Dynamics of plant and insect communities across shifting cultivation fallow in Arunachal Pradesh, Eastern Himalaya

by

Mencho Sena

Enrollment no: 50BB24A73023

Dissertation Thesis

Submitted to Academy of Scientific and Innovative Research

For the partial fulfilment for the degree

Master of Science

in

Wildlife Science

Under the supervision of

Amit Kumar, Scientist-E (Supervisor)
Ritesh K. Gautam, Scientist-C (Co-Supervisor)

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

AcSIR

July 2026

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

DECLARATION

I hereby declare that the work conducted under the thesis entitled *"Dynamics of plant and insect communities across shifting cultivation fallow in Arunachal Pradesh, Eastern Himalaya"* is a record of original and independent research work done by me and subsequently submitted for the award of the degree of Master's in Wildlife Science at the Academy of Scientific and Innovative Research. This research work has been carried out under the guidance and supervision of Dr. Amit Kumar, Scientist- E and co-supervision of Sh. Ritesh Kumar Gautam, Scientist- C of the Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

Mencho Sena

Enrollment no. 50BB24A73023

Place: Dehradun

Date: 17th July 2026

Dr. Amit Kumar
Supervisor

Sh. Ritesh Kumar Gautam
Co-Supervisor

पत्रपेटी सं 18 चन्द्रबनी देहरादून-248001, उत्तराखण्ड भारत
Post Box No. 18, Chandrabani, Dehradun-248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स .+91-135-2640111 से 2640115, फैक्स :0135-2640117
EPABX +91-135-2640111 to 2640115, Fax · 0135-2640117
ई–मेल/E-mail wii@wii.gov.in, वेब/website . www.wii.gov.in

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that the thesis by Ms. Mencho Sena entitled *"Dynamics of plant and insect communities across shifting cultivation fallow in Arunachal Pradesh, Eastern Himalaya"* is an original and independent research work submitted to the Academy of Scientific and Innovative Research, for the award of the degree of Master's in Wildlife Science.

Ms. Mencho Sena has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

Dr. Amit Kumar
Supervisor

Sh. Ritesh Kumar Gautam
Co-Supervisor

Dr. Ruchi Badola
Dean
Faculty of Wildlife Science

पत्रपेटी सं 18 चन्द्रबनी देहरादून-248001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun-248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स .+91-135-2640111 से 2640115, फैक्स :0135-2640117
EPABX +91-135-2640111 to 2640115, Fax : 0135-2640117
ई–मेल/E-mail wii@wii.gov.in, वेब/website . www.wii.gov.in

“In every walk with nature, one receives far more than what he seeks”

- John Muir

ACKNOWLEDGEMENTS

There are so many people to thank who have helped me along this journey. First of all, I thank the Almighty for his blessings. I would like to thank the Director and the Dean for their support. I would like to thank my Supervisor Dr. Amit Kumar for all the help, support and encouragement throughout the course and the whole dissertation process. I also thank my co supervisor Sh. Ritesh Kumar Gautam for support. I thank my Course Director Dr. Sutirtha Dutta who throughout the course has helped and encouraged me. I also thank and extend my gratitude to all the faculty who have helped me throughout these two years. I also thank the admin staff for their support throughout the course. I would like to extend my gratitude to Arunachal Forest Department for issuing the permission to conduct the study. I also would like to thank Yomcha sir, Namita madam and Namo for helping me out with the permissions. I also thank the Gaonburrah of the villages who helped me in carrying out my work without any issue. This work would not have been possible without the help of many people on the field, Seseng dada for always accompanying me throughout the field season, Pondang huhu, wiwi for helping me learn so much about the jhum fields and local names of the plants, Mrs. Pangba Morang (enyai Nyaiwom maa) for coming with even when you had a lot of work helping me to identify the sites and taking me there, Mr.Natam Kochong (ehu) who is an excellent craftsman and who has so much knowledge about the forest, his crazy identification skill through barks, leafs etc. has been very helpful, Mrs. Pumrang Kochong (enyai). I would also like to thank Aimon for helping me out with the maps and review. Feba, Lian and Kim for the love and care. I also would like to thank all my seniors of the 19th MSc and juniors of the 21st MSc. I would like to thank Peru for helping during the concept note. I also would like to thank Manas for helping out with last moment analysis. I would like to thank my friends from Freshwater Ecology, especially Esther, Cherie, Nayana, Yashi, Priyanjali, Prateeti for being a great friend with all the banter, jokes and laughter, Smriti for friendship and companionship in the lab. This course

wouldn't have been easy and fun without my friends of the 20th MSc, the late-night trail walks, discussions, wall scribbling before exams, meeting the deadlines, cooking, music, food. Thank you all for. Akshay for being kind and thoughtful, our discussions about football, playing table tennis, I will remember. Sunny matcha, I will remember your positivity, uplifting enthusiasm. Pritham for thoughtful discussions and for always being kind to me. Rohan, thanks for helping out with the maps. Himani and Ardra for your friendship, thoughtful discussions, encouragement and helping me whenever I needed advices, Srajal, for friendship, discussions help and encouragement. Gayathri for friendship and help whenever needed. Ashwati for being kind always and listening to all my yapping even when you're tired. Ashutosh my Spurs fan club teammate, hopefully soon Spurs will win something big, I really enjoyed thoughtful discussions with you across topics from football, history and many more. Kirutika for listening and encouraging me and always opening the doors of your room whenever needed. Bryan, I will remember the music nights, late-night trail walks, especially the leopard walks. Sumedha and Tanya for always being encouraging, helping me with all small things, listening to me talking continuously. Srinjan and Shreyas, thanks for helping out every time whenever I need help with some technical stuff, for all the discussions and friendship. Joshika my roommate these 2 years would not have been as it has been without you; I will remember the discussions, talk and lots of laughter and your kindness. Last but not the least, I would not be here today if not for the love, support, help, prayer and encouragement from my parents and all my family members. I would like to thank maa (asai's), wawa, nyainyai, mama, ephu, ngingi, engung, ewae, saisai because wherever I am, I am grateful to them. And most importantly my awi, taitai and wiwi for your prayers and love which has helped me get here. And to all who has been part of this journey in WII, Thank you.

- Mencho Sena

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE OF PLAGIARISM CHECK

It is certified that the Master's dissertation thesis titled **"Dynamics of plant and insect communities across shifting cultivation fallow in Arunachal Pradesh, Eastern Himalaya."** submitted by **Mencho Sena** has been examined by us for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

a) Thesis has significant new work/knowledge as compared to already published work or work under consideration for publication elsewhere.
b) No sentence, equation, diagram, table, paragraph or section is found to have been copied verbatim from previous work unless it was placed under quotation marks and the source was duly cited.
c) The work presented is original work of the author (i.e., there is no plagiarism) and there is no fabrication of data or result by manipulating research materials, equipment or processes, or by changing or by omitting data or results such that the research is not accurately represented.

The similarity indices as reported by the software Drillbit are as follows:

Software used	Date	Total world count	Similarity index
Drillbit	15.07.2026	12489	5%

The similarity index came as above. Scientific names, measuring units (SI) and references have been excluded from documents.

15/7/26

Mr. Manohar Pathak
Librarian

मनोहर पाठक / Manohar Pathak
पुस्तकालयाध्यक्ष / (Librarian)
पुस्तकालय एवं प्रलेखन केन्द्र
Library and Documentation Centre
भारतीय वन्यजीव संस्थान
Wildlife Institute of India
चन्द्रबनी, देहरादून, उत्तराखंड
Chandrabani, Dehradun - 248 001

Dr. Amit Kumar
Supervisor

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून-248 001, उत्तराखण्ड, भारत
P.B. No. 18, Chandrabani, Dehradun-248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स. :+91-135-2640114, 2640115, 2646100, फैक्स : 0135-2640117
EPABX : +91-135-2640114, 2640115, 2646100, Fax : 0135-2640117
ई–मेल/E-mail : wii@wii.gov.in, वेब/website : www.wii.gov.in

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Shifting cultivation or jhum is a form of agriculture practice that is practiced by several communities around the world. In jhum cultivation, a patch of forest is slashed, burned, and cultivated for a limited period of time, and later on the patch is left for the regeneration vis a vis recovery of vegetation. Ecologically, such habitats provide a clear disturbance gradient to understand biodiversity recovery, including the process of establishment. Several studies have been carried out in the tropical forest around the world; however limited studies have looked at the recovery in the shifting cultivation landscape of North Eastern region in general and specifically in Arunachal Pradesh.

The present study was conducted in Nampong, Changlang district of Arunachal Pradesh to investigate the dynamics of plant communities across shifting cultivation fallows of different ages. The vegetation was sampled across five different age classes vis-à-vis., 1, 5, 15, 25, 35 and forest as a control site. For vegetation sampling, 10m circular nested plots were used to sample for trees and 3.5m circular plots were used to sample for shrubs. To understand the community composition, diversity indices using the vegan package in R, following which a species accumulation was run to check sampling adequacy, were estimated. Following, which a Non-Metric Multidimensional Scaling (NMDS) was run to see how communities changed across fallows, followed by Indicator species Analysis and Similarity Percentages (SIMPER) analysis. Generalized Linear Model (GLM) with Poisson was run to check which factors influence the species richness.

Based on the sampling and field observations, change in communities across fallows of different ages, with the forest having the highest species count, was observed. Simpson showed how diversity changed across fallow along with a decrease in 25-year-old which may be due to the presence of several species of *Bamboo* and *Musa*. NMDS showed a distinct pattern across

age class, though there were overlaps in the mid-successional changes. Further, indicator species analysis was used to understand the association of species with respect to successional stages; such as *Mesua ferrea, Terminalia chebula* were associated with forest, *Agalaia edulis* and *Albizia* sp. with 35 and 25-year-old fallows, and species such as *Zanthozyllum rhetsa* in the early fallows. The SIMPER analysis showed the dissimilarity in the species across fallows of different ages, which showed that *Trema orientalis*, *Macaranga denticulata*, *Croton persimilis*, bamboo species, and *Musa* species contributed to differences among successional stages, and species such as *Baccaurea ramiflora* and *Mesua ferrea* were the species distinct in forest classes, suggesting the requirement of longer periods of recovery for the fallows.

The understory communities of young fallows were dominated by invasive species such as *Chromolaena odorata*, *Erigeron sumatrensis*, and *Mikania micrantha*. Their abundance declined with increasing fallow age, indicating that canopy development and habitat recovery reduce the dominance of invasive species. Older fallows and forest sites increasingly consisted forest-associated species such as *Gnetum montanum*, *Calamus* spp., *Phrynium pubinerve*, and *Entada* sp., reflecting progressive recovery of understory vegetation.

Model selection based on AICc identified fallow age as the strongest predictor of both tree and understory species richness, highlighting the importance of successional stage in shaping vegetation recovery. The influence of topographic and spatial variables was comparatively weaker. The study highlights the importance of protecting the remnant forested areas, and avoiding as well as reducing fallow cycles for the biodiversity to be resilient in the shifting cultivation landscapes of Arunachal Pradesh.

1. INTRODUCTION

Agriculture accounts for 4.8 billion hectares, about one-third of the Earth's land surface, however, its impact of on land and water is massive (FAO, 2026). While agricultural production is essential for sustaining human populations, its expansion often occurs at the expense of natural ecosystems, particularly tropical forests. However, tropical forests are among the most biologically diverse ecosystems on Earth, harboring more than 77% of the tree species & 62% of the vertebrates known on earth, despite covering less than 10% of the global land surface (Gibson et al., 2011, Gatti et. Al., 2022, Pillay et. Al., 2022). These forests provide critical ecosystem services, including carbon storage, nutrient cycling, climate regulation, soil conservation, and maintenance of hydrological processes (Chazdon, R. L., et al., 2020). While, disturbance plays a fundamental role in shaping forest ecosystems, the natural disturbances such as storms, landslides, and fires, as well as anthropogenic disturbances, including logging and agriculture, alter the vegetation structure and species composition. Following disturbance, ecosystems undergo ecological succession, a process through which biological communities gradually recover and change over time (Odum, 1969). Succession involves shifts in species composition, community structure, and ecosystem functioning, often transitioning from pioneer-dominated communities towards more mature and complex forest systems.

Understanding patterns of ecological succession is particularly important in tropical regions where human-induced disturbances are widespread. Secondary forests that regenerate following agricultural abandonment now constitute a substantial proportion of tropical forest landscapes and play an increasingly important role in biodiversity conservation and ecosystem recovery (Chazdon, 2003). The recovery of plant communities during succession is influenced by multiple factors, including disturbance intensity, environmental conditions, landscape context, and the availability of propagule sources (Guariguata & Ostertag, 2001). Therefore,

studies investigating changes in community composition and diversity across successional gradients provide valuable insights into ecosystem resilience and recovery processes.

Community ecology offers a useful approach for understanding ecological recovery following a disturbance. Changes in species richness, diversity, evenness, and community composition reflect underlying ecological processes such as colonization, competition, environmental filtering, and species turnover (Magurran, 2004). Examining these patterns across successional stages is therefore essential for understanding how disturbed ecosystems recover and for informing conservation and sustainable land management strategies (Chazdon, 2008). The recovery of biodiversity and ecosystem functioning following disturbance has become an important focus of ecological research, particularly in tropical regions where land-use change is widespread (Chazdon, 2014). Among the various forms of land use practiced in tropical landscapes, shifting cultivation is one of the most extensive and important agriculture system (Cairns 2007). As shifting cultivation creates a mosaic of cultivated fields, regenerating fallows, and mature forest patches, it provides a model for understanding patterns of ecological succession and community recovery. Thus, examining vegetation dynamics within shifting cultivation landscapes can provide important insights into the processes governing biodiversity maintenance and forest regeneration.

1.1 Shifting cultivation: a traditional farming system

Globally, shifting cultivation, often called ‘slash and burn’ is practiced across tropical regions of Asia, Africa, and Latin America and supports the livelihoods of millions of people. (Fox et al., 2009). In India, shifting cultivation, commonly referred to as podu, kumri, penda or *jhum* in Northeast India, but because of colonial forest policies and land use regulations has led to decline of this practice in the peninsular India (Toky & Ramakrishnan, 1981, Guha and Gadgil, 1989) and is now prevalent mostly in the Northeastern states of India. This system of agriculture has shaped the traditional land use systems, cultures and traditions of the region.

The system involves the clearing of forest vegetation, followed by burning of the biomass and cultivation of crops for a certain time period, after which the land is left fallow to allow natural regeneration of vegetation and recovery of soil fertility before being reused in subsequent cultivation cycles which further shapes the landscape of the region (Ramakrishnan 1992). This system of agriculture is often seen as a major factor for loss of tropical forest and biodiversity. Thus, the ecological consequences of shifting cultivation have been widely discussed (Toky and Ramakrishan, 1983, Myer, 1980, Ranjan & Upadhyay, 1999). Earlier studies often emphasized its role in deforestation and forest degradation, particularly where shortened fallow periods prevent adequate ecological recovery. More recent research, however, recognizes shifting cultivation as a complex socio-ecological system whose impacts depend strongly on fallow duration, cultivation intensity, and landscape context (Cairns, 2015). When sufficient fallow periods are maintained, regenerating secondary forests can support considerable biodiversity and contribute to ecosystem recovery (Chazdon, R.L., et al., Rozendaal, D.M.A., et al.)

1.2 Disturbance vs. Succession

The recovery of plant communities following disturbance has been a central topic in ecological research for several decades (Connell,1977). Secondary succession is a gradual process in which species composition, community structure, and ecosystem functioning change as vegetation develops following disturbance (Odum, 1969). In tropical forests, succession is generally characterized by the replacement of pioneer species by increasingly shade-tolerant and late-successional taxa, leading to greater structural complexity and biodiversity over time (Finegan, 1996). Numerous studies have demonstrated that species richness and diversity tend to increase with increasing time since disturbance. Chazdon (2003) reported that regenerating secondary forests can recover substantial levels of biodiversity through natural succession, although complete recovery may require several decades or even centuries. Similarly,

Guariguata and Ostertag (2001) found that secondary forests increase in species richness, biomass, and structural complexity with increasing age. Whereas, successional pathways are not always linear, studies have shown that intermediate successional stages exhibit unique community characteristics due to the presence of pioneer and late-successional species. Local environmental conditions and historical land-use practices result in substantial variation in recovery patterns among sites (Lebrija-Trejos et al., 2010, Klanderud et al., 2010).

While species richness and diversity provide important information about community recovery, changes in species composition often provide deeper insights into successional dynamics. Species turnover during succession reflects processes such as colonization, competition, environmental filtering, and dispersal limitation (Norden et al., 2009). Studies from tropical forests have consistently reported gradual shifts in species composition as succession progresses. Early successional communities are typically dominated by fast-growing pioneer species adapted to disturbed environments, whereas older forests contain a greater proportion of shade-tolerant and forest-dependent species (Letcher & Chazdon, 2009). Despite this trend, complete convergence with old-growth forest communities is often slow and may never be the same as mature forest for hundreds of years. Rozendaal et al. (2019) states that Secondary forests recover remarkably fast in species richness but slowly in species composition. Vegetation recovery following disturbance is influenced not only by successional age but also by a range of environmental factors. Canopy cover regulates light availability and microclimatic conditions; Photosynthetic utilization of light is therefore a major component of the regeneration responses of forest species within the larger context of forest dynamics and succession (Chazdon. R. L. et., al, 1996, Montgomery, R. A., et. Al., 2001). Further, leaf litter accumulation also plays an important role in ecosystem recovery by contributing to nutrient cycling, soil moisture retention, and seedling establishment. Studies have shown that litter depth often increases with succession and is positively associated with forest regeneration

processes (Facelli & Pickett, 1991). Topographic factors such as elevation, slope, and aspect can further influence vegetation patterns by affecting temperature, moisture availability, and soil development (Gumbo et al., 2018, Ribeiro et al., 2020). Disturbance intensity, proximity to seed sources, and landscape connectivity have likewise been identified as important determinants of regeneration success and community assembly (Guariguata & Ostertag, 200, Clark and Clark, 2001).

1.3 Diverse North-East India

Located in the Eastern Himalaya, the North-East India represents one of the most biodiverse regions of the world and an integral part of the Indo-Malayan biodiversity hotspot, and Arunachal Pradesh part of the Eastern Himalaya Biodiversity Hotspot, is known for its high endemism and richness (Myers et al., 2000; Mittermeier et al., 2011). Owing to its unique biogeographic position at the confluence of the Indo-Malayan, Indo-Chinese, and Palearctic realms, Northeast India supports a rich assemblage of flora and fauna, many of which are endemic or restricted in distribution (Mani, 1974; Rodgers & Panwar, 1988). Research conducted by Tripathi and Barik (2003) demonstrated that species richness, biomass, and structural complexity generally increase with increasing fallow age. Similar observations were reported by Mishra et al. (2004), who found progressive recovery of woody vegetation in secondary forests across shifting cultivation gradients. Studies of bird communities (Raman, 1996 & 1998), show the community reaching an asymptote by 25 years. According to Raman and Mandal (2016), jhum mosaics support more bird species than monoculture plantations. Despite these contributions, much of the available research has focused on biomass accumulation, carbon dynamics, or broad vegetation structure. Comparatively meagre studies have examined community composition and successional changes in species assemblages, particularly within Arunachal Pradesh. Furthermore, the influence of environmental variables on vegetation recovery remains insufficiently understood in many parts of the Eastern

Himalaya; therefore, detailed studies examining patterns of plant community structure, diversity, and composition across multiple successional stages within shifting cultivation landscapes of Arunachal Pradesh are essential.

The insect (and broader arthropod) community responses to land-use change, however, fallow succession are comparatively less well documented. Another key international theme is how intensification, shortened fallow lengths and land-use change are impacting the sustainability of swidden systems, biodiversity and ecosystem recovery. The review by Delang and Li (2013) argued that although fallow vegetation and forests of varied ages inside swidden mosaics have considerable biodiversity potential, there is high variation in outcomes across sites, and successional pathways are strongly driven by fallow length, site history, fire frequency, soil type and adjacent forest cover.

1.4. Aim and Objectives

To assess how plant and insect communities change across shifting cultivation fallow of different ages.

Key Objectives:

The key objectives of the proposed study include:

1. To assess the structure and composition of plant communities across shifting cultivation fallow of different ages.
2. To understand the factors influencing plants distribution across the shifting cultivation fallow of different ages.
3. To study the ground-dwelling insects viz., beetle assemblages across shifting cultivation fallow of different ages.

1.4.1. Research Questions:

Research Question 1: What is the population status of plant species across shifting cultivation fallow of different ages?

Research Question 2: How do the ground-dwelling insects (beetles) change across shifting cultivation fallow?

Hypothesis & predictions:

Hypothesis 1:

Vegetation communities will change across fallow land of different ages and richness will increase as the age increases.

Prediction:

The species richness will vary as the age of the fallow increases and will reach stability once the secondary forest reaches the same structural form as the primary forest.

Hypothesis 2:

Factors such as age and size of the fallow, distance from the closest fallow, distance from the village, distance from the stream will influence community composition across fallow.

Prediction:

The diversity of the community will increase as the complexity increases.

Hypothesis 3:

The rate of recovery of insects (beetles) will vary across fallows of different ages.

Prediction: The species richness will increase as the age of the fallow increases and will reach an asymptote once the secondary forest reaches the same structural form as the primary forest.

2. MATERIALS AND METHODS

2.1. Study Area:

Arunachal Pradesh, being a part of the Indo-Burma Biodiversity Hotspot, is known for its unique ecological and geographical significance, as it presents itself with variations in altitude, ranging from tropical lowlands to alpine zones, which in turn result in a wide range of climatic and ecological conditions that support many organisms. The study area is located in Nampong, Arunachal Pradesh (Fig. 1), which lies in the transition zone between the Eastern Himalaya and the Patkai Hills, which are part of the larger Arakan Yoma range. This transitional setting contributes to a diverse topography, ranging from hills, valleys, evergreen and semi-evergreen forests, interspersed with shifting cultivation (*jhum*); this creates a mosaic of habitats that supports different flora and fauna. The climate of the area is humid with a subtropical monsoon which extends from April to August with annual rainfall of about 2000-3000 mm. Temperature here varies from 6-25 degrees Celsius in winter and about 20-38 degrees in summer. The vegetation of the region mostly consists of tropical evergreen and semi-evergreen forest (Champion and Seth, 1968). The area holds cultural significance because of the indigenous tribal communities that inhabit this area and who have been relying on this area for centuries, practicing swidden agriculture, paddy cultivation and resource use. This area is also historically significant for 'the Stillwell Road' built during the Second World War by the allied forces to stop Japanese infiltration, and has served as a passageway for many Indo-Burma tribes even before the Second World War.

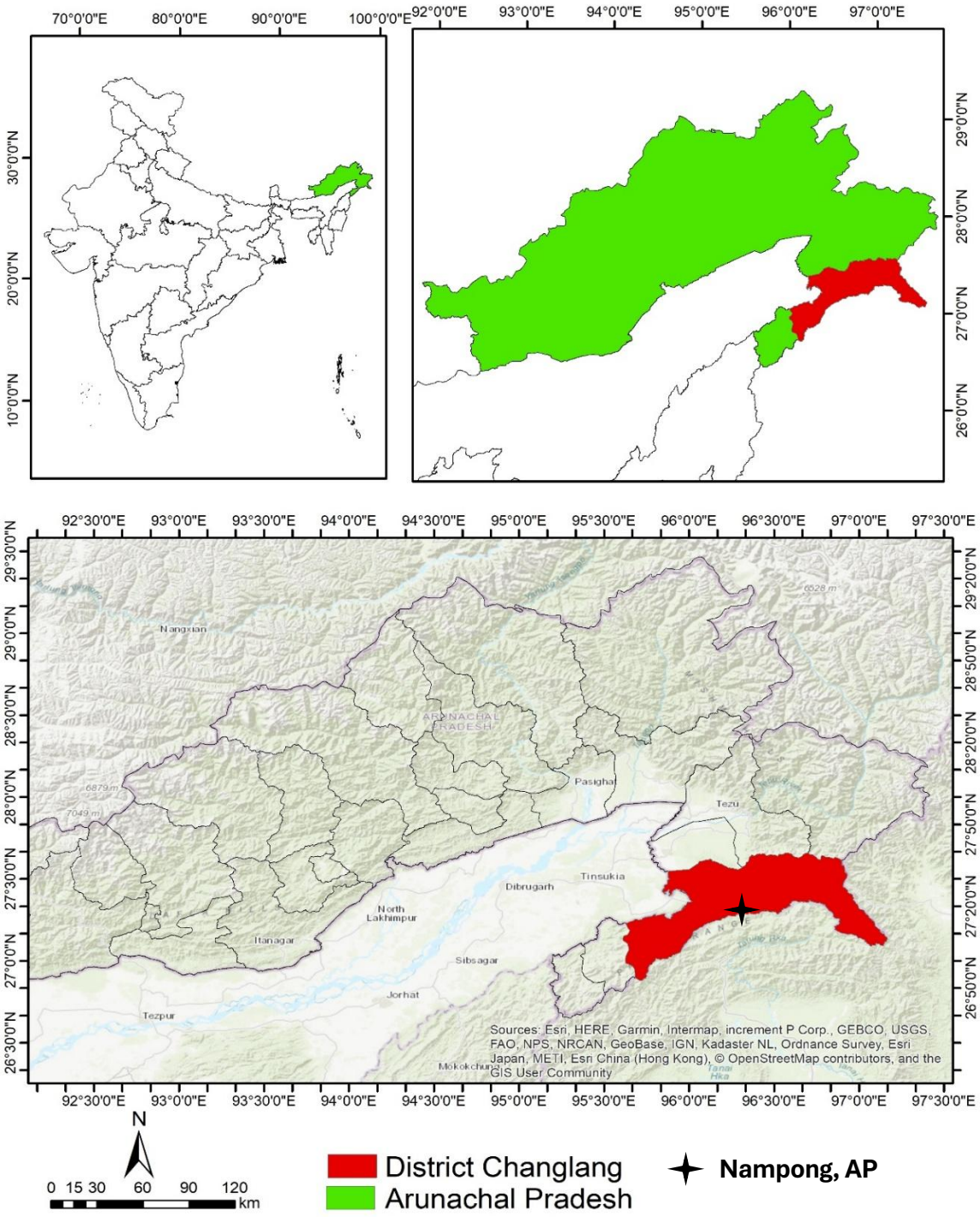

Fig. 1: Map showing the study area.

2.2. Methodology

2.2.1 Study design

Based on reconnaissance and interactions with the local communities and various stakeholders, the study sites were selected within Nampong region of Arunachal Pradesh. The sampling sites were classified into 5 classes based on the age of the fallow. Five fallows of each class (totaling 30) were selected across different ages, such as 1, 5, 15, 25 and 35 years, and were compared against adjacent forest (05) patches (Fig. 2; Table 1; Plate 1-6).

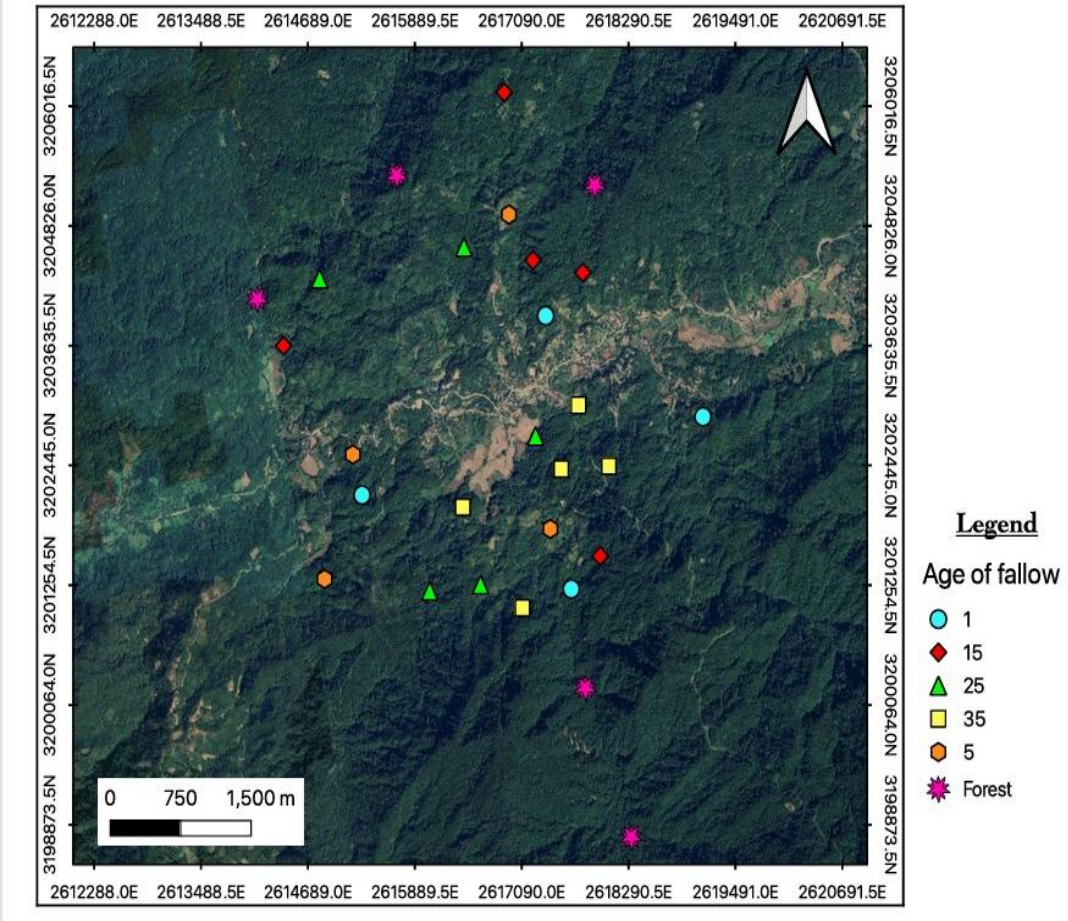

Fig. 2: Location of the selected fallow sites in Nampong.

Further, covariates such as the size of the fallow, slope, aspect, elevation, distance from the closest forest patch, distance from the closest fallow, distance from the village and distance from the stream in view were considered. Representative sampling sites/units were sampled

for studying the aforementioned objectives. Thus, a total of 150 sampling sites (25 per age class) were sampled across fallows of different ages (Table 1).

Table 1. Sampling approach adopted in the study.

Age of the fallow (year)	No. of sampling sites	No. sampling plots
1	5	25
5	5	25
15	5	25
25	5	25
35	5	25
Forest	5	25
Total	30	150

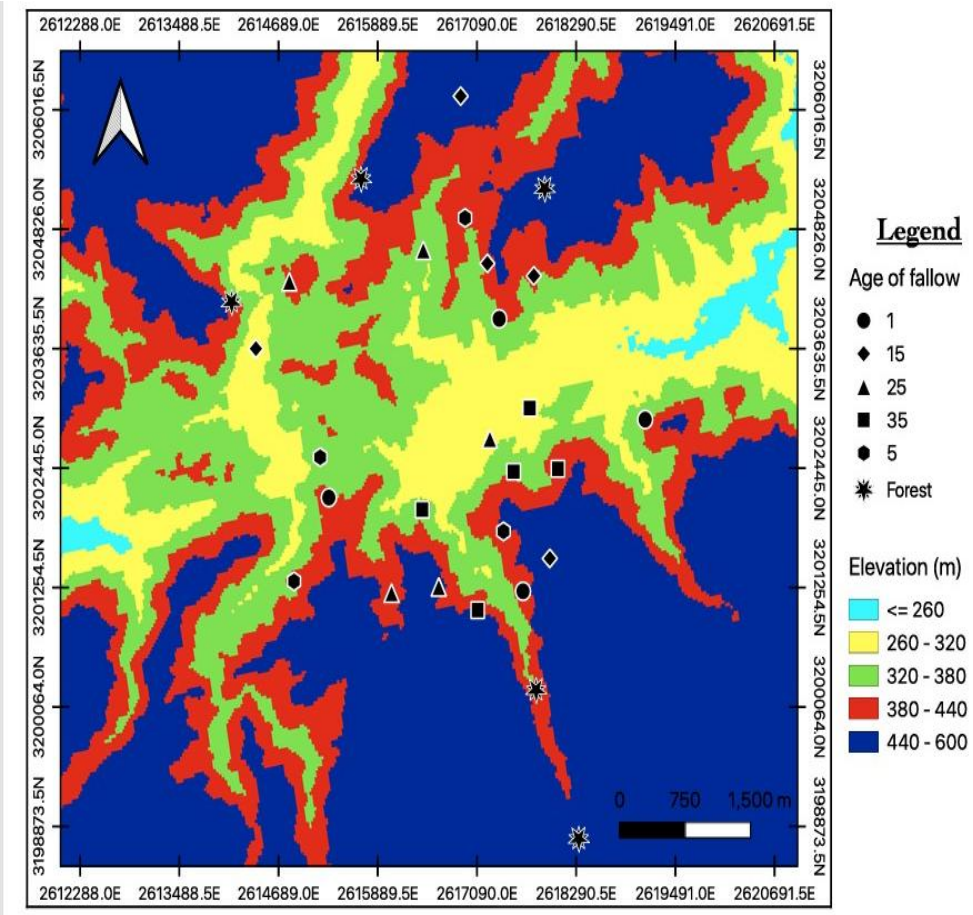

Fig 3. Fallow sites across elevation bands

Fig 4. Ongoing fallow (one year).

Fig 5: A five-year fallow largely colonized by Bamboo species.

Fig 6. Bamboo brakes stabilizing a 15-year-old fallow.

Fig 7. A 25-year-old fallow dominated by tree ferns and other woody vegetation.

Fig: 8. A stabilized (largely with woody vegetation) 35-year-old fallow.

Fig 9. Jhum of one-year-old adjacent to a natural forest patch.

2.3. Field methods

The fallow of different ages was selected based on reconnaissance surveys and discussion with locals. The sites were selected based on the age of a fallow land.

(i) Vegetation sampling: A nested plot was laid in the center of the site, in which 10m circular plots were laid for trees, 3.5m circular plots for understory shrubs, climbers, saplings (Holmgren, 2003). Further, 4 plots (20m, 30m, 50m, 60m) from the center were also sampled. A buffer from the edge was maintained to account for edge effect. All trees (>20 cm dbh) were identified through expert consultation, regional field guide (Page et al. 2022), Plant net and were accounted for along with shrubs and saplings. Along with it, covariates were also collected.

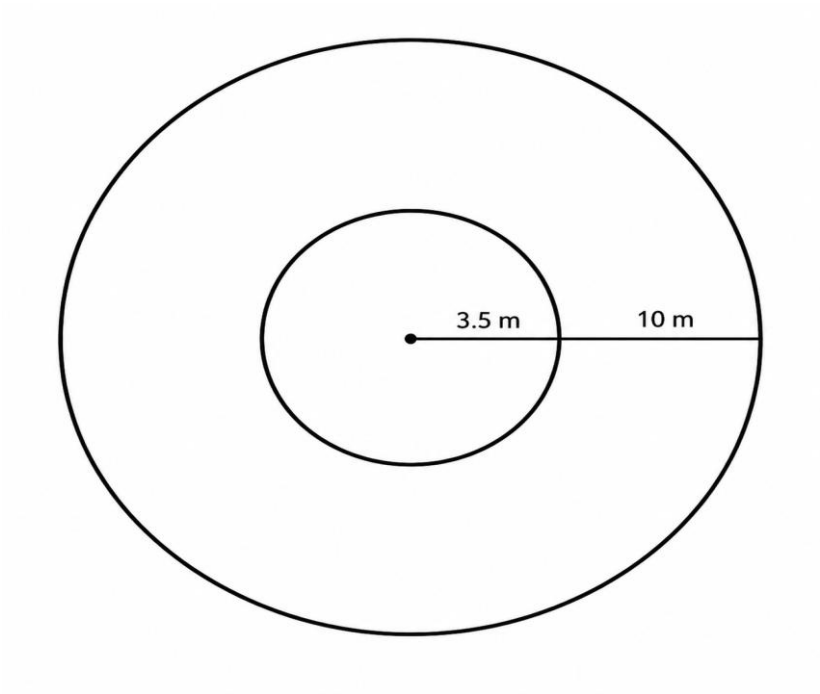

Fig 10. Design of the vegetation sampling plot laid in the study.

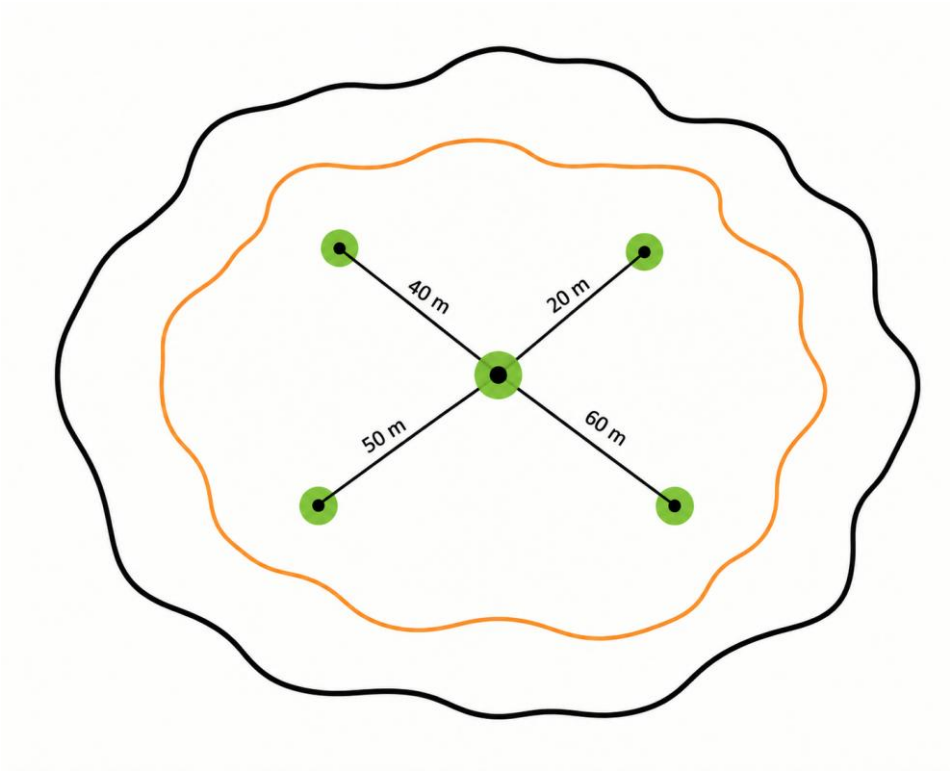

Fig 11. Sampling plot design of the study.

ii) **Insect (beetle) sampling:** For insect sampling, pitfall traps were placed in the same vegetation plots filled with surfactant solution (Anderagg, 2022). The traps were kept for 24 hours and the samples were stored in 70% ethanol.

2.4. Analytical Methods

Vegetation data obtained from different jhum fallow age classes (1, 5, 15, 25, 35 years) and forest sites were organized into species-by-plot community matrices in MS Excel and cleaned by converting all abundance values to numeric form and replacing missing values with zeros. The matrices were transposed so that plots formed rows and species formed columns for ecological analysis.

Alpha diversity was calculated for each plot using the *vegan* package in R. Species richness, Shannon diversity, Simpson diversity, and Pielou's evenness were computed for all age classes to assess variation in plant diversity across the successional gradient. Histograms were generated to check the normality of the data. If the data is normally distributed, ANOVA was

performed to test the difference between fallows of different age and forest. If the data is not normally distributed, Kruskal-Wallis test (Non-parametric test) was performed to compare among the treatments, and Pair-wise Wilcoxon test was used for pairwise comparison between treatments. Species accumulation curves were also generated using random permutations to evaluate sampling adequacy and compare species richness patterns among age classes.

Community composition was analyzed using Bray–Curtis dissimilarity, followed by Non-metric Multidimensional Scaling (NMDS) to visualize differences in species composition across successional stages. Then, PERMANOVA was used to test the significance of compositional differences among age classes, followed by Indicator analysis and SIMPER analysis which identified key species contributing to dissimilarity.

The variables such as slope, aspect and elevation were derived through Digital Elevation Model (DEM), while the nearest fallow, forest, water body was recorded during sampling and later the distance from the fallow, distance from the forest patch, distance from water and distance from the village was calculated with the help of GIS tools.

A Pearson correlation test along with Variance Inflation Factors (VIF) were used to check for multicollinearity. Variables with high value $|r| > 0.7$ were not included in the same model. Generalized Linear Models (GLM) with Poisson distribution was used to examine the effects of age class and environmental variables on species richness. Model selection was based on AICc and model diagnostics were performed.

3. RESULTS

3.1 Tree community

Species richness was observed to be highest in the old-growth forest and generally lower in the fallow sites. The 25-year fallow showed the lowest median richness, indicating reduced species numbers compared to other fallows (Fig. 12), however, species richness increased with sampling effort in all age classes (Fig. 13). Among fallows, species richness generally increased with fallow age, with 35-year fallows showing greater richness accumulation than younger fallows. The 15-year-old and 25-year-old fallows exhibited intermediate richness, with their curves converging, although these communities contained more species than the youngest fallows, which had not yet attained the richness levels as had been observed in older fallows or the forest.

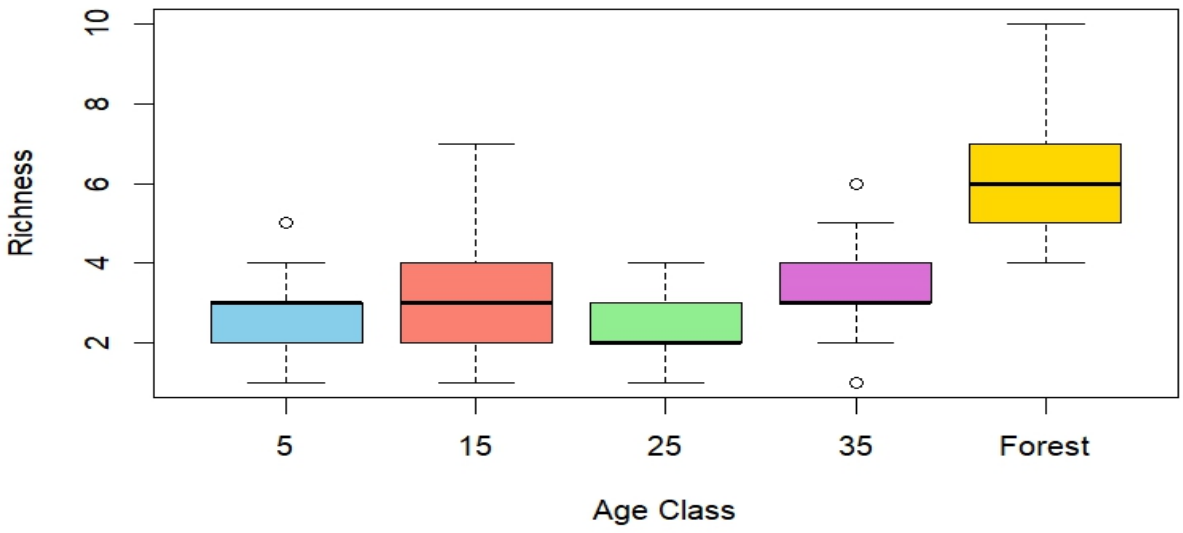

Fig 12. Richness of trees across different age classes.

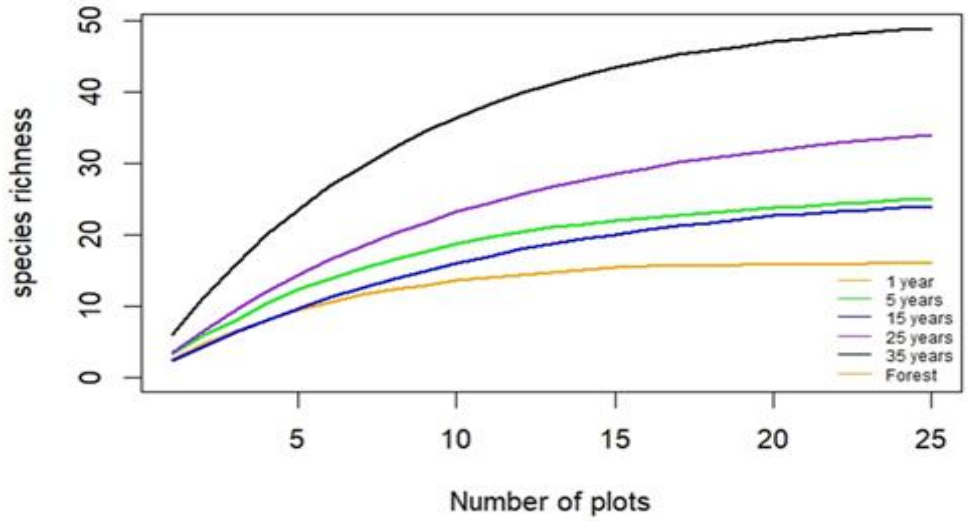

Fig 13. Species accumulation curve of trees by age classes.

Of the selected sites, the Simpson diversity was highest in the old-growth forest, reflecting higher species diversity and abundance balance. Diversity was lowest in the 25-year fallow and increased towards the mature forest stage (Fig. 14).

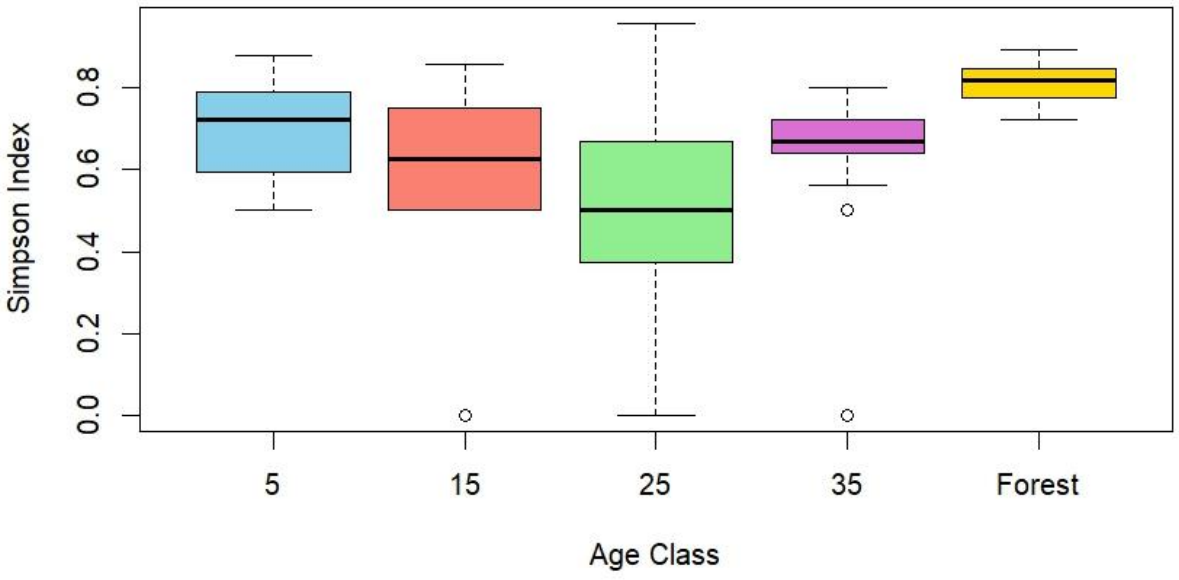

Fig 14. Simpson Diversity across different age classes.

Non-metric multidimensional scaling (NMDS) ordination revealed a gradual shift in tree community composition across the successional gradient from young fallows to mature forest (Fig.15). Permutational multivariate analysis of variance (PERMANOVA) indicated significant differences in community composition among age classes ($F = 4.05$, $R^2 = 0.119$, $p = 0.001$). The test for homogeneity of multivariate dispersion was significant (PERMDISP, $F = 2.71$, $p = 0.035$).

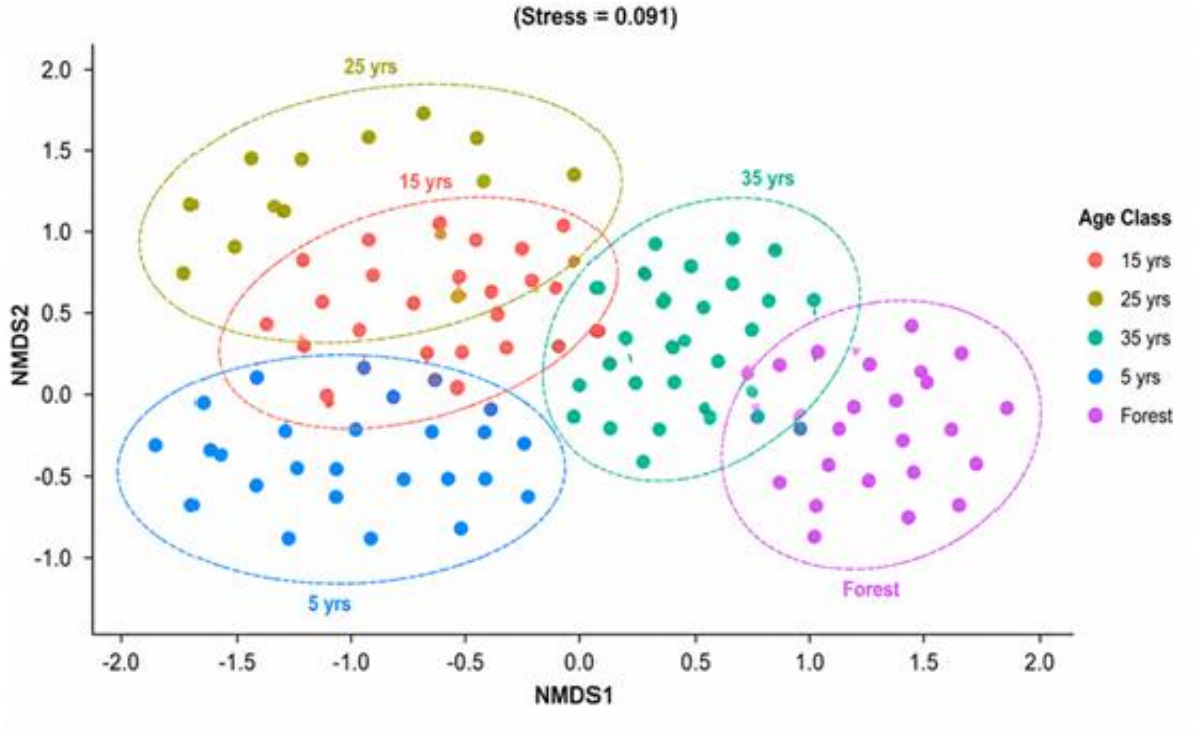

Fig 15. NMDS of trees by age class.

Indicator species analysis showed the species indicating the fallows of different ages where young fallows were characterized by *Zanthoxylum rhetsa, Ficus variegata* indicating their adaptations to disturbed habitats. The older fallow of 25 and 35 years indicated the presence of species such as *Albizia sp., Agalaia edulis.* Forest comprised of *Shorea assamica, Terminalia chebula, Dipterocarpus macrocarpus* indicators (Table 2). This highlights the gradual replacement of species across fallows of different age.

Table 2: Indicator tree species

Indicator Tree Species	5 years	15 years	25 years	35 years	Forest
Zanthoxylum rhetsa	0.45				
Ficus variegata	0.25				
Macaranga sp.		0.4			
Albizia sp.			0.2		
Livistona jenkinsiana			0.15	0.25	
Agalaia edulis				0.3	0.1
Terminalia chebula					0.3
Shorea assamica					0.25
Mesua ferrea					0.4
Dipterocarpus macrocarpus		0.15		0.2	0.45

SIMPER analysis revealed that across fallow ages, 5 and 15-year-old fallows were driven by species such as *Croton persimilis*, *Ficus auriculata*, *Zanthoxylum rhetsa*, *Macaranga denticulata*, and *Trema orientalis*. (Table 3). Whereas the 15 and 25-year-old fallows were mainly stabilized by *Musa sp., Castanopis indica* and Bamboo sp. (Table 4). In the 35 and the 25-year fallow lands, *Musa sp., Duabanga grandiflora, Bamboo sp.* were identified as drivers of dissimilarity (Table 5). And between forest area and 35-year-old fallow *Mesua ferrea, Baccaurea ramiflora and Dipterocarpus macrocarpus* were identified as the drivers of dissimilarity (Table 6).

Table 3. Dominant species driving dissimilarity between 5 and 15-year fallow.

Sl no.	Species	Contribution	5 year fallow (mean abundance)	15 year fallow (mean abundance)	Trend (5→15 yr)	p-value
1	*Croton persimilis*	9.08	0.24	0.52	↑	0.001
2	*Ficus auriculata*	6.3	0.24	0.28	↑	0.001
3	*Zanthoxylum rhetsa*	5.72	0.44	0	↓	0.001
4	*Macaranga denticulata*	5.65	0.2	0.32	↑	0.001
5	*Trema orientale*	5.52	0.28	0.12	↓	0.001

Table 4. Dominant species driving dissimilarity between 15 and 25-year fallow.

Sl no.	Species	Contribution	15 year fallow (mean abundance)	25 year fallow (mean abundance)	Trend (15→25 yr)	p-value
1	Musa sp. 1	10.83	0.4	0.68	↑	0.003
2	Bamboo sp. 1	9.9	0.2	0.56	↑	0.001
3	Croton persimilis	8.31	0.52	0.16	↓	0.002
4	Castanopsis indica	5.85	0.32	0.24	↓	0.01
5	Ficus auriculata	4.91	0.28	0.12	↓	0.029

Table 5. Dominant species driving dissimilarity between 25 and 35-year fallow.

Sl no.	Species	Contribution	25 year fallow (mean abundance)	35 year fallow (mean abundance)	Trend (25→35 yr)	p-value
1	Musa sp. 1	9.84	0.68	0.36	↓	0.025
2	Bamboo sp. 1	7.81	0.56	0	↓	0.012
3	Castanopsis indica	5.48	0.24	0.28	↑	0.026
4	Musa sp. 2	4.9	0	0.4	↑	0.063
5	Duabanga grandiflora	3.57	0.16	0.2	↑	0.009

Table 6. Dominant species driving dissimilarity between 35-year fallow and forest.

Sl no.	Species	Contribution	35 year fallow (mean abundance)	Forest (mean abundance)	Trend (35→Forest)	p-value
1	*Musa sp. 2*	5.51	0.4	0.36	↓	0.015
2	*Dipterocarpus macrocarpus*	4.79	0.16	0.48	↑	0.006
3	*Musa sp. 1*	4.06	0.36	0.24	↓	0.887
4	*Mesua ferrea*	3.05	0	0.36	↑	0.001
5	*Baccaurea ramiflora*	3.05	0.08	0.32	↑	0.013

3.2 Understory community

Species richness was steadily increased from 1 year fallow to 35-year-old fallow and the of 35-year-old fallow had the highest number of species among all. However, species richness increased with sampling effort in all age classes (Fig. 16).

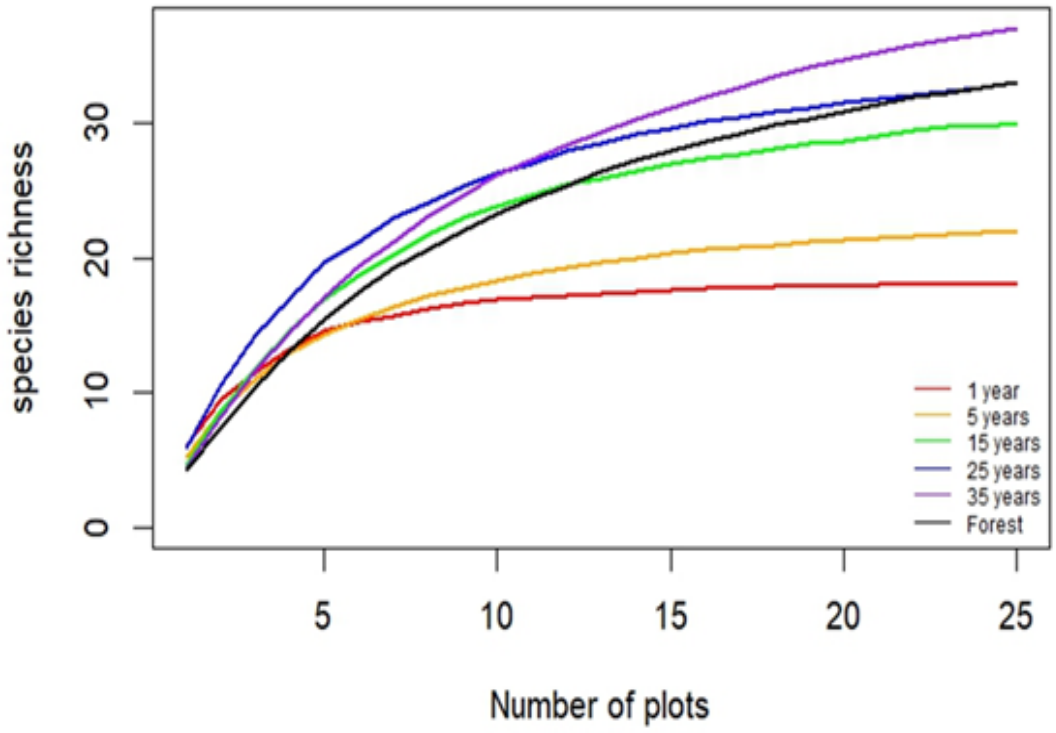

Fig 16. Species accumulation curves of understory vegetation.

The Simpson diversity was differed across age classes, the highest diversity was observed in the 25-year-old fallow, with a high median value, reflecting higher species diversity and abundance balance. Diversity was comparatively high in the 1-year fallow. Forest and 35-year-old fallow showed moderate diversity (Fig. 17). Altogether, the understory communities were more diverse during intermediate stages of fallow before gradually transitioning towards forest communities.

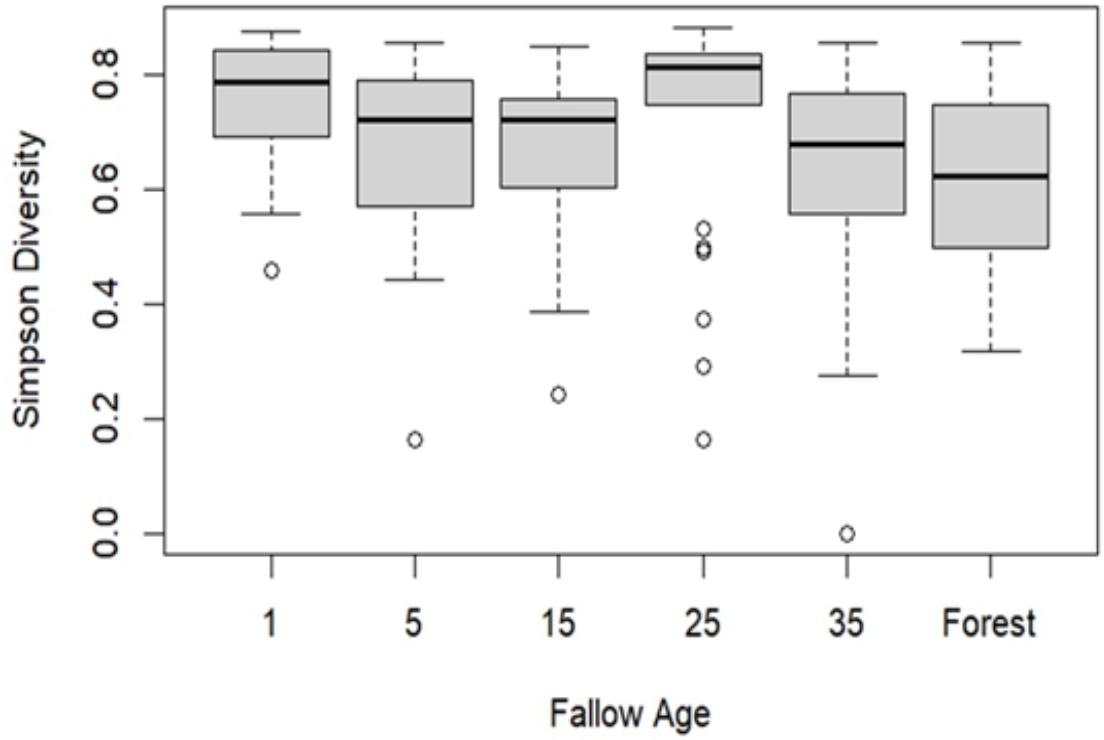

Fig 17. Understory Simpson diversity.

Non-metric multidimensional scaling (NMDS) ordination showed a gradual shift in understory community composition across the successional gradient from young fallows to mature forest (Fig. 18). The one-year age class formed a different cluster assemblage, whereas in 5- and 15-year-old fallow the communities starts to shift but a lot of overlap can be seen between the mid successional fallows and the forest and 35-year-old also had a substantial overlap. Permutational multivariate analysis of variance (PERMANOVA) indicated significant differences in community composition among age classes ($F = 7.91$, $R^2 = 0.251$, $p = 0.001$). The test for homogeneity of multivariate dispersion was significant (PERMDISP, $F = 16.51$, $p = 0.001$).

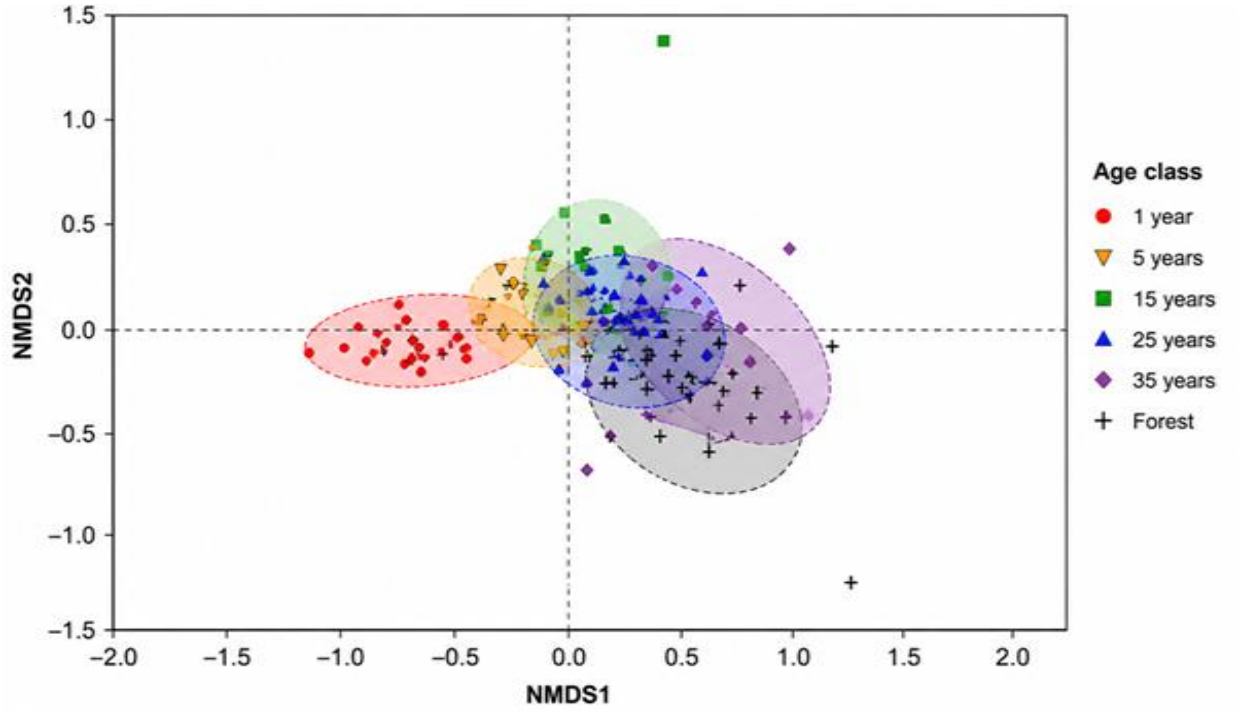

Fig 18. NMDS Ordination of understory species.

Indicator species analysis showed the species indicating the fallows of different ages where 1 year old fallows were characterized by *Chromolaena odorata* and *Erigeron sumatrensis* which are invasive species; both with indicator values of 0.8 indicating their adaptations to disturbed habitats. The 5-year-old fallow was characterized by *Thysanolaena maxima* with an indicator value of 0.6. 15- and 25-year fallow were indicated the presence of species such as *Albizia sp.* (0.5), *Litsea sp.* (0.4), Pig fern (0.6) and *Myxopyrum smilacifolium* (0.4), respectively. The 35-year-old fallow comprised of *Smilax sp., Wallichia caryotoides* and *Carisa sp.,* all with an indicator value of 0.4 and forest comprised of *Calumus tenius,* with an indicator value of 0.6, *Dipterocarpus macrocarpus* and *Entada* sp., with an indicator value of 0.4 each (Table 7). This highlights the gradual replacement of species across fallows of different age with disturbance adapted species coming up in the younger fallows followed by woody shade tolerant lianas and ratans in the older fallow and forest.

Table 7. Understory indicator species across fallows of different ages and forest.

Indicator Species	1 year	5 years	15 years	25 years	35 years	Forest
Chromolaena odorata	0.80	0.50				
Erigeron sumatraensis	0.80					
Thysanolaena maxima		0.60				
Albizia sp.			0.50			
Litsea sp.			0.40			
Pig fern				0.60		
Myxopyrum smilacifolium				0.40		
Smilax sp.					0.40	
Wallichia caryotoides					0.40	
Carissa sp.					0.40	
Calamus tenuis						0.60
Dipterocarpus macrocarpus						0.40
Entada sp.						0.40

SIMPER analysis revealed that across fallow ages, 1 and 5-year-old fallows were driven by decline in species such as *Chromolaena odorata, Erigeron sumatrensis* in the 5-year-old fallows whereas increase in species such as *Phyrynium pubinerve and Thysanolaena latifolia* were observed in the 5-year-old fallows (Table 8)The dissimilarity in the 5 and 15-year-old fallows were mainly due to increase in *Phyrynium pubinerve in* the 15-year-old fallow and decrease in species such as *Thysanolaena latifolia, Ageratum conyzoides* and *Chromolaena odorata* in the 15 year old fallow (Table 9)In the 15 and the 25-year fallow lands, *Phyrinium pubinerve along with Gnetum montanum and Hypolepis sp.* were identified as drivers of dissimilarity (Table 10)The transition in the 25 and the 35 year old forest were driven by species such as Chamrai, Pig Fern, and *Phyrinium pubinerve* (Table 11)And between forest area and 35-year-old fallow *Gnetum montanum, Calamus tenius* and *Calamus floribundus* increased and *Phyrinium pubinerve* decreased in the forest sites were identified as the drivers of dissimilarity (Table 12)

Table 8. Understory species contributing to dissimilarity between 1 and 5-year-old fallow.

Sl. No.	Species	Contribution (%)	1-year fallow	5-year fallow	Trend (1→5 yr)	p-value
1	*Phrynium pubinerve*	9.75	0.00	2.00	↑	0.080
2	*Chromolaena odorata*	8.72	1.88	0.00	↓	0.001
3	*Thysanolaena latifolia*	8.39	0.00	2.04	↑	0.001
4	*Erigeron sumatrensis*	7.18	1.64	0.00	↓	0.001

Table 9. Understory species contributing to dissimilarity between 5 & 15-year-old fallow.

Sl. No.	Species	Contribution (%)	5-year fallow	15-year fallow	Trend (5→15 yr)	p-value
1	*Phrynium pubinerve*	11.10	2.00	2.28	↑	0.340
2	*Thysanolaena latifolia*	9.11	2.04	0.88	↓	0.028
3	*Ageratum conyzoides*	5.22	1.32	0.00	↓	0.026
4	*Chromolaena odorata*	4.81	1.24	0.00	↓	0.317

Table 10. Understory species contributing to dissimilarity between 15 and 25-year old fallow.

Sl. No.	Species	Contribution (%)	15-year fallow	25-year fallow	Trend (15→25 yr))	p-value
1	*Phrynium pubinerve*	11.10	2.28	2.40	↑	0.345
2	*Gnetum montanum*	7.07	0.60	1.36	↑	0.473
3	*Hypolepsis sp.*	4.88	0.88	0.80	↓	0.001

Table 11. Understory species contributing to dissimilarity between 25 and 35-year-old fallow.

Sl. No.	Species	Contribution (%)	25-year fallow	35-year fallow	Trend (25→35 yr)	p-value
1	*Phrynium pubinerve*	11.73	2.40	1.92	↓	0.156
2	*Chamrai*	3.51	0.56	0.60	↑	0.001
3	Pig fern	3.18	0.88	0.00	↓	0.001

Table 12. Understory species contributing to dissimilarity between 35 and forest.

Sl. No.	Species	Contribution (%)	35-year fallow	Forest	Trend (35 yr→Forest)	p-value
1	*Phrynium pubinerve*	12.68	1.92	1.56	↓	0.047
2	*Gnetum montanum*	11.05	0.12	2.92	↑	0.012
3	*Calamus tenuis*	5.89	0.00	1.12	↑	0.001
4	*Calamus floribundus*	5.74	0.60	1.04	↑	0.002

3.3. Factors affecting the tree community in the fallow sites

To understand the factors influencing the plant community across shifting cultivation fallow of different ages a Generalised Linear Model (GLM) with poisson was run with richness as response. Variance Inflation Factors (VIF) were run checked for multicollinearity. Multiple univariate and candidate models were also run and the Akaike Information Criterion (AICc) was compared to select the best model. Thus, the univariate model with Age Class had the lowest AIC value of 447.65, showing that age was the major factor responsible for plant community assemblage across fallows of different ages (Table 13).

Table 13. Model estimates for the best-ranked model.

Predictor	Estimate	SE	Z value	p-value
Intercept (Forest)	1.812	0.081	22.408	0.001***
5-year fallow	-0.826	0.147	-5.637	0.001***
15-year fallow	-0.612	0.136	-4.486	0.001***
25-year fallow	-0.987	0.155	-6363	0.001***
35-year fallow	-0.542	0.133	-4.064	0.001***

3.4. Factors affecting the understory community in the fallow sites

To understand the factors influencing the understory community across shifting cultivation fallow of different ages a Generalized Linear Model (GLM) with Poisson was run with richness as response. Variance Inflation Factors (VIF) were run checked for multicollinearity. Multiple univariate and candidate models were also run and the Akaike Information Criterion (AICc)

was compared to select the best model. Thus, the univariate model with Age Class had the lowest AIC value of 644.66, showing that age was the major factor responsible for understory community assemblage across fallows of different ages (Table. 14).

Table 14. Model estimates for the best-ranked model.

Predictor	Estimate	SE	z-value	p-value
Intercept (Forest)	1.406	0.099	14.201	0.001***
1-year fallow	0.405	0.128	3.172	0.002***
5-year fallow	0.203	0.133	1.524	0.128
15-year fallow	0.137	0.135	1.013	0.311
25-year fallow	0.386	0.128	3.005	0.003***
35-year fallow	0.12	0.136	0.882	0.378

3.5 Insect (Beetle) community

Despite sampling efforts i.e., 150 pitfall traps across all fallow age classes and forest sites, very few beetle specimens were recorded during the study period. Though ants of subfamily Formicinae and Myrmicinae (no. of all individuals across sites >100) and other insect species such as grasshoppers (>10), millipedes (>5), etc. were noticed in the pitfall trap. Therefore, analyses of beetle diversity and community composition could not be performed.

4. DISCUSSION

4.1. Tree community structure across fallows of different ages

The study investigated the patterns of the plant community structure of the shifting cultivation fallows in Nampong, Arunachal Pradesh. For trees, the species richness was observed to be highest in the old-growth forest and generally lower in the fallow sites. The highest species richness was observed in the forest. The shifting cultivation fallows showed a gradual change in the tree communities of across ages. Gradual increase in structural complexity, canopy and leaf litter has been noticed across the fallows of different ages and the forest. The one-year-old fallow was devoid of trees and as a result the canopy cover was absent. The fallow mostly contained herbs, some shrubs and sapling along with remains of previous cultivated crops. Whereas the five-year-old fallow showed the establishment of the woody vegetation. although the fallow consisted of some trees, shrubs and herbs, the canopy was mostly open with very limited leaf litter accumulation. High light and exposed conditions favored the growth of tree species such as Macaranga, Ficus etc. By 15 years, the fallow showed increase in canopy cover and a greater number of species of trees and bamboo brakes along with some herbs, shrubs. The 25-year-old fallow showed further canopy development and increased leaf litter accumulation. In this stage there was replacement of many species. The 35-year-old fallow consist of trees, bamboo brakes, shrubs and very few herbs and increasing canopy and leaf litter cover indicating the community development towards the forest. The forest was fully closed canopy and thick leaf litter layer and consisted of trees, lianas, some shrubs, and hardly any herbs species. The results show that age influences the change in the community composition of the area.

The diversity increased from younger 5-year-old fallow to the forest areas. But, again the dip in the diversity and richness noticed in the 25-year-old fallow may be due to the competition between the pioneer species and late successional species ((T et al., 2024). The decline

observed may be due to increasing competition between pioneer species and mid successional and late successional species (Cantera et al., 2024). This may also be due to non-linear replacement of species following disturbance and local conditions, dispersal limitation and disturbance history might influence the species richness of the area (Lanta et al., 2023)

There was a gradual change in the species assemblage from younger fallow to forest. Though many overlaps can be seen among the fallow of younger ages, the overlap with the forest is relatively less, indicating the community differences. The PERMANOVA revealed significant difference between the tree communities of different age classes. The age of the fallow explained 11.9 % of the variation. This indicates that many other factors influence the community composition of the area (Lavrishchev et al., 2024)

The 5 and 15 year fallow was mostly characterized by *Zanthoxylum rhetsa*, *Ficus varigeta*. The presence of *Zanthoxylum rhetsa* is the sign of a young fallow as it is a spice grown during the cultivation and the presence of *Ficus variegata* indicates its association with open disturbed habitats (Hendrayana et al., 2025). The mid successional stages mostly comprised *Albizia sp., Agalia spectabilis* and also *Dipterocarpus macrocarpus* in the 35-year-old fallow. The presence of species such as *Agalia spectabilis, Livstonia sp., Chisocheton cumingianus.* shows the increase in the recruitment of new species and showing some commonality within the sites advancing towards species of the forest community. The forest was characterized by species such as *Mesua ferrea, Shorea assamica* and *Terminalia chebula* (Nath et al., 2005). These species are components of mature forests, which are generally shade-tolerant. *Dipterocarpus macrocarpus* also occurred in many of the age classes, namely 15, 35 and forest, their presence in the young fallow may be due to seed availability, dispersal through birds and animals (Gonzales et al., 2009) and closeness to forest sites (Charles et al., 2016). Thus, the indicator species analysis shows a gradual shift from one species to another across the fallow classes and the forest suggesting the recovery of the fallows towards forest community.

Different species were responsible for community dissimilarity. The early successional fallow of 5 and 15 indicated species like *Trema orientalis, Croton persimilis* and *Macranga denticulata* which are identified as early colonisers. The 15 and 25 showed that *Musa* sp.1 and *Bamboo* sp. 1 influence this age class. This may be the reason for lower diversity indices observation in the fig.23 with bamboo leading to cover much of the space as thus, affecting the presence of other species (Park & Bang, 2024). As the age progressed the shift to species like *Castanopis indica, Mesua ferrea, Dipterocarpus macrocarpus* were the species responsible for the community dissimilarity. The replacement of species reflects the transition from pioneer to mature forest species. The change in the community could be seen across age classes, but the accumulation curves show the huge difference between the species richness between the fallow and the forest, indicating the huge amount of time it will take for the fallows to recover to mature forest (Murdjoko et al., 2022). This suggests the recovery of tree community is a slow and prolonged process. The delayed convergence may also be attributed to seed limitation and dispersal limitation (Van Breugel et al., 2025) as many depend on nearby forest patches and dispersers such as animals and birds for regeneration. The decline in the dispersers through habitat degradation and anthropogenic pressures may also constrain regeneration and further prolong the recovery (Carvalho & Pizo, 2026). Additionally, the forest species are characterized by slow growth rates and specific requirements which may restrict their establishment in the fallows. The effects of past and repeated disturbances may further alter the conditions by further extending the recovery periods to several decades (Elsy et al., 2023).

4.2. Understory community structure across fallows of different ages

Across fallows of different ages and the fallows, the richness increased from younger fallows to old fallows. This pattern is explained with the classical models of succession where species richness increases as the age increases and the environmental conditions become favorable for colonization and establishment (Gogoi et al., 2020). Though the species richness of the understory community increases from young fallows to old fallows, the Shannon diversity of the understory community differed among the fallow of different ages and the forest (Panzou et al., 2024). The 25-year-old fallow supported the highest diversity of understory species, this may be due to Intermediate disturbance hypothesis proposed by Connell, 1978, which states that the diversity is highest at intermediate levels of disturbance, where both the pioneer and the late successional species coexist (Meyer et al., 2021). This has been noticed in the field with mix of species in the mid successional fallows along with some cane species coming up. Though the diversity was highest in the mid successional stages the difference in the stem size is visually distinct among the fallows and the forest with forest having larger girth (Mirabel et al., 2020). Similar patterns have been reported from shifting cultivation landscapes across Northeast India and Southeast Asia, where intermediate-aged fallows often support the highest plant diversity (Tripathi et al., 2004; Khumbongmayum et al., 2005). Also, the diversity in the 1-year-old is higher than the 5 and 15- year fallows, this may be due to the flush of species such as *Chromolaena odorata, Erigeron sumatrensis, Mikania micrantha* in the one-year-old fallow, which highlights the susceptibility of newly disturbed areas to invasives (Cameroon et al., 2020). The dominance of these invasive species in the younger fallow may suppress the native species regeneration through competition for nutrients, light and space. However, their declining abundance also suggests that the canopy development and recovery of the trees are reducing them (Langmaier & Lapin, 2020). Similar patterns have been noticed in other

recovering forests where increasing canopy closure limits the persistence of the light demanding invasive species (Jones & Yamamoto, 2024d).

The separated clusters with overlaps show the turnover of species following disturbance and the gradual recovery and replacement by the forest associated understory species. The distinct clustering of the 1-year-old fallow indicates that the recently disturbed sites support species that differ a lot from the older fallows and forest. This reflects the dominance of species adaptability to the open habitats and disturbed environments (Martínez-Ramos et al., 2021). As the age increased there is an increasing overlap in the communities suggesting a gradual recovery of the understory (Van Breugel et al., 2007). A clear overlap is also seen in the 35-year-old fallow and forest which shows that the understory community recovery is faster than the tree community recovery (Lebrija-Trejos et al., 2008). This may be because understory herbs, climbers and shrubs have shorter life cycles and faster colonization rates than canopy trees, allowing them to respond more rapidly to improving environmental conditions.

PERMANOVA confirmed the understory community differed significantly among age classes indicating it as a major driver of change. Age class explain approximately 25% of the variation although additional factors such as dispersal, epiphytic characteristics may influence the understory community structure. It was also noticed that the among the different classes the older fallows and the forest plots exhibit greater distances to group centroids than the younger fallow suggesting a more heterogenous community. Greater heterogeneity in older fallows may result from increasing structural complexity, variation in light availability and the coexistence of species with different ecological requirements (Ehbrecht et al., 2026)

The young 1-year old fallow were characterized by *Chromolaena odorata, Erigeron sumatrensis,* whereas intermediate fallows were indicated by species such as *Thysanolaena maxima*, *Albizia* sp., and *Litsea* sp., which shows the recovery and development of woody

understory vegetation. Older fallow and forest sites were indicated with canes and lianas such as *Calamus tenuis*, *Entada* sp., *Wallichia caryotoides*, and *Smilax* sp., and sapling of *Dipterocarpus* sp. These are the species that are associated with mature forest environment and indicates recovery of forest understory community within longer fallow cycles.

Different species drove change between the different age classes. Again, *Chromolaena odorata*, *Erigeron sumatrensis*, and *Ageratum conyzoides* contributed substantially to differences involving young fallows, whereas *Phrynium pubinerve*, *Gnetum montanum*, *Calamus tenuis*, and *Calamus floribundus* increasingly contributed to dissimilarities in older fallows and forest sites. This shift reflects a transition from disturbance adapted vegetation to a recovering shade tolerant understory vegetation.

The repeated occurrence of *Phrynium pubinerve* across multiple ages suggests that this species may play a significant role during intermediate and late stages of understory recovery. Likewise, the increasing abundance of *Gnetum* and *Calamus* species in older fallows reflects the gradual establishment of forest-associated climbers and palms as the fallow recovery proceeds.

Although both tree and understory communities showed clear successional recovery, the two layers differed in the rates of recovery. Understory communities in the older fallow showed a substantial overlap with the forest sites, showing faster recovery by forest species. In contrast the tree communities remained somewhat distinct from the forest site indicating that the recovery of canopy structure and tree species require longer period of time (Lennox et al., 2018). These differences are likely due to shorter life cycles and faster colonization rates of the understory species compared to long lived forest tree species. These findings highlight the importance of maintaining longer fallow cycles and conserving the remaining forest patches

which serve as a source of seeds and propagules which will further aid in the recovery of the shifting cultivation landscapes (Poorter et al., 2021).

4.3. Factors affecting tree community in the fallow sites

Model selection based on AICc showed that age was the strongest factor influencing tree richness across fallow of different ages. It had a greater influence on species accumulation than topographic variables such as slope, elevation and spatial variables such as distance from water and distance from the forest. The importance of age as the driving force is as how classical ecological succession theory explains, which is that as age increases, the disturbance effects slow down thus leading to structural complexity and diversity as age increases (Conell and Slatyer, 1977; Odum, 1969). As fallow age increases, canopy cover develops, litter accumulates, and environmental conditions become increasingly favorable for the establishment of woody species, resulting in greater species richness and structural complexity.

Similar findings have been reported from other studies, where stand age was found to be a stronger predictor of species accumulation than static environmental variables in tropical secondary forests (Van Der Sande et al., 2024, Guariguata and Ostertag, 2001). Norden et al. (2015) further showed that successional trajectories are largely predictable by stand age, with younger fallows dominated by pioneer species and older stands exhibiting greater structural complexity and shade-tolerant species. Although age being the most important driver, did not explain all variation in the tree richness (Valente et al., 2025, Dalmaso et al., 2020). Previous studies have shown that local environment conditions, disturbance history, dispersal limitation can influence this (Uhl et. al., 1988). In my study site, the differences between the topographic variables such as elevation and slope may be low to capture the effects of it in the tree community.

4.4. Factors affecting understory community in the fallow sites

The AICc based model selection indicated that understory community was strongly influenced by fallow age, which further determined the species richness, diversity and community composition across shifting cultivation fallows of different ages. The importance of age likely reflects the substantial changes in environmental conditions that occur during succession (Sharma et al., 2022). As fallow age increases, canopy cover increases, litter accumulates, and habitat complexity increases, leading to changes in light availability, soil moisture, and microclimatic conditions. These changes facilitate the replacement of disturbance-adapted species by increasingly shade-tolerant and forest-associated understory. The strong influence of age is further supported by the NMDS and PERMANOVA analyses, which demonstrated significant shifts in understory community composition across the successional gradient. Older fallows exhibited greater community heterogeneity than younger fallows, suggesting that increasing structural complexity creates a wider range of ecological niches and promotes species coexistence. Overall, the results indicate that fallow age is the primary driver of understory community assembly in the study area, influencing species richness, diversity, community composition, and the transition from disturbance-dominated vegetation to increasingly forest-like understory communities

4.5. Changing nature of shifting cultivation

The results of the present study show how fallow age plays a crucial role in the recovery. Tree community analyses have showed that with age the structural complexity has increased and suggests that shorter cycles may affect the successional process, canopy development, species richness before it can recover. thus, interrupting the recovery process and limiting the establishment of many forests associated species. Shifting cultivation in the study area has undergone many changes in the recent past with fallow cycles decreasing from traditional 20-

30 to 5-12 years. Likewise, it has been noticed in many areas around the world (Bhat et al., 2024). Increasing population, scarcity of land and policy restrictions are some of the reasons for the shorter fallow cycles. However, the study area showed evidence of this practice gradually fading, with the need for more capital and also young people wanting to go outside for more opportunities and thus the jhums are now being converted into the monoculture of Tea plantation, Areca nut, Pineapple etc. (Borah et al., 2018). Though without doubt shifting cultivation leads to deforestation and affects biodiversity, the fallows create a heterogenous mosaics of patches and also support more biodiversity than the monoculture plantation (Mandal & Raman, 2016). Thus, reducing fallow age may reduce opportunities for natural recovery and may alter ecological processes. In the study area, shifting cultivation provides resources such as food and income for many, as it is the only source of income, especially for women who support their households. In addition, shifting cultivation is not only a livelihood strategy but also contributes to the local economy of the area, as the produce is sold in local markets. This suggests future policy and land use planning needs promotion of sustainable fallow management along with conservation of already existing forest patches as seed source but, also keeping in mind the cultural and economic significance of these practices among indigenous communities (Martin et al., 2023).

5. LIMITATIONS OF THE STUDY

Although, findings highlight age as the dominant factor that influences tree richness, some of the limitation of the study is also substitution of long-term monitoring with chrono sequence approach which assumes that they have similar conditions. Along with it the data failed to capture other factors such as seed dispersal soil nutrients and microclimate. The data also didn't capture functional traits which could have explained better about the contribution of the ecosystem functions such as nutrient cycling and resilience. The study did not capture the socio-economic surveys which could have helped understand the economic value of the

shifting cultivation in terms of economic cost and benefit. Despite sampling across fallow, community analysis couldn't be performed for beetles. But in contrast, the pitfall captured several ground-dwelling arthropods including ants, grasshoppers and other invertebrates. The low capture of beetles may be due to season as they are reported to hibernate (Dunn, 2017). It may also be due to the sampling method applied, which is a pitfall trap using surfactant solution and in which sampling techniques such as baited pitfall traps along visual encounter survey and active hand sampling might have been more effective. Other factors such as leaf litter, vegetation, decaying microhabitats may also affect the beetle community, therefore incorporation of longer sampling across seasons along with more relevant sampling techniques might complement the collection of beetles.

6. CONSERVATION IMPLICATIONS

The findings indicate that forest is important for the recovery of shifting cultivation fallows in the landscape. These forest act as seed banks as well as genetic bank which further serves as the seed source that help in the recovery of the fallow. Therefore, without conserving these patches, the recovery of the fallows will be hampered severely as they depend on these seed banks for recovery. Therefore, in this context community conserved areas (CCAs) presents a strategy while also guided by the cultural and traditional rules of the specific area along with ecological processes. CCA presents itself as a model strategy for conservation of forest plots, but it comes with challenges and limitations which include resource conflicts, economic pressures.

7. CONCLUSION

Shifting cultivation remains an important land-use system in the Eastern Himalaya, and the regeneration of fallow vegetation plays a crucial role in maintaining biodiversity and ecosystem functions within these landscapes. The present study demonstrated that plant communities undergo changes during the course of secondary succession following the abandonment of cultivation. As fallow age increased, vegetation became more diverse and structurally complex, reflecting the gradual recovery of forest characteristics. The results indicate that species composition changes continuously along the successional gradient through the replacement of pioneer species by species associated with more mature stages of forest development. Younger fallows were characterized by species adapted to open and disturbed environments, whereas older fallows increasingly supported species commonly associated with mature forest habitats. This pattern highlights the importance of secondary succession in facilitating ecological recovery and promoting the re-establishment of forest biodiversity. Overall, the study highlights the critical role of fallow age in determining patterns of plant community recovery in shifting cultivation landscapes. Maintaining sufficiently long fallow periods is essential for allowing successional processes to proceed and for supporting the restoration of biodiversity and ecosystem integrity. In the face of increasing pressure to shorten fallow cycles, sustainable management practices that promote adequate regeneration periods and along with the preservation of the remaining forest, will play an important role for conserving the ecological resilience of forest ecosystems in Arunachal Pradesh and the wider Eastern Himalayan and Northeastern region with involvements from stakeholders.

8. REFERENCES

Achard, F., Eva, H. D., Stibig, H. J., Mayaux, P., Gallego, J., Richards, T., & Malingreau, J. P. (2002). Determination of deforestation rates of the world's humid tropical forests. Science, 297(5583), 999–1002.

Anderegg, G. C., Bowers, M. D., & McCain, C. M. (2022, January). STORAGE FACTORS INFLUENCING ETHANOL CONCENTRATION OF FLUID-PRESERVED INSECTS. In *Collection Forum* (Vol. 36, No. 1, pp. 23-39). Soc. for the Pres. of Natural History Collections.

Bhat, Y., Nandy, S., Das, K., Tamang, M., Padalia, H., Nath, A. J., Majumdar, K., Pebam, R., Thongni, P., Kurmi, B., Das, A. K., Kushwaha, S. P., & Singh, R. P. (2024). Vegetation disturbance and regrowth dynamics in shifting cultivation landscapes. Scientific Reports, 14(1), 28324. https://doi.org/10.1038/s41598-024-78089-9

Borah, J. R., Evans, K. L., & Edwards, D. P. (2018). Quantifying carbon stocks in shifting cultivation landscapes under divergent management scenarios relevant to REDD+. Ecological Applications, 28(6), 1581–1593. https://doi.org/10.1002/eap.1764

Bowman, D. M., Woinarski, J. C. Z., Sands, D. P. A., Wells, A., & McShane, V. J. (1990). Slash-and-burn agriculture in the wet coastal lowlands of Papua New Guinea: Response of birds, butterflies and reptiles. Journal of Biogeography, 227–239.

Brown, K. S. (1997). Diversity, disturbance, and sustainable use of Neotropical forests: Insects as indicators for conservation monitoring. Journal of Insect Conservation, 1(1), 25–42.

Cairns, M. (Ed.). (2007). Voices from the forest: Integrating indigenous knowledge into sustainable upland farming. Earthscan.

Cairns, M. F. (2015). Shifting cultivation and environmental change: Indigenous people, agriculture and forest conservation. Routledge.

Cameroon, N. H. O. C. P. B. 1. Y., Tchiengue, B., Neumann, K., & Rüdiger, W. (2020). Early succession in the tropical forest in southern Cameroon, Central Africa. Tropical Plant Research, 7(1), 126–136. https://doi.org/10.22271/tpr.2020.v7.i1.017

Cantera, I., Carteron, A., Guerrieri, A., Marta, S., Bonin, A., Ambrosini, R., Anthelme, F., Azzoni, R. S., Almond, P., Gazitúa, P. A., Cauvy-Fraunié, S., Lievano, J. L. C., Chand, P., Sharma, M. C., Clague, J., Rapre, J. a. C., Compostella, C., Encarnación, R. C., Dangles, O., . . . Ficetola, G. F. (2024). The importance of species addition 'versus' replacement varies over succession in plant communities after glacier retreat. Nature Plants, 10(2), 256–267. https://doi.org/10.1038/s41477-023-01609-4

Carvalho, R. B., & Pizo, M. A. (2026). The potential of generalist and Disturbance-Tolerant seed dispersers in the restoration of neotropical degraded areas. Biotropica, 58(3). https://doi.org/10.1111/btp.70197

Charles, L. S., Dwyer, J. M., & Mayfield, M. M. (2016). Rainforest seed rain into abandoned tropical Australian pasture is dependent on adjacent rainforest structure and extent. Austral Ecology, 42(2), 238–249. https://doi.org/10.1111/aec.12426

Chazdon, R. L. (2003). Tropical forest recovery: Legacies of human impact and natural disturbances. Perspectives in Plant Ecology, Evolution and Systematics, 6(1–2), 51–71.

Chazdon, R. L. (2008a). Beyond deforestation: Restoring forests and ecosystem services on degraded lands. Science, 320(5882), 1458–1460.

Chazdon, R. L. (2008b). Chance and determinism in tropical forest succession. Tropical Forest Community Ecology, 1, 384–408.

Chazdon, R. L. (2014). Second growth: The promise of tropical forest regeneration in an age of deforestation. University of Chicago Press.

Chazdon, R. L., Pearcy, R. W., Lee, D. W., & Fetcher, N. (1996). Photosynthetic responses of tropical forest plants to contrasting light environments. In Tropical Forest Plant Ecophysiology (pp. 5–55). Springer.

Clark, D. B., & Clark, D. A. (2000). Landscape-scale variation in forest structure and biomass in a tropical rain forest. Forest Ecology and Management, 137(1–3), 185–198.

Connell, J. H., & Slatyer, R. O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. The American Naturalist, 111(982), 1119–1144.

Dalmaso, C. A., Marques, M. C. M., Higuchi, P., Zwiener, V. P., & Marques, R. (2020). Spatial and temporal structure of diversity and demographic dynamics along a successional gradient of tropical forests in southern Brazil. Ecology and Evolution, 10(7), 3164–3177. https://doi.org/10.1002/ece3.5816

Dressler, W. H., Wilson, D., Clendenning, J., Cramb, R., Keenan, R., Mahanty, S., ... & Lasco, R. D. (2017). The impact of swidden decline on livelihoods and ecosystem services in Southeast Asia. Ambio, 46(3), 291–310.

Dunn, G. A. (2017). Collections of hibernating ground beetles (Coleoptera: carabidae). The Great Lakes Entomologist, 16(1). https://doi.org/10.22543/0090-0222.1459

Ehbrecht, M., Lehmann, T., Escobar, S., Donoso, D. A., Endara, M., Guevara-Andino, J. E., & Blüthgen, N. (2026). Recovery of forest structural complexity during secondary succession in a human-modified neotropical landscape. Journal of Ecology, 114(1). https://doi.org/10.1111/1365-2745.70241

Elsy, A. D., Pfeifer, M., Jones, I. L., DeWalt, S. J., Lopez, O. R., & Dent, D. H. (2023). Incomplete recovery of tree community composition and rare species after 120 years of tropical forest succession in Panama. Biotropica, 56(1), 36–49. https://doi.org/10.1111/btp.13275

Facelli, J. M., & Pickett, S. T. (1991). Plant litter: Its dynamics and effects on plant community structure. The Botanical Review, 57(1), 1–32.

Finegan, B. (1996). Pattern and process in neotropical secondary rain forests: The first 100 years of succession. Forest Ecology and Management, 77(1–3), 101–120.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., ... & Snyder, P. K. (2005). Global consequences of land use. Science, 309(5734), 570–574.

Fox, J., Fujita, Y., Ngidang, D., Peluso, N., Potter, L., Sakuntaladewi, N., ... & Thomas, D. (2009). Policies, political-economy, and swidden in Southeast Asia. Human Ecology, 37(3), 305–322.

Gatti, R. C., Reich, P. B., Gamarra, J. G., Crowther, T., Hui, C., Morera, A., ... & Park, M. (2022). The number of tree species on Earth. Proceedings of the National Academy of Sciences, 119(6), e2115329119.

Gogoi, A., Sahoo, U. K., & Saikia, H. (2020). Vegetation and ecosystem carbon recovery following shifting cultivation in Mizoram-Manipur-Kachin rainforest eco-region, Southern Asia. Ecological Processes, 9(1). https://doi.org/10.1186/s13717-020-00225-w

Gonzales, R. S., Ingle, N. R., Lagunzad, D. A., & Nakashizuka, T. (2009). Seed dispersal by birds and bats in lowland Philippine Forest Successional area. Biotropica, 41(4), 452–458. https://doi.org/10.1111/j.1744-7429.2009.00501.x

Guariguata, M. R., & Ostertag, R. (2001). Neotropical secondary forest succession: Changes in structural and functional characteristics. Forest Ecology and Management, 148(1–3), 185–206.

Guha, R., & Gadgil, M. (1989). State forestry and social conflict in British India. Past & Present, 123, 141–177.

Hendrayana, Y., Adhya, I., Kosasih, D., Widhiono, I., Alfahri, F. F., Apriantika, I. S., & Vaines, S. (2025). Selection of Ficus spp. species for rehabilitation of degraded land in

Kuningan District, West Java, Indonesia. Biodiversitas Journal of Biological Diversity, 26(7). https://doi.org/10.13057/biodiv/d260711

Holmgren, J., Nilsson, M., & Olsson, H. (2003). Estimation of tree height and stem volume on plots using airborne laser scanning. *Forest Science*, *49*(3), 419-428.

Jones, C. C., & Yamamoto, M. H. (2024d). Long-term patterns and mechanisms of plant invasions in forests: the role of forest age and land-use history. Biological Invasions, 26(9), 3125–3145. https://doi.org/10.1007/s10530-024-03365-8

Klanderud, K., Mbolatiana, H. Z. H., Vololomboahangy, M. N., Radimbison, M. A., Roger, E., Totland, Ø., & Rajeriarison, C. (2010). Recovery of plant species richness and composition after slash-and-burn agriculture in Madagascar. Biodiversity and Conservation, 19(1), 187–204.

Langmaier, M., & Lapin, K. (2020). A systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. Frontiers in Plant Science, 11, 524969. https://doi.org/10.3389/fpls.2020.524969

Lanta, V., Mudrák, O., Dvorský, M., Bartoš, M., Šebek, P., Čížek, L., & Doležal, J. (2023). Multifaceted diversity changes reveal community assembly mechanisms during early stages of post-logging forest succession. Plant Ecology, 224(4), 335–347. https://doi.org/10.1007/s11258-023-01306-4

Lanta, V., Mudrák, O., Dvorský, M., Bartoš, M., Šebek, P., Čížek, L., & Doležal, J. (2023). Multifaceted diversity changes reveal community assembly mechanisms during early stages of post-logging forest succession. Plant Ecology, 224(4), 335–347. https://doi.org/10.1007/s11258-023-01306-4

Lavrishchev, A., Litvinovich, A., Abakumov, E., Kimeklis, A., Gladkov, G., Andronov, E., & Polyakov, V. (2024). Soil microbiome of abandoned plaggic podzol of Different-Aged fallow

Lands and native podzol in South Taiga (Leningrad region). Agronomy, 14(3), 429. https://doi.org/10.3390/agronomy14030429

Lebrija-Trejos, E., Bongers, F., Pérez-García, E. A., & Meave, J. A. (2008). Successional change and resilience of a very dry tropical deciduous forest following shifting agriculture. Biotropica, 40(4), 422–431. https://doi.org/10.1111/j.1744-7429.2008.00398.x

Lennox, G. D., Gardner, T. A., Thomson, J. R., Ferreira, J., Berenguer, E., Lees, A. C., Mac Nally, R., Aragão, L. E. O. C., Ferraz, S. F. B., Louzada, J., Moura, N. G., Oliveira, V. H. F., Pardini, R., Solar, R. R. C., Mello, F. Z. V., Vieira, I. C. G., & Barlow, J. (2018). Second rate or a second chance? Assessing biomass and biodiversity recovery in regenerating Amazonian forests. Global Change Biology, 24(12), 5680–5694. https://doi.org/10.1111/gcb.14443

Lohbeck, M., Lebrija-Trejos, E., Martínez-Ramos, M., Meave, J. A., Poorter, L., & Bongers, F. (2015). Functional trait strategies of trees in dry and wet tropical forests. PLoS ONE, 10(4), e0123741.

Luff, M. L. (1975). Some features influencing the efficiency of pitfall traps. Oecologia, 345–357.

Magurran, A. E. (2003). Measuring biological diversity. John Wiley & Sons.

Mandal, J., & Raman, T. R. S. (2016). Shifting agriculture supports more tropical forest birds than oil palm or teak plantations in Mizoram, northeast India. Ornithological Applications, 118(2), 345–359. https://doi.org/10.1650/condor-15-163.1

Martin, D. A., Llopis, J. C., Raveloaritiana, E., Coomes, O. T., Andriamihaja, O. R., Bruun, T. B., Heinimann, A., Mertz, O., Rakotonarivo, O. S., & Zaehringer, J. G. (2023). Drivers and consequences of archetypical shifting cultivation transitions. People and Nature, 5(2), 529–541. https://doi.org/10.1002/pan3.10435

Martínez-Ramos, M., Del Mar Gallego-Mahecha, M., Valverde, T., Vega, E., & Bongers, F. (2021). Demographic differentiation among pioneer tree species during secondary succession

of a Neotropical rainforest. Journal of Ecology, 109(10), 3572–3586. https://doi.org/10.1111/1365-2745.13738

Meyer, P., Schmidt, M., Feldmann, E., Willig, J., & Larkin, R. (2021). Long-term development of species richness in a central European beech (*Fagus sylvatica)* forest affected by windthrow—Support for the intermediate disturbance hypothesis? Ecology and Evolution, 11(18), 12801–12815. https://doi.org/10.1002/ece3.8028

Mirabel, A., Hérault, B., & Marcon, E. (2020). Diverging taxonomic and functional trajectories following disturbance in a Neotropical forest. The Science of the Total Environment, 720, 137397. https://doi.org/10.1016/j.scitotenv.2020.137397

Montgomery, R. A., & Chazdon, R. L. (2001). Forest structure, canopy architecture, and light transmittance in tropical wet forests. Ecology, 82(10), 2707–2718.

Murdjoko, A., Brearley, F. Q., Ungirwalu, A., Djitmau, D. A., & Benu, N. M. H. (2022). Secondary Succession after Slash-and-Burn Cultivation in Papuan Lowland Forest, Indonesia. Forests, 13(3), 434. https://doi.org/10.3390/f13030434

Myers, N. (1980). The present status and future prospects of tropical moist forests. Environmental Conservation, 7(2), 101–114.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), 853–858.

Nath, P., Arunachalam, A., Khan, M., Arunachalam, K., & Barbhuiya, A. (2005). Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India. Biodiversity and Conservation, 14(9), 2109–2135. https://doi.org/10.1007/s10531-004-4361-1

Norden, N., Chazdon, R. L., Chao, A., Jiang, Y. H., & Vílchez-Alvarado, B. (2009). Resilience of tropical rain forests: Tree community reassembly in secondary forests. Ecology Letters, 12(5), 385–394.

Odum, E. P. (1969). The strategy of ecosystem development. Science, 164(3877), 262–270.

P., Becknell, J., . . . Sciences, E. (2024). Tropical forest succession increases trtaxonomic and functional tree richness but decreases evenness. Utrecht University Repository (Utrecht University). https://dspace.library.uu.nl/handle/1874/471859

Page, N., Datta, A., & Basu, B. (2022). Trees of Arunachal Pradesh: a field guide. Nature Conservation Foundation.

Panzou, G. J. L., Mankessi, F., Ngambou, F. C. T., Douh, C., Ndzai, S. F., Nzala, D., & Koubouana, F. (2024). Natural forest regeneration over a fallow age chronosequence in central African moist forests. African Journal of Ecology, 62(2). https://doi.org/10.1111/aje.13255

Park, S., & Bang, H. (2024). Analysis of the effect of the expansion of bamboo forest on forest plant communities. Journal of the Faculty of Agriculture Kyushu University, 69(2), 73–82. https://doi.org/10.5109/7234020

Pawar, S. S., Rawat, G. S., & Choudhury, B. C. (2004). Recovery of frog and lizard communities following primary habitat alteration in Mizoram, Northeast India. BMC Ecology, 4(1), 10.

Pillay, R., Venter, M., Aragon-Osejo, J., González-del-Pliego, P., Hansen, A. J., Watson, J. E., & Venter, O. (2022). Tropical forests are home to over half of the world's vertebrate species. Frontiers in Ecology and the Environment, 20(1), 10–15.

Poorter, L., Craven, D., Jakovac, C. C., Van Der Sande, M. T., Amissah, L., Bongers, F., ... & Hérault, B. (2021). Multidimensional tropical forest recovery. Science, 374(6573), 1370–1376.

Poorter, L., Craven, D., Jakovac, C. C., Van Der Sande, M. T., Amissah, L., Bongers, F., Chazdon, R. L., Farrior, C. E., Kambach, S., Meave, J. A., Muñoz, R., Norden, N., Rüger, N., Van Breugel, M., Zambrano, A. M. A., Amani, B., Andrade, J. L., Brancalion, P. H. S., Broadbent, E. N., . . . Hérault, B. (2021). Multidimensional tropical forest recovery. Science, 374(6573), 1370–1376. https://doi.org/10.1126/science.abh3629

Ramakrishnan, P. S. (1992). Shifting agriculture and sustainable development: An interdisciplinary study from north-eastern India.

Ramakrishnan, P. S. (1993). Shifting agriculture and sustainable development: An interdisciplinary study from north-eastern India. Oxford University Press.

Raman, T. S. (2001). Effect of slash-and-burn shifting cultivation on rainforest birds in Mizoram, northeast India. Conservation Biology, 15(3), 685–698.

Raman, T. S., Rawat, G. S., & Johnsingh, A. J. T. (1998). Recovery of tropical rainforest avifauna following shifting cultivation in Mizoram. Journal of Applied Ecology, 35(2), 214–231.

Ranjan, R., & Upadhyay, V. P. (1999). Ecological problems due to shifting cultivation. Current Science, 77(10), 1246–1250.

Rodgers, W. A., & Panwar, H. S. (1988). Planning a wildlife protected area network in India.

Rozendaal, D. M., Bongers, F., Aide, T. M., Alvarez-Dávila, E., Ascarrunz, N., Balvanera, P., ... & Poorter, L. (2019). Biodiversity recovery of Neotropical secondary forests. Science Advances, 5(3), eaau3114.

Sharma, S. B., Kumar, S., Ovung, E. Y., & Konsam, B. (2022). Vegetation dynamics and soil nutrients across different shifting cultivation fallows in Montane Subtropical Forest of Mizoram, NE India. Acta Oecologica, 115, 103833. https://doi.org/10.1016/j.actao.2022.103833

T, V. D. S. M., Poorter, L., Derroire, G., Marcos, D. E. S. M., Lohbeck, M., Müller, S. C., Bhaskar, R., Michiel, V. B., Dupuy-Rada, J. M., Durán, S. M., Jakovac, C. C., Paz, H., Rozendaal, D., MA, Brancalion, P., Craven, D., Francisco, M. A., Almeida, J. S., Balvanera,

Toky, O. P., & Ramakrishnan, P. S. (1981). Run-off and infiltration losses related to shifting agriculture (jhum) in northeastern India. Environmental Conservation, 8(4), 313–321.

Toky, O. P., & Ramakrishnan, P. S. (1983). Secondary succession following slash and burn agriculture in North-Eastern India: I. Biomass, litterfall and productivity. Journal of Ecology, 735–745.

Valente, C., Hollunder, R., Moura, C., Siqueira, G., Dias, H., & Da Silva, G. (2025). Assessing forest succession along environment, trait, and composition gradients in the Brazilian Atlantic Forest. Forests, 16(7), 1169. https://doi.org/10.3390/f16071169

Van Breugel, M., Bongers, F., & Martínez-Ramos, M. (2007). Species dynamics during early secondary forest succession: recruitment, mortality and species turnover. Biotropica, 39(5), 610–619. https://doi.org/10.1111/j.1744-7429.2007.00316.x

Van Breugel, M., Hall, J. S., Bailon, M., & Craven, D. (2025). Persistent effects of landscape context on recruitment dynamics during secondary succession of tropical forests. Global Change Biology, 31(1), e70037. https://doi.org/10.1111/gcb.70037

Van Der Sande, M. T., Poorter, L., Derroire, G., Santo, M. M. D. E., Lohbeck, M., Müller, S. C., Bhaskar, R., Van Breugel, M., Dupuy-Rada, J. M., Durán, S. M., Jakovac, C. C., Paz, H., Rozendaal, D. M. A., Brancalion, P., Craven, D., Ardilla, F. M., Almeida, J. S., Balvanera, P., Becknell, J., . . . Bongers, F. (2024). Tropical forest succession increases tree taxonomic and functional richness but decreases evenness. Global Ecology and Biogeography, 33(8). https://doi.org/10.1111/geb.13856

Van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., ... & Ziegler, A. D. (2012). Trends, drivers and impacts of changes in swidden cultivation. Global Environmental Change, 22(2), 418–429.

Wickham, H., Chang, W., Henry, L., Pedersen, T. L., Takahashi, K., Wilke, C., Woo, K., Yutani, H., Dunnington, D., & Van Den Brand, T. (2007). ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics [Dataset]. https://doi.org/10.32614/cran.package.ggplot2

Zachos, F. E., & Habel, J. C. (Eds.). (2011). Biodiversity hotspots: Distribution and protection of conservation priority areas. Springer.

10.APPENDIX:

List of species recorded in fallow land and forested areas.

Sl. No.	Botanical name	Common / Local name	Habit
1	*Aesculus assamica Griff.*		Tree
2	*Ageratum conyzoides* L.		Herb
3	*Aglaia edulis* (Roxb.) Wall.		Tree
4	*Aglaia spectabilis* (Miq.) S.S.Jain & S.Bennet		Tree
5	*Ailanthus integrifolia* Lam.		Tree
6	*Albizia chinensis* (Osbeck) Merr.		Tree
7	*Allaeanthus kurzii* Hook.f.		Climber
8	*Allium sp.*		Herb
9	*Alocasia macrorrhizos* (L.) G.Don		Herb
10	*Alstonia scholaris* (L.) R.Br		Tree
11	*Liquidambar excelsa (Noronha) Oken*		Tree
12	*Artocarpus chaplasha* Roxb.	Wild Jackfruit	Tree
13	*Baccaurea ramiflora* Lour.		Tree
14	*Bamboo sp.*		Grass
15	*Bischofia javanica* Blume		Tree

16	*Blumea balsamifera* (L.) DC.		Shrub
17	*Bombax ceiba* L.	Semal	Tree
18	*Brassaiopsis hispida* Seem.		Shrub
19	*Bridelia sp.*		Shrub
20	*Butea monosperma* (Lam.) Kuntze		Tree
21	*Calamus floribundus* Griff.		Palm (Rattan)
22	*Calamus tenuis* Roxb.	Jheng	Palm (Rattan)
23	*Camellia sinensis* (L.) Kuntze		Shrub
24	*Canarium resiniferum* Bruce ex King		Tree
25	*Canarium strictum* Roxb.	*Dhuna*	Tree
26	*Carissa sp.*		Shrub
27	*Caryota urens* L.		Tree
28	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Vajang	Tree
29	*Castanopsis tribuloides* (Sm.) A.DC.		Tree
30	*Chisocheton cumingianus* (C.DC.) Harms		Tree
31	*Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill		Tree
32	*Chromolaena odorata* (L.) R.M.King & H.Rob.		Shrub (Invasive)

33	*Chukrasia tabularis* A.Juss.		Tree
34	*Cissus sp.*		Climber
35	*Clerodendrum sp.*		Shrub
36	*Combretum sp.*		Liana
37	*Croton persimilis* Müll.Arg.	Jom	Tree
38	*Dioscorea sp.*		Climber
39	*Dipterocarpus macrocarpus* Vesque / *Dipterocarpus retusus* Blume	Hollong	Tree
40	*Diplazium sp.*	Krindong	Fern
41	*Duabanga grandiflora* (Roxb. ex DC.) Walp.		Tree
42	*Dysoxylum mollissimum (*Spreng.) Blume ex G.Don		Tree
43	*Elaeocarpus rugosus* Roxb. ex G.Don		Tree
44	*Elaeocarpus sphaericus* (Gaertn.) Heer		Tree
45	*Elatostema sp.*		Herb
46	*Entada sp.*		Liana
47	*Erigeron sumatrensis* Retz.		Herb (Invasive
48	*Erythropalum scandens* Blume		Climber
49	*Falconeria insignis* Royle		Tree
50	*Ficus auriculata* Lour.	Sapthong	Tree

51	*Ficus geniculata* Kurz.		Tree
52	*Ficus punctata* Thunb.		Tree
53	*Ficus semicordata* Miq.		Tree
54	*Ficus variegata* Blume.		Tree
55	*Gnetum montanum* Markgr.		Liana
56	*Goniothalamus sesquipedalis* (Colebr. ex Wall.) Hook.f. & Thomson		Shrub
57	*Gynocardia odorata* R. Br.		Tree
58	*Hodgsonia macrocarpa* (Blume) Cogn.		Climber
59	*Horsfieldia kingii* (Hook.f.) Warb.		Tree
60	*Ixora sp.*		Shrub
61	*Knema erratica* (Hook.f. & Thomson) J.Sinclair		Tree
62	*Kydia calycina* Roxb.		Tree
63	*Lasianthus sp.*		Shrub
64	*Leea sp.*		Shrub
65	*Litsea monopetala* (Roxb.) Pers.		Tree
66	*Livistona jenkinsiana* Griff.		Tree
67	*Lygodium sp.*		Climbing fern
68	*Macaranga denticulata* (Blume) Müll.Arg.		Tree

69	*Macaranga indica* Wight		Tree
70	*Maesa indica* (Roxb.) Sweet		Shrub
71	*Magnolia champaca* (L.) Baill. ex Pierre		Tree
72	*Magnolia hodgsonii* (Hook.f. & Thomson) H.Keng		Tree
73	*Mallotus tetracoccus* (Roxb.) Kurz		Tree
74	*Mangifera sylvatica* Roxb.		Tree
75	*Margaritaria indica* (Dalzell) Airy Shaw		Tree
76	*Meliosma pinnata* (Roxb.) Maxim.		Tree
77	*Mesua ferrea* L.		Tree
78	*Mikania micrantha* Kunth		Climber (Invasive)
79	*Mucuna macrocarpa* Wall.		Liana
80	*Musa sp.*		
81	*Myxopyrum smilacifolium* (Wall.) Blume		Liana
82	*Neolamarckia cadamba* (Roxb.) Bosser	Kadam	Tree
83	*Osbeckia sp.*		Shrub
84	*Oxalis corniculata* L.		Herb
85	*Peliosanthes sp.*		Herb

86	*Phoebe cooperiana* P.C.Kanjilal & Das	Khupcho	Tree
87	*Phrynium pubinerve* Blume	Nyipja	Herb
88	*Phymatosorus sp.*		Fern
89	*Piper sp.*		Climber
90	*Pothos sp.*		Climber
91	*Pteridium sp.*		Fern
92	*Pterospermum acerifolium*		Tree
93	*Pycnarrhena pleniflora* Miers ex Hook.f. & Thomson	Holok lota	Shrub/Liana
94	*Salacca secunda* Griff.		Shrub
95	*Sapindus mukorossi* Gaertn.		Tree
96	*Sarcochlamys pulcherrima* (Roxb.) Gaudich.		Shrub
97	*Saurauia sp.*		Tree
98	*Schima wallichii* (DC.) Korth.		Tree
99	*Selaginella sp.*		Fern
100	*Shorea assamica* Dyer	Mekai	Tree
101	*Smilax roxburghiana* Wall. ex Hook.f.		Climber
102	*Spondias pinnata (*L.f.) Kurz		Tree
103	*Stemona tuberosa* Lour.		Climber
104	*Stephania sp.*		Climber

105	*Sterculia villosa* Roxb. ex Sm.		Tree
106	*Syzygium claviflorum* (Roxb.) Wall. ex Steud.		Tree
107	*Terminalia chebula* Retz.	Hilika	Tree
108	*Terminalia myriocarpa* Van Heurck & Müll.Arg.		Tree
109	*Tetrameles nudiflora* R.Br.		Tree
110	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda		Grass
111	*Toona ciliata* M.Roem.		Tree
112	*Trema orientale* (L.) Blume		Tree
113	*Trevesia palmata* (Roxb. ex Lindl.) Vis.		Tree
114	*Wallichia caryotoides* Roxb.		Shrub
115	*Zanthoxylum rhetsa (Roxb.) DC.*	Chikokjaa	Tree
116	*Zingiber sp.*	Tsiing	Herb