182	122	470180	2037190	470199	2037190	470192	2037163	470179	2037170	SZ	MF	North

No	Date of measurement	Standard plot	Coordinate x (center)	Coordinate y (center)	Elevation (m ASL)	x1	y1	x2	y2	x3	y3	x4	y4	Functional zoning	Position	Direction of plot
13	2023-12-23	H13	469921	2037275	110	469915	2037277	469932	2037287	469941	2037272	469921	2037267	SZ	MS	North
14	2023-12-25	H14	469917	2037181	163	469922	2037190	469928	2037171	469907	2037170	469898	2037183	SZ	MP	Multi-direction
15	2023-12-25	H15	469954	2037086	225	469939	2037078	469957	2037075	469962	2037097	469939	2037093	SZ	MP	Multi-direction
16	2023-12-26	H16	470087	2037099	130	470099	2037083	470097	2037104	470074	2037115	470076	2037096	SZ	MP	Multi-Direction
17	2023-12-26	H17	470090	2037055	153	470098	2037054	470071	2037047	470068	2037030	470096	2037048	EZ	MS	East
18	2023-12-26	H18	470040	2036876	188	470047	2036889	470051	2036876	470029	2036872	470026	2036888	SZ	MS	South
19	2023-12-27	H19	469971	2036719	163	469979	2036728	469966	2036732	469961	2036713	469970	2036718	EZ	MS	South
20	2023-12-27	H20	470036	2036693	82	470040	2036695	470030	2036685	470027	2036695	470042	2036709	EZ	MF	South
21	2023-12-28	H21	469895	2037386	86	469905	2037396	469885	2037395	469883	2037381	469905	2037379	EZ	MF	North
22	2024-04-06	H25	470022	2037402	99	470033	2037417	470017	2037410	470016	2037400	470037	2037400	EZ	MF	North
23	2024-04-07	H26	469538	2037584	100	469550	2037592	469527	2037598	469529	2037581	469553	2037580	EZ	MF	North
24	2024-04-07	H27	469532	2037445	114	469546	2037449	469525	2037439	469533	2037422	469543	2037443	EZ	MS	North
25	2024-04-08	H28	469554	2037220	195	469561	2037222	469543	2037234	469541	2037206	469566	2037210	SZ	MS	North
26	2024-04-08	H29	469546	2037354	141	469542	2037358	469531	2037340	469552	2037340	469558	2037363	SZ	MS	North
27	2024-04-07	D1	470357	2036438	92	470347	2036451	470371	2036445	470366	2036425	470342	2036432	EZ	MS	East

No	Date of measurement	Stan-dard plot	Coor dinate x (center)	Coordinate y (center)	Elevation (m ASL)	x1	y1	x2	y2	x3	y3	x4	y4	Func-tional zoning	Position	Direction of plot
28	2024-04-07	D2	470338	2036040	104	470327	2036052	470352	2036048	470349	2036028	470324	2036033	SZ	MS	North
29	2024-04-07	D3	470410	2035634	210	470399	2035645	470424	2035643	470422	2035623	470397	2035625	SZ	MP	Multi-direction
30	2024-04-08	D4	469794	2035980	233	469803	2035993	469805	2035968	469785	2035967	469783	2035992	SZ	MP	Multi-direction
31	2024-04-08	D5	469998	2036269	203	469994	2036284	470012	2036277	470003	2036253	469984	2036261	SZ	MP	Multi-direction
32	2024-04-08	D6	470049	2036426	198	470046	2036442	470064	2036432	470052	2036410	470034	2036420	SZ	MS	North
33	2024-04-08	D7	469778	2036784	223	469788	2036797	469788	2036772	469768	2036772	469768	2036797	SZ	MS	North
34	2024-04-08	D8	470160	2037140	137	470173	2037151	470173	2037131	470148	2037130	470148	2037150	SZ	MS	North
35	2024-04-09	D9	469324	2036943	296	469330	2036958	469340	2036940	469317	2036928	469308	2036946	SZ	MS	North
36	2024-04-09	D10	468872	2036929	395	468872	2036945	468888	2036933	468873	2036913	468857	2036925	SZ	MS	North
37	2024-04-09	D11	469360	2037411	134	469369	2037425	469375	2037406	469351	2037398	469345	2037417	EZ	MS	North

ANNEX 3: HOW TO CALCULATE IVI (IMPORTANT VALUE INDEX)

The IVI of each species is determined by the following formula:

IVI = RD + RF + RBA, (Mishra, 1968)

Where:

Relative Density (RD)

$$RD(\%) = \frac{\text{Denstity (D) of the study species}}{\text{Total density ofall species}} \text{ x } 100$$

Density of a study species (D)

$$D = \frac{\text{Total individual ofa study species occur in all study quadrats}}{\text{Total study quadrats}}$$

Relative Frequency (RF) (%)

$$RF(\%) = \frac{\text{Frequency (F)ofoccurence of a study species}}{\text{Total frequency of occurence of all species}} \text{ x } 100$$

Frequency F

$$F = \frac{\text{Number of quadrats wich species occurence}}{\text{Total study quardrats}}$$

Relative Basal Area (RBA) (%)

$$RBA(\%) = \frac{\text{Basal area (BA) of species}}{\text{Total basal area of all species}} \text{ x } 100$$

Basal area (BA) (m^3)

$$BA = \frac{3.14 * (\text{diameter})^2}{4 * 10000}$$

ANNEX 4: LATIN NAMES OF TREES AND OTHER SCIENTIFIC DETAILS OF TREES, WOOD DENSITY

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
1	Bái bái	Not specified yet	Acronychia	Rutaceae	N/A
2	Ba bét	Mallotus paniculatus (Lam.) Müll. Arg.	Mallotus	Euphorbiaceae	0.42
3	Bưởi bung	Not specified yet	Acronychia	Rutaceae	N/A
4	Bộp bù	Not specified yet	Ficus	Moraceae	0.36
5	Bình linh	Not specified yet	Vitex	Lamiaceae	0.8
6	Bời lời	Not specified yet	Litsea	Lauraceae	0.56
7	Bộp	Ficus Championi	Ficus	Moraceae	0.89
8	Ba soi	Macaranga denticulata Muell. - Arg.	Macaranga	Euphorbiaceae	N/A
9	Bứa	Garcinia oblongifolia Champ. ex Benth., 1851	Garcinia	Clusiaceae	0.685
10	Cây chua	Not specified yet	Not specified yet	Not specified yet	N/A
11	Chân chim	Vitex parviflora Juss	Vitex	Lamiaceae	0.7
12	Cà ganh (Mã Liêng)	Not specified yet	Not specified yet	Not specified yet	N/A

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
13	Chay	Not specified yet	Artocarpus	Moraceae	N/A
14	Chẩn	Not specified yet	Microdesmis	Pandaceae	N/A
15	Chẹo	Not specified yet	Engelhardtia	Juglandaceae	0.68
16	Chènh chènh	Cinamomum burmannii (Nees et T. Neess) Blume, 1826	Cinamomum	Lauraceae	N/A
17	Chua ke	Not specified yet	Microcos	Tiliaceae	N/A
18	Chua lụy	Not specified yet	Not specified yet	Meliaceae	N/A
19	Chẹo trắng	Not specified yet	Engelhardtia	Juglandaceae	0.68
20	Chua	Not specified yet	Chukrasia	Meliaceae	N/A
21	Chua khét	Not specified yet	Chukrasia	Meliaceae	N/A
22	Cà Lằng (Mã Liêng)	Not specified yet	Not specified yet	Not specified yet	N/A
23	Cồng sữa	Not specified yet	Castanopsis	Fabaceae	0.48
24	Cóc	Not specified yet	Not specified yet	Not specified yet	0.38
25	Cồng	Castanopsis cerebrina (Hick. et A. Camus) Barnett, 1944	Castanopsis	Fabaceae	0.77
26	Cà ổi	Not specified yet	Castanopsis	Fabaceae	0.68

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
27	Côm	Elaeocarpus griffithii A. Gray	Elaeocarpus	Elaeocarpaceae	0.55
28	Cỏ sữa	Not specified yet	Not specified yet	Not specified yet	N/A
29	Cu thìa	Not specified yet	Not specified yet	Not specified yet	N/A
30	Cu vẹ	Not specified yet	Not specified yet	Not specified yet	N/A
31	Da bò	Not specified yet	Not specified yet	Not specified yet	N/A
32	Đái bò	Not specified yet	Archidendron	Fabaceae	N/A
33	Dâu da	Not specified yet	Baccaurea	Euphorbiaceae	N/A
34	Đá deng	Not specified yet	Not specified yet	Not specified yet	N/A
35	Đung	Not specified yet	Not specified yet	Not specified yet	N/A
36	Dành dành	Not specified yet	Not specified yet	Not specified yet	N/A
37	Đung dung	Not specified yet	Not specified yet	Not specified yet	N/A
38	Dẻ đỏ	Lithocarpus ducampii (Hickel & A. Camus) A. Camus	Lithocarpus	Fagaceae	0.84
39	Dè	Not specified yet	Cinamomum	Lauraceae	N/A
40	De gừng	Not specified yet	Cinamomum	Lauraceae	N/A
41	Dẻ bộp	Castanopsis lecomtei Hickel & Camus	Castanopsis	Fagaceae	0.89

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
42	Dẻ	Not specified yet	Not specified yet	Fagaceae	0.84
43	De tanh	Not specified yet	Cinamomum	Lauraceae	0.484
44	De vàng	Not specified yet	Cinamomum	Lauraceae	0.484
45	De	Not specified yet	Cinamomum	Lauraceae	N/A
46	Đinh	Not specified yet	Markhamia	Bignoniaceae	N/A
47	Giổi đá	Not specified yet	Michelia	Magnoliaceae	0.63
48	Giổi	Michelia gioi (A. Chev.) Sima & H. Yu	Michelia	Alismataceae	0.62
49	Giổi mít	Not specified yet	Michelia	Magnoliaceae	0.63
50	Dè ổ sâu	Not specified yet	Cinamomum	Lauraceae	N/A
51	Đập tru	Not specified yet	Not specified yet	Not specified yet	N/A
52	Dung dá	Not specified yet	Symplocos	Symplocaceae	N/A
53	Dung	Not specified yet	Symplocos	Symplocaceae	0.59
54	Ô đước	Not specified yet	Lindera	Lauraceae	N/A
55	Gác	Aphanamixis grandiflora Blume	Aphanamixis	Meliaceae	0.73
56	Gắng	Not specified yet	Not specified yet	Not specified yet	N/A
57	Gác hương	Not specified yet	Aphanamixis	Meliaceae	N/A

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
58	Gáo	Neolamareka cadamba (Roxb.) Bosser, 1984	Neolamareka	Rubiaceae	0.63
59	Giang máu	Not specified yet	Not specified yet	Not specified yet	0.46
60	Hiên	Not specified yet	Not specified yet	Not specified yet	N/A
61	Hoàng linh	Peltophorum pterocarpum (DC.) Backer ex K. Heyne	Peltophorum	Fabaceae	0.74
62	Kháo	Not specified yet	Cinnadenia	Lauraceae	0.71
63	Khế rừng	Not specified yet	Averrhoa	Oxalidaceae	0.46
64	Khôi	Not specified yet	Not specified yet	Not specified yet	N/A
65	Kiền kiền	Not specified yet	Hopea pierrei Hance	Dipterocarpaceae	0.68
66	Lèo heo	Not specified yet	Not specified yet	Not specified yet	N/A
67	Lim xanh	Erythrophleum fordii Oliv.	Erythrophleum	Fabaceae	0.93
68	Lành ngạnh	Cratoxylon cochinchinensis (Lour.) Blume	Cratoxylon	Hypericaceae	0.88
69	Lóc nác	Not specified yet	Not specified yet	Not specified yet	N/A
70	Máng chèo	Not specified yet	Not specified yet	Not specified yet	N/A
71	Máu chó	Knema conferta (King) Warb.	Knema	Myristicaceae	0.691

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
72	Mặt cắt	Not specified yet	Not specified yet	Not specified yet	N/A
73	Mán đỉa	Archidendron clypearia (Jack) I.C.Nielsen	Archidendron	Fabaceae	N/A
74	Mít rừng	Not specified yet	Artocarpus	Moraceae	0.46
75	Mòi	Not specified yet	Not specified yet	Not specified yet	N/A
76	Giổi mỡ	Manglietia conifera Dandy, 1930	Manglietia	Magnoliaceae	0.6
77	Màng tang	Litsea cubeba (Lour.) Pers., 1807	Litsea	Lauraceae	0.64
78	Mức	Wrightia annamensis Eberh. & Dubard	Wrightia	Apocynaceae	0.47
79	Nang	Alangium ridleyi King	Alangium	Alangiaceae	0.57
80	Nâu	Not specified yet	Not specified yet	Not specified yet	N/A
81	Nóc chuối	Not specified yet	Not specified yet	Not specified yet	N/A
82	Nang cui	Not specified yet	Not specified yet	Not specified yet	N/A
83	Ngát	Gironniera subaequalis Planch.	Gironniera	Cannabaceae	N/A
84	Ngát vàng	Not specified yet	Gironniera	Cannabaceae	N/A
85	Nhíu	Not specified yet	Not specified yet	Not specified yet	N/A

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
86	Núc nác	Oroxylum indicum (L.) Kurz	Oroxylum	Bignoniaceae	0.46
87	Nhọ nghệ	Not specified yet	Diospyros	Ebenaceae	N/A
88	Nhọ nồi	Not specified yet	Diospyros	Ebenaceae	N/A
89	Nu	Not specified yet	Not specified yet	Not specified yet	N/A
90	Re hương	Cinnamomum parthenoxylum (Jack) Meisn.	Cinnamomum	Lauraceae	0.69
91	Ràng ràng	Not specified yet	Ormosia	Fabaceae	0.61
92	Ràng ràng mít	Ormosia balansae Drake	Ormosia	Fabaceae	0.61
93	Ràng ràng mỡ	Not specified yet	Ormosia	Fabaceae	N/A
94	Sâm cau trắng	Not specified yet	Not specified yet	Hypoxidaceae	N/A
95	Sến	Not specified yet	Shorea	Dipterocarpaceae	N/A
96	Sang mòi	Not specified yet	Not specified yet	Not specified yet	N/A
97	Sang mây	Stelechocarpus cauliflorus (Scheff.) J. Sincl.	Stelechocarpus	Annonaceae	N/A
98	Sung nước	Not specified yet	Ficus	Moraceae	N/A

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
99	Sông	Garcinia cochinchinensis (Lour.) Choisy, 1824	Garcinia	Guttiferae	N/A
100	SP	Not specified yet	Not specified yet	Not specified yet	0.46
101	Sang quýt	Not specified yet	Not specified yet	Not specified yet	N/A
102	Sồi trắng	Not specified yet	Not specified yet	Fagaceae	N/A
103	Sung	Ficus racemosa L.	Ficus	Moraceae	0.35
104	Săng vải	Not specified yet	Not specified yet	Not specified yet	N/A
105	Táu	Not specified yet	Vatica	Dipterocarpaceae	0.99
106	Thôi thôi	Alangium platanifolium Harms.	Alangium	Alangiaceae	N/A
107	Thắt chuột	Not specified yet	Not specified yet	Not specified yet	0.46
108	Tện	Not specified yet	Not specified yet	Not specified yet	N/A
109	Thị	Not specified yet	Not specified yet	Ebenaceae	0.83
110	Thuột luột	Not specified yet	Not specified yet	Not specified yet	N/A
111	Tai mang	Not specified yet	Not specified yet	Not specified yet	N/A
112	Thòi mòi	Not specified yet	Not specified yet	Not specified yet	N/A
113	Trường	Not specified yet	Paviesia	Sapindaceae	0.81

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
114	Trường mật	Paviesia anamonsis	Paviesia	Sapindaceae	N/A
115	Trường nước	Not specified yet	Paviesia	Sapindaceae	0.85
116	Trồi	Not specified yet	Not specified yet	Not specified yet	N/A
117	Trai mang	Not specified yet	Not specified yet	Not specified yet	N/A
118	Trám đen	Canarium pimela Leenh., 1959	Canarium	Burseraceae	0.76
119	Trện	Not specified yet	Not specified yet	Not specified yet	N/A
120	Tròi	Not specified yet	Not specified yet	Not specified yet	N/A
121	Trâm trắng	Not specified yet	Syzygium	Myrtaceae	0.73
122	Trín	Schima wallichii Choisy	Schima	Theaceae	0.61
123	Trám	Not specified yet	Canarium	Burseraceae	0.76
124	Trâm đỏ	Not specified yet	Not specified yet	Not specified yet	0.46
125	Trâm	Syzygium cinereum	Syzygium	Myrtaceae	0.73
126	Trẩu	Vernicia montana Lour.	Vernicia	Euphorbiaceae	0.42
127	Trám trắng	Canarium album (Lour.) Raeusch.	Canarium	Burseraceae	0.61
128	Tâm thối	Not specified yet	Not specified yet	Not specified yet	N/A
129	Trâm trện	Not specified yet	Syzygium	Myrtaceae	N/A

No	Local name	Latin name	Genus	Family	WD (VN Standard 12619-2-2019)
130	Vạng	Endospermum chinense Benth.	Endospermum	Euphorbiaceae	0.5
131	Vàng mẹ	Not specified yet	Not specified yet	Not specified yet	N/A
132	Vú bò	Ficus heterophyllus L.,	Ficus	Moraceae	N/A
133	Vàng giành	Not specified yet	Not specified yet	Not specified yet	0.46
134	Vàng tâm	Manglietia fordiana Oliv.	Manglietia	Magnoliaceae	0.631
135	Vừ	Not specified yet	Not specified yet	Not specified yet	N/A
136	Xương cá	Canthium didynum Roxb	Canthium	Rubiaceae	0.42
137	Xoan đào	Prunus arborea (Blume) Kalkman	Prunus	Rosaceae	0.57
138	Xám xám	Not specified yet	Not specified yet	Not specified yet	N/A

ANNEX 5: LIST OF MEMBERS PARTICIPATING IN MEASUREMENT IN EACH STANDARD PLOT

No	Standard plot	Member	Team leader	Note taker
1	H1	Nguyễn Thành Trung	x	
2	H1	Trần Đình Khánh		x
3	H1	Nguyễn Mỹ Linh		x
4	H1	Viêng Phết		
5	H1	Lê Văn Ka		
6	H1	Nguyễn Đức Sự		
7	H1	Hoàng Văn Đước		
8	H1	Đặng Như Băng		
9	H1	Hồ Văn Huệ		
10	H1	Lộc Văn Vìn		
11	H2	Nguyễn Thành Trung	x	
12	H2	Trần Đình Khánh		x
13	H2	Nguyễn Mỹ Linh		x
14	H2	Viêng Phết		
15	H2	Lê Văn Ka		
16	H2	Nguyễn Đức Sự		
17	H2	Hoàng Văn Đước		
18	H2	Đặng Như Băng		
19	H2	Hồ Văn Huệ		
20	H2	Lộc Văn Vìn		
21	H3	Nguyễn Thành Trung	x	
22	H3	Trần Đình Khánh		x
23	H3	Nguyễn Mỹ Linh		x
24	H3	Viêng Phết		
25	H3	Lê Văn Ka		
26	H3	Nguyễn Đức Sự		
27	H3	Hoàng Văn Đước		
28	H3	Đặng Như Băng		
29	H3	Hồ Văn Huệ		
30	H3	Lộc Văn Vìn		

No	Standard plot	Member	Team leader	Note taker
31	H4	Nguyễn Thành Trung	x	
32	H4	Trần Đình Khánh		x
33	H4	Nguyễn Mỹ Linh		x
34	H4	Viêng Phết		
35	H4	Lê Văn Ka		
36	H4	Nguyễn Đức Sự		
37	H4	Hoàng Văn Đước		
38	H4	Đặng Như Băng		
39	H4	Hồ Văn Huệ		
40	H4	Lộc Văn Vìn		
41	H5	Hoàng Văn Đước	x	
42	H5	Trần Đình Khánh		x
43	H5	Đặng Như Băng		x
44	H5	Viêng Phết		
45	H5	Nguyễn Đức Sự		
46	H5	Hồ Văn Huệ		
47	H5	Lộc Văn Vìn		
48	H6	Hoàng Văn Đước	x	
49	H6	Trần Đình Khánh		x
50	H6	Đặng Như Băng		x
51	H6	Viêng Phết		
52	H6	Nguyễn Đức Sự		
53	H6	Hồ Văn Huệ		
54	H6	Lộc Văn Vìn		
55	H7	Hoàng Văn Đước	x	
56	H7	Trần Đình Khánh		x
57	H7	Đặng Như Băng		x
58	H7	Viêng Phết		
59	H7	Lê Văn Ka		
60	H7	Nguyễn Đức Sự		
61	H7	Hồ Văn Huệ		
62	H7	Lộc Văn Vìn		

No	Standard plot	Member	Team leader	Note taker
63	H7	Nghiêm Minh Lương		
64	H8	Hoàng Văn Đước	x	
65	H8	Trần Đình Khánh		x
66	H8	Đặng Như Băng		x
67	H8	Viêng Phết		
68	H8	Lê Văn Ka		
69	H8	Nguyễn Đức Sự		
70	H8	Hồ Văn Huệ		
71	H8	Lộc Văn Vìn		
72	H8	Nghiêm Minh Lương		
73	H9	Nguyễn Thành Trung	x	
74	H9	Trần Đình Khánh		x
75	H9	Nguyễn Mỹ Linh		x
76	H9	Viêng Phết		
77	H9	Lê Văn Ka		
78	H9	Nguyễn Đức Sự		
79	H9	Hoàng Văn Đước		
80	H9	Đặng Như Băng		
81	H9	Hồ Văn Huệ		
82	H9	Lộc Văn Vìn		
83	H10	Nguyễn Thành Trung	x	
84	H10	Trần Đình Khánh		x
85	H10	Nguyễn Mỹ Linh		x
86	H10	Viêng Phết		
87	H10	Lê Văn Ka		
88	H10	Nguyễn Đức Sự		
89	H10	Hoàng Văn Đước		
90	H10	Đặng Như Băng		
91	H10	Hồ Văn Huệ		
92	H10	Lộc Văn Vìn		
93	H11	Nguyễn Thành Trung	x	
94	H11	Trần Đình Khánh		x

No	Standard plot	Member	Team leader	Note taker
95	H11	Nguyễn Mỹ Linh		x
96	H11	Viêng Phết		
97	H11	Nguyễn Đức Sự		
98	H11	Hoàng Văn Đước		
99	H11	Đặng Như Băng		
100	H11	Hồ Văn Huệ		
101	H11	Lộc Văn Vìn		
102	H12	Nguyễn Thành Trung	x	
103	H12	Trần Đình Khánh		x
104	H12	Nguyễn Mỹ Linh		x
105	H12	Viêng Phết		
106	H12	Nguyễn Đức Sự		
107	H12	Hoàng Văn Đước		
108	H12	Đặng Như Băng		
109	H12	Hồ Văn Huệ		
110	H12	Lộc Văn Vìn		
111	H13	Nguyễn Thành Trung	x	
112	H13	Trần Đình Khánh		x
113	H13	Nguyễn Mỹ Linh		x
114	H13	Viêng Phết		
115	H13	Nguyễn Đức Sự		
116	H13	Hoàng Văn Đước		
117	H13	Đặng Như Băng		
118	H13	Hồ Văn Huệ		
119	H13	Lộc Văn Vìn		
120	H14	Nguyễn Thành Trung	x	
121	H14	Trần Đình Khánh		x
122	H14	Nguyễn Mỹ Linh		x
123	H14	Viêng Phết		
124	H14	Nguyễn Đức Sự		
125	H14	Hoàng Văn Đước		
126	H14	Đặng Như Băng		

No	Standard plot	Member	Team leader	Note taker
127	H14	Hồ Văn Huệ		
128	H14	Lộc Văn Vìn		
129	H15	Nguyễn Thành Trung	x	
130	H15	Trần Đình Khánh		x
131	H15	Nguyễn Mỹ Linh		x
132	H15	Viêng Phết		
133	H15	Lê Văn Ka		
134	H15	Nguyễn Đức Sự		
135	H15	Hoàng Văn Đước		
136	H15	Đặng Như Băng		
137	H15	Hồ Văn Huệ		
138	H15	Lộc Văn Vìn		
139	H16	Nguyễn Thành Trung	x	
140	H16	Trần Đình Khánh		x
141	H16	Nguyễn Mỹ Linh		x
142	H16	Viêng Phết		
143	H16	Lê Văn Ka		
144	H16	Nguyễn Đức Sự		
145	H16	Hoàng Văn Đước		
146	H16	Đặng Như Băng		
147	H16	Hồ Văn Huệ		
148	H16	Lộc Văn Vìn		
149	H17	Nguyễn Thành Trung	x	
150	H17	Trần Đình Khánh		x
151	H17	Nguyễn Mỹ Linh		x
152	H17	Viêng Phết		
153	H17	Lê Văn Ka		
154	H17	Nguyễn Đức Sự		
155	H17	Hoàng Văn Đước		
156	H17	Đặng Như Băng		
157	H17	Hồ Văn Huệ		
158	H17	Lộc Văn Vìn		

No	Standard plot	Member	Team leader	Note taker
159	H18	Nguyễn Thành Trung	x	
160	H18	Trần Đình Khánh		x
161	H18	Nguyễn Mỹ Linh		x
162	H18	Viêng Phết		
163	H18	Lê Văn Ka		
164	H18	Nguyễn Đức Sự		
165	H18	Hoàng Văn Đước		
166	H18	Đặng Như Băng		
167	H18	Hồ Văn Huệ		
168	H18	Lộc Văn Vìn		
169	H19	Nguyễn Thành Trung	x	
170	H19	Trần Đình Khánh		x
171	H19	Nguyễn Mỹ Linh		x
172	H19	Viêng Phết		
173	H19	Nguyễn Đức Sự		
174	H19	Hoàng Văn Đước		
175	H19	Đặng Như Băng		
176	H19	Hồ Văn Huệ		
177	H19	Lộc Văn Vìn		
178	H20	Nguyễn Thành Trung	x	
179	H20	Trần Đình Khánh		x
180	H20	Nguyễn Mỹ Linh		x
181	H20	Viêng Phết		
182	H20	Nguyễn Đức Sự		
183	H20	Hoàng Văn Đước		
184	H20	Đặng Như Băng		
185	H20	Hồ Văn Huệ		
186	H20	Lộc Văn Vìn		
187	H21	Nguyễn Thành Trung	x	
188	H21	Trần Đình Khánh		x
189	H21	Nguyễn Mỹ Linh		x
190	H21	Viêng Phết		

No	Standard plot	Member	Team leader	Note taker
191	H21	Lê Văn Ka		
192	H21	Nguyễn Đức Sự		
193	H21	Hoàng Văn Đước		
194	H21	Đặng Như Băng		
195	H21	Hồ Văn Huệ		
196	H21	Lộc Văn Vìn		
197	H25	Nguyễn Thành Trung	x	
198	H25	Trần Đình Khánh		x
200	H25	Lê Văn Ka		
201	H25	Nghiêm Minh Lương		
202	H25	Hồ Văn Huệ		
203	H25	Trần Thị Đào		
204	H25	Cao Thị Thìu		
205	H25	Lộc Văn Vìn		
206	H25	Đặng Như Băng		
207	H25	Nguyễn Đức Sự		
208	H25	Võ Văn Thế		
209	H25	Nguyễn Tiến Hồ		
210	H25	Ngô Văn Hùng		
211	H25	Nguyễn Tiến Vương		
212	H26	Trần Đình Khánh	x	x
215	H26	Lê Văn Ka		
216	H26	Nghiêm Minh Lương		
217	H26	Hồ Văn Huệ		
218	H26	Trần Thị Đào		
219	H26	Cao Thị Thìu		
220	H26	Trần Văn Sơn		
221	H27	Trần Đình Khánh	x	x
224	H27	Lê Văn Ka		
225	H27	Nghiêm Minh Lương		
226	H27	Hồ Văn Huệ		
227	H27	Trần Thị Đào		

No	Standard plot	Member	Team leader	Note taker
228	H27	Cao Thị Thìu		
229	H27	Trần Văn Sơn		
230	H28	Trần Đình Khánh	x	x
233	H28	Lê Văn Ka		
234	H28	Nghiêm Minh Lương		
235	H28	Hồ Văn Huệ		
236	H28	Trần Thị Đào		
237	H28	Cao Thị Thìu		
238	H28	Trần Văn Sơn		
239	H29	Trần Đình Khánh	x	x
242	H29	Lê Văn Ka		
243	H29	Nghiêm Minh Lương		
244	H29	Hồ Văn Huệ		
245	H29	Trần Thị Đào		
246	H29	Cao Thị Thìu		
247	H29	Trần Văn Sơn		
248	D1	Trương Cao Hùng	x	
249	D1	Nguyễn Tiến Vương		x
250	D1	Nguyễn Minh Thụ		x
251	D1	Nguyễn Thành Trung		
252	D1	Ngô Văn Hùng		
253	D1	Trương Cao Hùng		
254	D1	Nguyễn Đức Sự		
255	D1	Nguyễn Tiến Hồ		
256	D1	Lộc Văn Vìn		
257	D2	Trương Cao Hùng	x	
258	D2	Nguyễn Tiến Vương		x
259	D2	Nguyễn Minh Thụ		x
260	D2	Nguyễn Thành Trung		
261	D2	Ngô Văn Hùng		
262	D2	Trương Cao Hùng		
263	D2	Nguyễn Đức Sự		

No	Standard plot	Member	Team leader	Note taker
264	D2	Nguyễn Tiến Hồ		
265	D2	Lộc Văn Vìn		
266	D3	Trương Cao Hùng	x	
267	D3	Nguyễn Tiến Vương		x
268	D3	Nguyễn Minh Thụ		x
269	D3	Nguyễn Thành Trung		
270	D3	Ngô Văn Hùng		
271	D3	Trương Cao Hùng		
272	D3	Nguyễn Đức Sự		
273	D3	Nguyễn Tiến Hồ		
274	D3	Lộc Văn Vìn		
275	D4	Trương Cao Hùng	x	
276	D4	Nguyễn Tiến Vương		x
277	D4	Nguyễn Minh Thụ		x
278	D4	Nguyễn Thành Trung		
279	D4	Ngô Văn Hùng		
280	D4	Trương Cao Hùng		
281	D4	Nguyễn Đức Sự		
282	D4	Nguyễn Tiến Hồ		
283	D4	Lộc Văn Vìn		
284	D5	Trương Cao Hùng	x	
285	D5	Nguyễn Tiến Vương		x
286	D5	Nguyễn Minh Thụ		x
287	D5	Nguyễn Thành Trung		
288	D5	Ngô Văn Hùng		
289	D5	Trương Cao Hùng		
290	D5	Nguyễn Đức Sự		
291	D5	Nguyễn Tiến Hồ		
292	D5	Lộc Văn Vìn		
293	D6	Trương Cao Hùng	x	
294	D6	Nguyễn Tiến Vương		x
295	D6	Nguyễn Minh Thụ		x

No	Standard plot	Member	Team leader	Note taker
296	D6	Nguyễn Thành Trung		
297	D6	Ngô Văn Hùng		
298	D6	Trương Cao Hùng		
299	D6	Nguyễn Đức Sự		
300	D6	Nguyễn Tiến Hồ		
301	D6	Lộc Văn Vìn		
302	D7	Trương Cao Hùng	x	
303	D7	Nguyễn Tiến Vương		x
304	D7	Nguyễn Minh Thụ		x
305	D7	Nguyễn Thành Trung		
306	D7	Ngô Văn Hùng		
307	D7	Trương Cao Hùng		
308	D7	Nguyễn Đức Sự		
309	D7	Nguyễn Tiến Hồ		
310	D7	Lộc Văn Vìn		
311	D8	Trương Cao Hùng	x	
312	D8	Nguyễn Tiến Vương		x
313	D8	Nguyễn Minh Thụ		x
314	D8	Nguyễn Thành Trung		
315	D8	Ngô Văn Hùng		
316	D8	Trương Cao Hùng		
317	D8	Nguyễn Đức Sự		
318	D8	Nguyễn Tiến Hồ		
319	D8	Lộc Văn Vìn		
320	D9	Trương Cao Hùng	x	
321	D9	Nguyễn Tiến Vương		x
322	D9	Nguyễn Minh Thụ		x
323	D9	Nguyễn Thành Trung		
324	D9	Ngô Văn Hùng		
325	D9	Trương Cao Hùng		
326	D9	Nguyễn Đức Sự		
327	D9	Nguyễn Tiến Hồ		

No	Standard plot	Member	Team leader	Note taker
328	D9	Lộc Văn Vìn		
329	D10	Trương Cao Hùng	x	
330	D10	Nguyễn Tiến Vương		x
331	D10	Nguyễn Minh Thụ		x
332	D10	Nguyễn Thành Trung		
333	D10	Ngô Văn Hùng		
334	D10	Trương Cao Hùng		
335	D10	Nguyễn Đức Sự		
336	D10	Nguyễn Tiến Hồ		
337	D10	Lộc Văn Vìn		
338	D11	Trương Cao Hùng	x	
339	D11	Nguyễn Tiến Vương		x
340	D11	Nguyễn Minh Thụ		x
341	D11	Nguyễn Thành Trung		
342	D11	Ngô Văn Hùng		
343	D11	Trương Cao Hùng		
344	D11	Nguyễn Đức Sự		
345	D11	Nguyễn Tiến Hồ		
346	D11	Lộc Văn Vìn		