RECOVERY OF SMALL MAMMAL COMMUNITIES DURING RESTORATION OF UPLAND EVERGREEN FOREST IN NORTHERN THAILAND

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BACHELOR OF SCIENCE
(ENVIRONMENTAL SCIENCE)

CHIANG MAI UNIVERSITY
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A PROJECT SUBMITTED TO CHIANG MAI UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE (ENVIRONMENTAL SCIENCE)

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This study is dedicated to my parents who never stopped believing in me and taught me to follow my dreams and continually provided moral, emotional and financial support.

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Nay Tun Lin

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ABSTRACT

Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) has spent over 30 years restoring tropical forest ecosystems using the Framework Species Method (FSM). While forest restoration is increasingly prioritized for biodiversity conservation, few studies assess its impact on mammal recovery. Restoring seed-dispersing mammals is especially important, as their return enhances seed dispersal and supports the recovery of ecological functionality. This study tested the hypothesis that the FSM encourages recovery of small mammal communities, when applied to restore upland evergreen forest ecosystem in northern Thailand. From May to November 2024, mammal surveys were carried out, using automatic camera traps in the upper Mae Sa Valley within Doi Suthep-Pui National Park, placed in evergreen forest of two different ages (12- and 24-year-old), restored by the FSM; a nearby area of reference forest (disturbed primary evergreen forest) and a control site (degraded area), where no restoration interventions had been implemented. To interpret the results, Frequency of Detection (FD) was calculated. The camera-traps revealed the presence of 20 mammal species across the study area, including the critically endangered Sunda pangolin (*Manis javanica*) in the reference forest and the 12-year-old forest. The more common species included Common Palm Civet (*Paradoxurus hermaphroditus*), Large Indian Civet (*Viverra zibetha*) and Crab-eating Mongoose (*Herpestes urva*). Mammal activity and species richness in restored plots was around 50% that of reference forest, suggesting steady recovery of

ecological functionality. The similarity of mammal species in two restored forests was 80%. Although there were 71.43 % similarity of mammal species between the younger restoration plot and the reference forest, the older restoration plot shared only 64.29% of the reference forest's species. Highest mammal activity was recorded in the reference forest (FD = 42.94) and the lowest in control habitat (FD = 1.96). FD values in 12- and 24-year-old restoration plots were 43% and 55% of the reference forest value, indicating steady increase in mammal activity as restoration progresses. In 24-year-old restoration plot, 63% of the tree species recorded had established naturally via seed dispersal and more than 75% of them were dispersed by mammals and/or birds. The study supports a key principle of the Framework Species Method (FSM): planting a limited number of tree species can attract seed-dispersing mammals and enhance seed dispersal into restoration plots.

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FSM	The Framework Species Method
FORRU-CMU	Forest Restoration Research Unit – Chiang Mai University
EGF	Evergreen Rain Forest
ANR	Assisted Natural Regeneration
CON	Control site
R12	12-year-old restored forest
R24	24 -year-old restored forest
REF	Reference forest

CHAPTER 1

Introduction

1.1 Background

"Restoration of tropical forests is no longer a pipedream but a realistically achievable goal." (FORRU, 2005).

This is the result of research carried out by many ecological scientists around the world, leading to the development of a range of effective restoration strategies. For the past 30 years, Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) has been developing one such strategy—the framework species method of forest restoration (FSM). It is applicable to moderately degraded sites, which retain some natural regeneration and are close to remnant forest (as a seed source). The technique involves planting 20-30 carefully selected tree species, representative of the reference forest, and caring for them for two or more years (e.g. weeding, applying fertilizer etc.) (FORRU, 2005). The method's success depends on re-colonization of restoration sites by seed-dispersing animals, to increase tree-species richness beyond the originally planted 20-30 tree species.

Although forest ecosystem restoration is now becoming highly prioritized for biodiversity conservation, few studies have measured the effects of restoration on biodiversity recovery, particularly the return of mammal species. This is because many mammal species in tropical forests are nocturnal and difficult to see. Biodiversity recovery is also one of the 4 primary indicators of restoration success, and it is closely interdependent on the other 3 (biomass accumulation, structural diversification and recovery of ecological functionality) (Elliott et al, 2013). Increased seed-dispersal by incoming mammals supports recovery of ecological functionality—re-establishment of a self-sustaining ecosystem that is independent of any further interventions. That involves recovery of all the mechanisms that result in a species-rich understory, ready to replace the planted trees, as they come to the end of their lives, i.e. pollination, seed dispersal, and seedling establishment. The return of seed-dispersing mammals is therefore a vital

component at the start of this process, particularly as mammals can disperse larger seeds than most birds and bats.

This study tested the hypothesis that the FSM encourages recovery of small mammal communities, when applied to restore upland evergreen forest in northern Thailand. Mammal surveys were carried out using automatic camera traps in the upper Mae Sa Valley within Doi Suthep-Pui National Park, placed in evergreen forest of two different ages, restored by the FSM, a nearby area of reference forest (disturbed primary evergreen forest) and a control site (degraded area), where no restoration interventions had been implemented.

1.2 Literature Review

1.2.1 Forest Restoration

Although deforestation is mainly caused by humans, forest recovery on degraded areas can be natural or human-assisted or managed (Lakanavichian, 2006). However, recovery of natural processes can be slow, due to limiting factors, such as lack of seed bank and seed dispersal from forest remnants, microclimatic conditions, soil degradation, competition with exotic grasses and herbaceous weeds, and seed and seedling predation (Aide and Cavelier, 1994; Holl, 2012). Consequently, active forest restoration is an essential key to accelerating forest recovery (Aerts and Honnay, 2011).

Whereas "reforestation", is a broad term, meaning the re-establishment of any kind of tree cover on deforested land (e.g. agroforestry, community forestry, plantations etc.) (FORRU, 2005), "forest restoration" has a more specific meaning. According to Webster's Seventh New Collegiate Dictionary, restoration simply means "bringing back to a former position or condition" or "a representation or reconstruction of the original form". In an ecological context, restoration can be defined as "returning the land to its former use and condition" (Bradshaw and Chadwick, 1980). According to the SER International Primer (2004), ecological restoration is "The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.". It is a specialized form of reforestation that is most appropriate where environmental protection and biodiversity conservation are the primary land-use goals (Elliott et al, 2013).

Forest restoration processes may involve protecting the remaining vegetation such as preventing fire by creating fire breaks or assisting natural regeneration (ANR) i.e., performing any set of activities that enhance the natural processes of forest regeneration such as weeding and applying fertilizer around natural seedlings as well as planting trees and/or sowing seeds (direct seeding) (FORRU, 2005; Elliott et al, 2013). The idea is to remove anthropogenic barriers to tree seedling establishment, i.e., weeds, cattle, fire etc., while assisting natural regeneration.

Before starting any restoration project, it is important to understand the reference forest, an undisturbed or near-natural forest ecosystem that serves as the model for restoration, to establish realistic restoration indicators and to decide which tree species to plant. International restoration guidelines define it as "the condition of the ecosystem as it would be had it not been degraded, adjusted as necessary to accommodate changed or predicted change in biotic or environmental conditions (e.g., climate change)" (Gann et al, 2019).

It is also crucial to know how degraded the restoration site is, because different stages of degradation require different restoration strategies. Five stages of degradation are recognized (stage 1 being the lowest and stage 5 being the highest) (Figure 1.1). Each degradation stage requires a different restoration strategy (i.e. protected natural regeneration, accelerated natural regeneration, framework species method, maximum diversity methods, etc.). The intensity, complexity and cost of restoration all increase, as the severity of degradation increases (Elliott et al, 2013). It is more expensive and labor-intensive to restore a forest at a higher degradation stage than a lower one.

The success of forest restoration can be measured through monitoring several parameters, particularly biomass (carbon storage in tree and soil) and biodiversity recovery (plants, birds and mammals). Such monitoring determines how quickly and to what extent biomass and biodiversity return to reference-forest levels. Monitoring all the species that comprise biodiversity in any area is not practical. So, for forest restoration, monitoring focuses on those components that relate directly to the re-establishment of ecological functionality, particularly seed dispersal and the seedling establishment of

recruit tree species (i.e. in-coming tree species not including those planted), especially those that indicate overall forest health (Elliott et al, 2013).
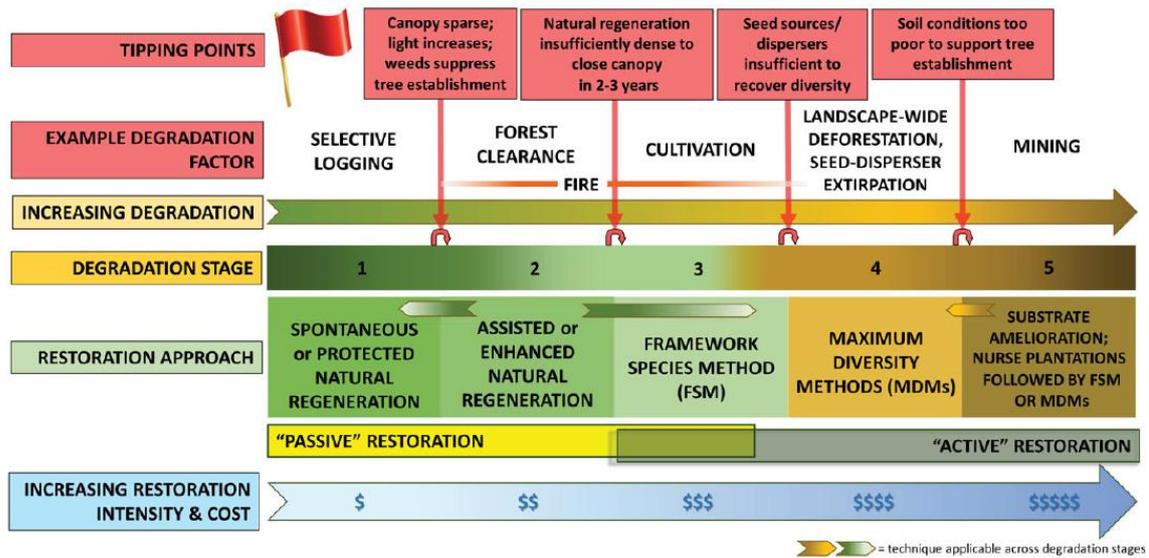
Figure 1.1 A scale of restoration interventions, which becomes more intensive and more expensive, as starting conditions become increasingly degraded (Elliott et al, 2022).

1.2.2 Framework Species Method (FSM)

Several different approaches have developed with each varying in intensity from ANR with no planting at all to the planting of all the tree species that formerly comprised the original climax forest (e.g. the maximum diversity method). FSM is a compromise between these two approaches. It is more effective at restoring biodiversity than the former, while requiring less inputs than the latter (FORRU, 2005). It is also one of the least intensive of the so-called "active" methods of forest restoration which involves complementing natural regeneration with tree planting on moderately degraded sites, located within seed-dispersal range of remnant forest (Elliott et al, 2022).

The technique involves planting mixtures of 20-30 forest tree species, typical of the reference forest ecosystem and caring them, i.e. weeding, fertilizer application and fire prevention, for two or more years. Framework species are selected for the following ecological characteristics; i) high survival rates when planted out in deforested sites, ii)

rapid growth, iii) dense, spreading crown that shade out herbaceous weeds, iv) ability to attract seed-dispersing wildlife by providing food, such as flowers and fruits, and shelter, v) resilience to burning and vi) easily propagated (Elliott et al, 2013; FORRU, 2005).
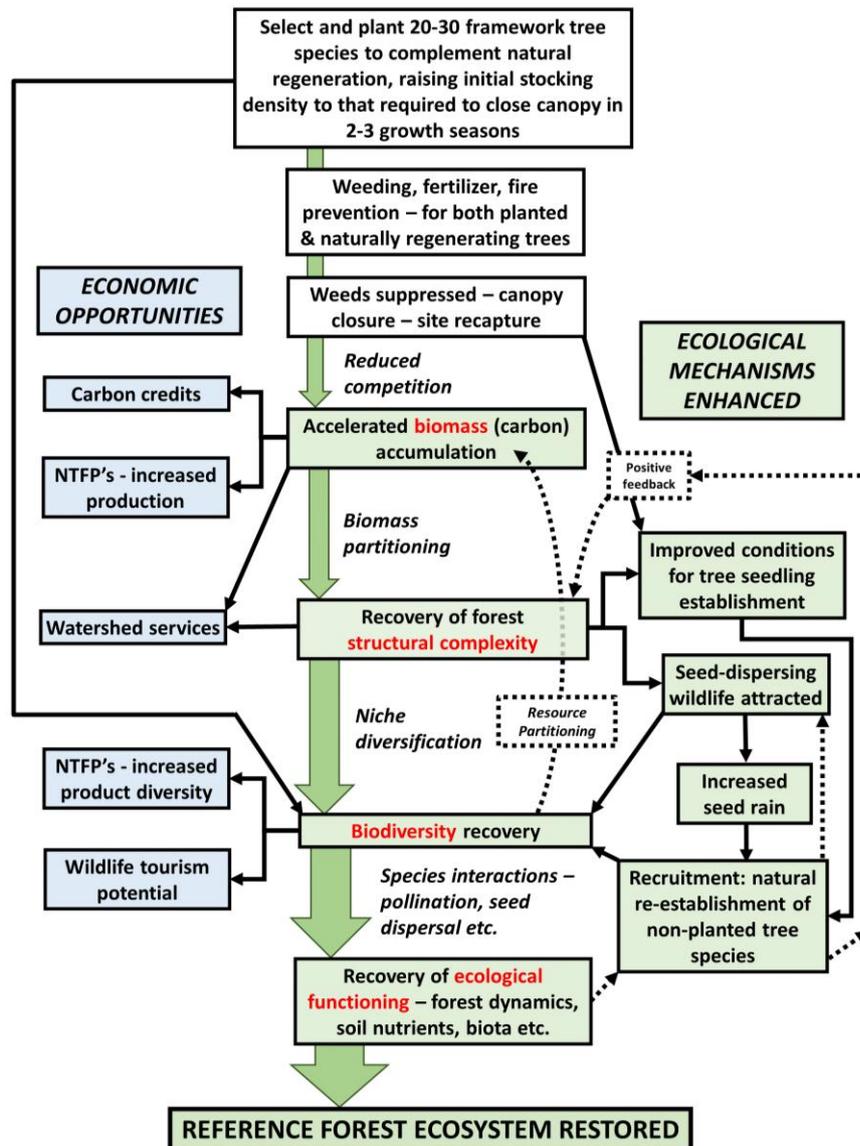
Figure 1.2 How the framework species method works.

The planted trees "recapture" the degraded site, by shading out weeds, re-establishing a multilayered canopy and restoring ecosystem processes, such as nutrient cycling. This creates a weed-free forest floor with a cooler and more humid microclimate, thus improving conditions for seed germination and seedling establishment of incoming

"recruit" (i.e. non-planted) tree species. Biodiversity recovery relies on seed-dispersing animals being attracted to the planted trees. These animals transport seeds of many additional tree species from nearby surviving forest into the planted sites (FORRU, 2005)

(Figure 1.2).

Figure 1.3 (a) Upper Mae Sa Valley, northern Thailand May 1998; (b) same location after planting framework tree species (3100 trees ha−1), left of track, 15 years old (31 species); right, 9 years old, (76 species); (c) forest interior after 21 years. A dense understory of recruit species (more than 70 measured in 0.46 ha) has developed beneath the closed canopy (Elliott et al, 2022). (Photos, D. Hitchcock & S. Elliott).

FORRU-CMU's chronosequence of FSM demonstration plots (Figure 1.3) has been recognized as one of the most successful examples of forest ecosystem restoration by several international agencies. For example, the FAO (Food and Agriculture Organization of the United Nations) included it in a compendium of exemplary

restoration case studies, not only for its sound science-based approach, but also for socio-economic considerations. The plot system was established in collaboration with the local Hmong ethnic minority community in the watershed above Ban Mae Sa in the Doi Suthep-Doi Pui National Park near Chiang Mai city (18°52007.2400 N, 98°51008.4700 E). The project fostered excellent working relationships among key stakeholders, reducing previously strained relations between villagers and the park authority. Local villagers were also able to leverage their participation in the project to gain greater political respect from authorities, leading to funding from local government for village infrastructure development (Mittelman et al, 2024).

1.2.3 Previous studies of small mammals relevant to forest restoration

Previously, small mammals research in Thailand tended to concentrate on their taxonomy. Information regarding the ecology of small mammals in the country was sparse (Ua-Apisitwong, 1988). Early studies of small mammal communities of Doi Suthep National Park in Northern Thailand were carried out by live traps, focusing mostly on rats, squirrels, tree shrew, etc. Nabhitabhata (1987) presented preliminary information on the species present at Doi Suthep, but no data of population densities or habitat preferences were provided. Ua-Apisitwong (1988) found that evergreen forest sites supported a higher abundance of small mammals (mostly rats) than deciduous forest sites. His study also discovered that distance between successive recaptures increased with the body size of rat species, indicating that larger rat species forage more widely than smaller ones.

Using live traps for rats and squirrels, Sharp (1995) reported that the population density of small mammals was higher in a large forest gap than in forest with complete canopy cover, although the species composition of the communities did not vary greatly between both habitats. This supported the supposition that forest gaps are a more suitable habitat for small mammals than closed forests, because the dense ground vegetation in gaps (mostly dense grasses and scrubs) provide security from predators. Furthermore, primary productivity is concentrated at ground level in gaps, so it is easier for non-arboreal small mammals to find food. In contrast in closed-canopy forest, most food resources are located in the canopy (Sharp, 1995).

Thaiying (2003) provided insights into the effects of early forest-restoration operations on small mammal communities, using live trapping with small box traps in the upland evergreen forest zone. Five *Rattus* species and two *Mus* species were captured. Fewer animals were trapped in the 2-year-old and 4-year-old forest restoration plots than in non-planted control plots, possibly due to disturbance by restoration activities, particularly weeding, reducing ground cover. Capture rates and species richness were lower than previously reported in mature natural forest nearby in Ua-Apisitwong's study (1988), probably due to isolation of the plots from the natural forest (Thaiying, 2003). Since all three of the above-mentioned studies used regular live rat traps, no data on species larger than rats or squirrels were collected.

Using camera traps, Kunchorn (2022) was first to reveal the presence of medium sized mammals, such as the Large Indian Civet (*Viverra zibetha*), the Small Indian Civet (*Viverricula indica*), the Hog Badger (*Arctonyx collaris*) and the Leopard Cat (*Prionailurus bengalensis*), in forest restoration plots in upland evergreen forest in Doi Suthep-Pui National Park. Species richness in a 9-year-old restoration forest at Mon Cham and 8-year-old restoration forest Mon Long was 67% and 32% that of the natural forest respectively, demonstrating the return of mammals during forest restoration (Kunchorn, 2022).

In the same restoration plot system 1-3 years later (2022 to 2024) another camera-trap survey (Laohasom et al, 2024) added several more to list of species recorded at the Mon Cham site including: the Sunda Pangolin (*Manis javanica*), Common Palm Civet (*Paradoxurus hermaphroditus*) and the Asiatic Golden Jackal (*Canis aureus*) in the plot system. That study recorded higher mammal activity in forested plots than in a (non-restored) control plot, but the relationship between mammal activity and forest age was inconsistent. This was because all plots were in close proximity to each other. So, mammals attracted to the restored plot also traversed the control and young restoration plots.

Further afield, in the Wet Tropics of Australia, Derhé et al. (2017) showed that while species richness and abundance did not vary much across restoration ages among mid-elevation (500–1,000 m) tropical rainforests, the total mammal biomass and mean species body mass increased steadily with restoration age. Older restoration sites (13-17

years old) displayed higher "functional evenness" meaning mammals fill a wider variety of ecological roles (e.g., more arboreal and seed-dispersing species) in more advanced restoration, compared with the terrestrial-heavy communities recorded in younger plots (1-5 years old). Community composition significantly shifted from invasive, herbivorous, terrestrial habitat generalists and open environment specialists in young restoration plots, to predominantly endemic, folivorous, arboreal and fossorial forest species in older restoration plots. The shift from pasture-like to more rainforest-like mammal communities began approximately 5 years after planting, corresponding with the age at which canopy closure begins to occur (Goosem and Tucker, 2013). Derhé et al. (2017) suggested that this shift demonstrates the potential of tropical forest restoration to recover rainforest-like, diverse faunal communities. This claim is also supported by Whitehead et al. (2014)'s study in the southern Atherton Tablelands, north-eastern Queensland, Australia, where he found that in restored habitats the species composition of small-mammal communities transitioned from predominantly grassland-adapted species to rainforest species overtime.

1.2.4 Ecological roles of mammals during forest restoration

All re-colonizing wildlife species (both plants and animals) contribute to biodiversity, but seed-dispersing animals can accelerate biodiversity recovery more than other species. In the forests of northern Thailand, seed dispersal by animals is more common than by wind. In Doi Suthep-Pui National Park, only 29% of the trees are wind-dispersed (FORRU, 2005). Hence, birds, fruit bats, and medium to small sized mammals are the major groups of interest during wildlife monitoring. Mammals can be divided into 3 groups of interest: i) frugivores, which could disperse seeds from intact forest into restored sites (e.g. large ungulates, civets, fruit bats and so on), ii) seed predators, which could limit the seedling establishment of recruit tree species in restored sites (particularly small rodents); and iii) carnivores, such as leopard cats, which could control populations of seed predators (e.g. rodents) (Elliott et al, 2013; Kunchorn, 2022).

The functional significance of medium-sized mammals of the types usually recorded on camera traps is that they have much wider gape than birds or fruit bats and can therefore ingest and disperse larger seeds. In the past, large frugivores like elephants, rhinos, and wild cattle were the most important dispersers of seeds from forest into

deforested areas. The elimination of most of these large mammals, over much of their former ranges in recent decades is now preventing dispersal of many large-seeded tree species (Corlett and Hau, 2000). Hence, large-seeded tree species have a much lower probability of recolonizing restoration sites than small seeded species (Ratanapongsai, 2020) and in degraded open sites, tree species with fruits < 14 mm diameter overwhelmingly dominate the seed rain (Au et al, 2006; Corlett, 2011; Blackham et al, 2013). The seed dispersal distance of mammals is also significantly further than that by birds (Tsunamoto et al, 2020). So, the remaining medium-sized mammals like civets and badgers have potentially a vital role to play in re-establishing such species and initiating the final steps towards full biodiversity recovery. Preventing hunting of these mammals is vital component of forest restoration projects (FORRU, 2005). Changes in mammalian community structure, following ecological forest restoration are therefore likely to have consequences for the integrity and stability of ecosystems undergoing restoration (Goheen et al. 2004).

1.2.5 Camera trapping

Mammals are much more difficult to survey than seed-dispersing birds, because most species are nocturnal and very shy. Consequently, direct observations of mammals are usually few and far between. Camera trapping is therefore an effective alternative way to determine the return of species to restoration sites (Elliott et al, 2013). Camera traps are a powerful tool for recording rare and elusive mammals and are very useful for obtaining the ecological data needed to formulate wildlife conservation plans. They have been used successfully in numerous studies of mammals, and potential applications of this field technique in wildlife studies are increasing (Jiménez et al, 2010). Camera traps record mammals in a non-invasive manner, regardless of the activity patterns and shyness of species since they photograph mammals as they pass in front of motion-sensitive sensors, providing objective observations with photographic evidence that can be archived and verified (Jansen et al, 2014). An advantage of the technique is that animals can be observed continuously, allowing more accurate estimates of animal abundance (Naruangsri, 2017).

Digital cameras, housed in camouflaged, weatherproof cases that are triggered by movement in the field of view, have never been cheaper (starting at US$ 100–200),

although poor image quality can sometimes hinder species identification. Live trapping, on the other hand, using locally available rat traps, enables close inspection for species identification and even collection of DNA samples, as well as accurate measurements of body weight and dimensions. However, it is also labor intensive and therefore expensive (Elliott et al, 2013). De Bondi et al. (2010) compared live trapping with camera trapping and reported that camera trapping recorded more animal species than live trapping did.

Estimating the abundance of wildlife populations lies at the heart of most ecological research and monitoring. For abundance estimation, detection probability can be defined as the likelihood that an individual will be detected (photographed or captured) if it is present in a sample unit during the time of the sample. In studies designed to estimate abundance using camera traps, camera trap placement in the sampling area affects the ability to detect individual animals and, therefore, the detection probability. For abundance estimation, cameras should be placed in locations that maximize the chance of detecting the target species. Closer spacing of cameras closes the gaps and increases the probability of detecting individual animals by increasing the number of cameras in a home range. Animals with more camera trap points in their home ranges may have higher detection probabilities than animals with fewer trap points, creating heterogeneity in detection probabilities. There are tradeoffs in camera trap deployment, because close trap spacing reduces sample-area coverage, resulting in fewer individuals being available for sampling. In contrast, wide spacing may create holes or reduce an individual's exposure to traps. Appropriate placement and spacing of camera sampling points depend on a thorough understanding of the target species' movement patterns and habitat use (O'Brien, 2011).

1.3 Objectives

- To assess the recovery of mammal communities during restoration of upland evergreen forest.
- To review the potential attractiveness of the planted framework tree species mix to mammals.
- To assess the extent to which mammals might contribute to the recovery of ecological functionality during ecosystem restoration by an assessment of the recruit-tree species (e.g. their dispersal modes).

1.4 Hypotheses

- The FSM facilitates species richness and recovery of small- to medium-sized mammal communities over time, thus contributing towards biodiversity recovery.

- Framework tree species attract mammals to restoration plots, thus contributing towards the increased establishment of recruit-tree species, which accelerates the restoration process itself.

1.5 Research scope

- Limitation: The scope of the study is limited to species identification and species richness only and inferred potential seed dispersal based on known habits of the animals recorded. Although a crude measure of "relative" abundance, it is not possible to calculate exact species population densities from camera trap data nor to directly observe seed dispersal occurring.

- Areas of Studies: Four study sites; 2 restored forests, natural forest (reference), and abandoned agricultural land (control) in the Upper Mae Sa Valley, Ban Mae Sa Mai, Mae Rim District, Chaing Mai Province.

- Period: May to November 2024.
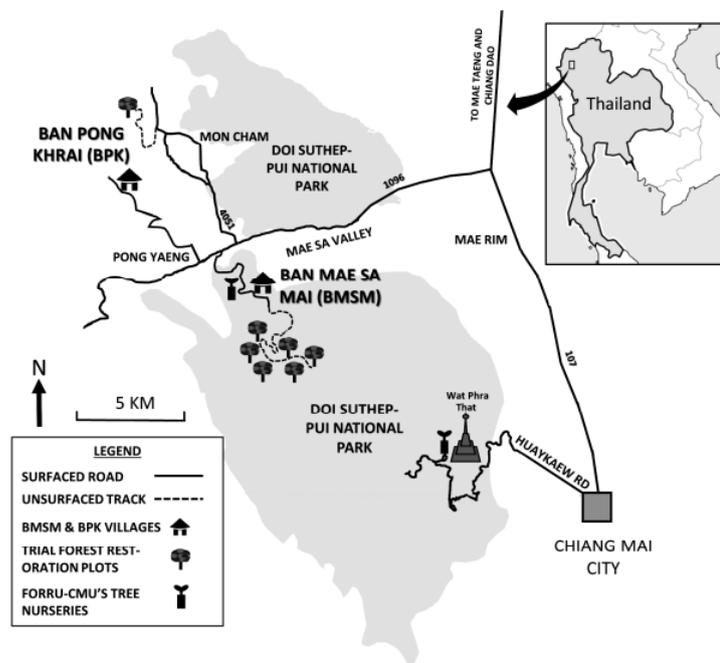
Figure 1.4 Location of the study area in relation to Chiang Mai, Doi Suthep-Pui National Park (Elliott et al, 2019).

CHAPTER 2

Materials and Methods

2.1 Study sites

The study area was FORRU-CMU's trial plot system in the upper Mae Sa Valley. The upper Mae Sa Valley lies mostly within Doi Suthep-Pui National Park, in Chiang Mai Province, northern Thailand, with the Hmong hill tribe communities of Ban Mae Sa Mai and Ban Mae Sa Noi (BMS) (combined population of 2,197) situated at 18°52′07.24″ N, 98°51′08.47″ E, 1,018 m above sea level. The restoration trial plot system is situated at 18°51′46.62″ N, 98°50′58.81″ E, 1,200–1,325 m above sea level, covering 33 ha of the watershed above the village, with each plot ranging from 0.48 to 6.4 ha. Doi Suthep-Pui National Authority requested FORRU-CMU to implement the project in 1996 (Figure 1.4).

The area has two main seasons: the wet season (May–October) and the dry season (mean monthly rainfall below 100 mm, November–April). The dry season is subdivided into the cool-dry season (November–January) and the hot-dry season (February–April). Average annual rainfall, recorded at the weather station nearest to the at a similar altitude (Kog-Ma Watershed Research Station), was 1,736 mm. Extreme temperatures range from a minimum of 4.5 °C in December to a maximum of 35.5 °C in March. Fire is a major constraint to forest restoration in this landscape. Villagers use fire to clear land for cultivation and, despite rules to prevent accidents, fires often ''escape'' and burn out of control over extensive areas (Elliott et al, 2024).

Originally, the area had been covered in "Primary, Evergreen, Seasonal Forest" (EGF, *sensu* Maxwell & Elliott (2001)) cleared from the 1950's to the early 80's, to provide land for the cultivation of cabbages, potatoes, and other cash crops. The condition of the area was stage-3 degradation (*sensu* Elliott et al. (2013), Chapter 3), i.e., regenerants (remnant mature seed trees, live tree stumps capable of coppicing, tree saplings, and tree seedlings, taller than 50 cm.) at densities lower than that needed to initiate canopy closure within 2 years (<3,100/ha), mostly suppressed by dominant weeds. The nearest remnant forest, "Pah Dong Saeng", lies 2–3 km from the plots (disturbed

primary EGF (Evergreen Forest), regenerating following opium poppy cultivation during the 1950–60's in small patches). The villagers regard it as a *de facto* community forest and a sacred area. Most of the slopes below the plots were cultivated for cabbage, when the plot system was initiated. Litchi orchards (*Litchi chinensis* Sonn.) lower down the valley are now in decline and are being replaced with horticultural crops, using plastic cloches. Villagers have invested in an irrigation system that delivered piped water from the upper watershed to the agricultural field lower down the valley (Elliott et al, 2024).

Data were collected at 4 sites within the area described above: i) abandoned agricultural land (control – starting conditions) (CON) (Figure 2.2), ii) 12-year-old (R12) (Figure 2.3) and iii) 24-year-old (R24) (Figure 2.4) restored forests and iv) in Pah Dong Saeng forest, which served as the reference forest for this project (REF), being the least disturbed forest remnant in the vicinity (Figure 2.1, 2.5). Control site (approximately 0.4 ha in area) is an open area heavily dominated by weeds with only few planted avocado trees and represents the conditions with no restoration effort (FORRU's original control plots were not used due to their close proximity to the restored plots and "spill over" effects). R12 is a younger forest with semi-open canopy, heavily dominated by pioneer tree species and covers about 1.42 ha in area. R24 is a more mature, older forest, covering an area of 0.82 ha, with a closed canopy, dominated by more shade-tolerant climax tree saplings and fewer weeds. Camera traps covered an area of approximately 1.6 ha within the reference Pah Dong Saeng forest (REF).
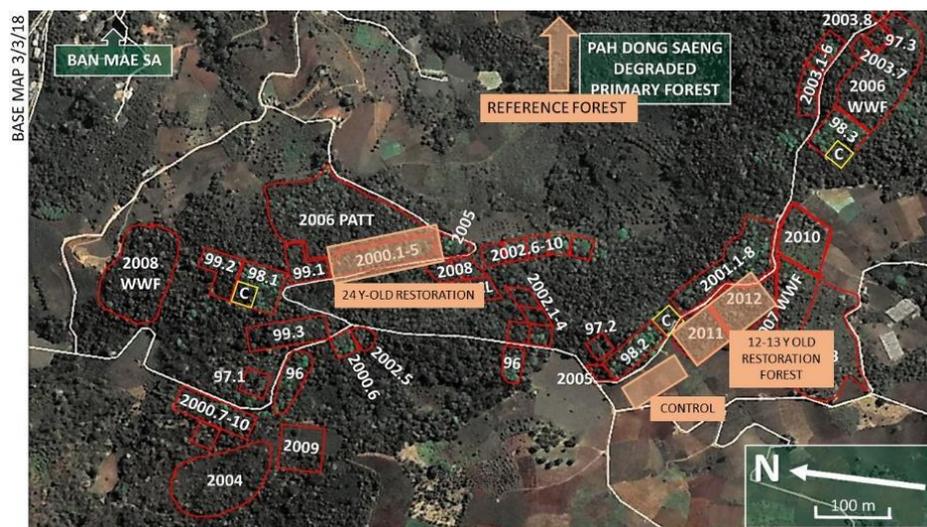
Figure 2.1 Location of 4 study sites in the Ban Mae Sa Mai restoration plot systems.

Figure 2.2 Abandoned agricultural land (CON).

Figure 2.3 12-year-old restored forest (R12).

Figure 2.4 24-year-old restored forest (R24).
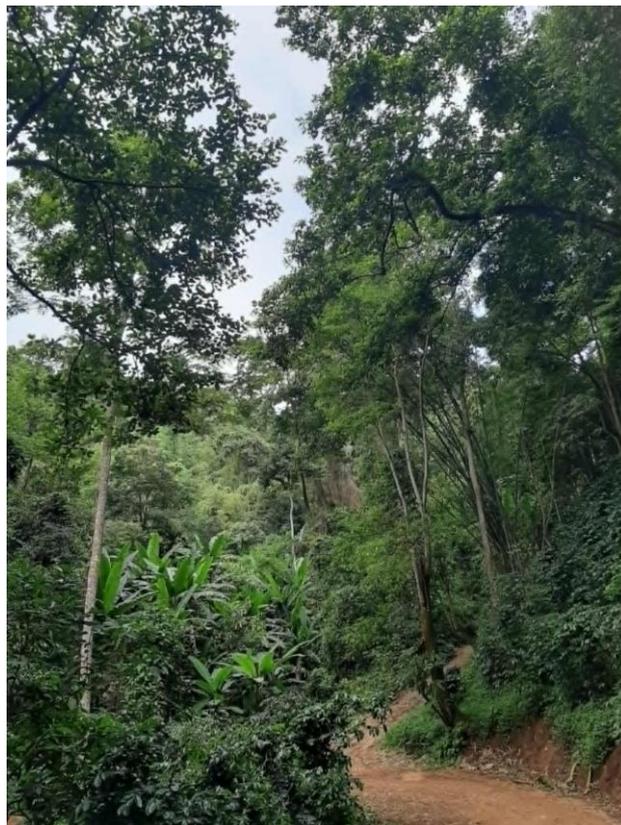
Figure 2.5 Pah Dong Saeng Natural Forest (REF).

2.2 Camera trap setting

Cameral traps were installed in each of the 4 study habitats (Figure 2.1). The cameras are triggered by objects moving in front of the lens. They produce colored photographs in daylight and black and white ones at night. The cameras were attached approximately 40 cm above the ground on tree trunks spaced, where animal activity was indicated by tracks and signs etc. following the protocol of Jiménez et al (2010). Spacing between the traps was not less than 50 m, but well within the plot interiors (to avoid edge effects). Overall, 16 cameras were used, 4 in each habitat. Total area covered depended on the vegetation density around each camera, restricting line of sight. Since the new cameras ordered had not arrived at the start of the project, initially 1 old camera was placed in CON, R12 & R24 on 1/5/24, as a preliminary study. Subsequently 4 cameras were placed simultaneously in each habitat from 9/5/24 to 2/11/24 (totally 708 trap-nights in reference forest and 716 trap-nights in each of the other three sites). The camera positions in all four habitats were changed every 2 months, to maximize area covered. The memory cards were inspected monthly for records of mammals.

Figure 2.6 Camera trap installed at the field site.

2.3 Data collection and analysis

For species identification, the book "A Field Guide to the Mammals of South-East Asia" by Charles M. Francis (Figure 2.7) was used. Each time an animal passes in front of a camera trap, it takes up to 3 photos. This counts as 1 animal encounter. When the camera captures multiple animals in 1 photo, multiple encounters are counted. When a single species appeared in photographs taken more than 30 minutes apart, the two subjects were treated as separate individuals (O'Brien et al., 2003). The number of encounters, expressed as a percentage of the total trap nights, therefore provides a rough indicator of animal activity (Laohasom, 2024). Frequency of detection (FD) and species richness were derived from the numbers of photographs. Species richness is the number of species recorded within each of the four habitats surveyed. FD was calculated as "FD = (E/TN) * 100", where E is the number of animal encounters and TN is the total number of trap nights. Therefore, FD can be also expressed as the number of animal detections per 100 trap nights. It is equivalent to a relative abundance index, revealing how common or rare each species is compared with other species within a defined location or community (Sollmann et al, 2013). Similarity index was calculated based on the Sorensen index for presence-absence data (Krebs, 1999) where Ss = (2Wx100)/(A+B). In this equation, W is the number of species present in both study sites, A and B are the number of species found in each study site.
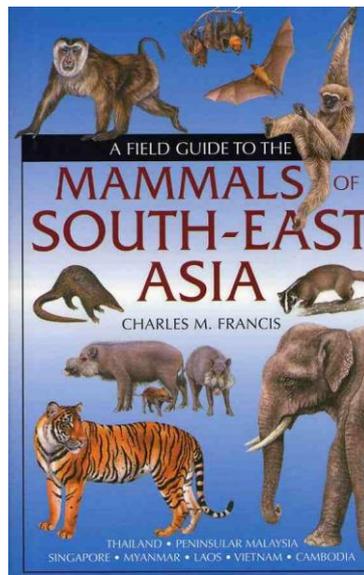
Figure 2.7 "A Field Guide to the Mammals of South-East Asia"

2.4 Determining dispersal modes of tree species

To review the potential attractiveness of framework tree species to mammals and the extent of mammals' contribution to the recovery of ecological functionality during restoration, dispersal modes of tree species were assessed. We assessed the list of tree species, both planted framework and recruit species, present in the 24-year-old forest (R24) (Table 5.6 & 5.7) reported in Tun (2025)'s study, in which he identified tree species for an assessment of tree-carbon accumulation in 8 circular sample plots (5 m radius). Tree species were identified with the help of FORRU's seed collectors (with 30 years' experience) and verified using the book "A Field Guide to Forest Trees of Northern Thailand" by Simon Gardner et al. (Figure 2.8) (Tun, 2025). The dispersal mode of each tree species was subsequently determined by reviewing existing literature, and their fruit morphologies and seed sizes obtained from FORRU's database.
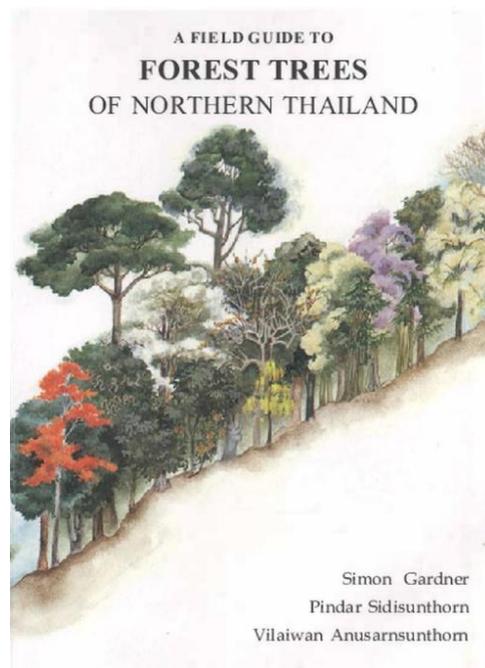
Figure 2.8 "A Field Guide to Forest Trees of Northern Thailand"

CHAPTER 3

Results and Discussion

3.1 Results

3.1.1 Species richness and similarity between each study sites

The camera traps detected 14 fully identifiable species, plus unidentified bat, squirrel and rat species, and at least 3 completely unidentifiable species across all sites. An unidentified species recorded in restorations plots might be the same species as one of the 3 species in the reference forest. Therefore, a total of at least 20 small and medium sized mammal species from 10 families were recorded in the camera-trap survey (Table 3.1). Only 4 species triggered the camera traps in the control plot (CON) (Figure 3.1). Ten species were recorded in each of the two restoration plots (R12 and R24), while eighteen mammal species were confirmed present in the reference forest (Figure 3.1). Species richness of the reference forest is considered as a target for restoration here. Thus, R12 and R24 are more than halfway through to reach the target species richness level (Figure 3.1).
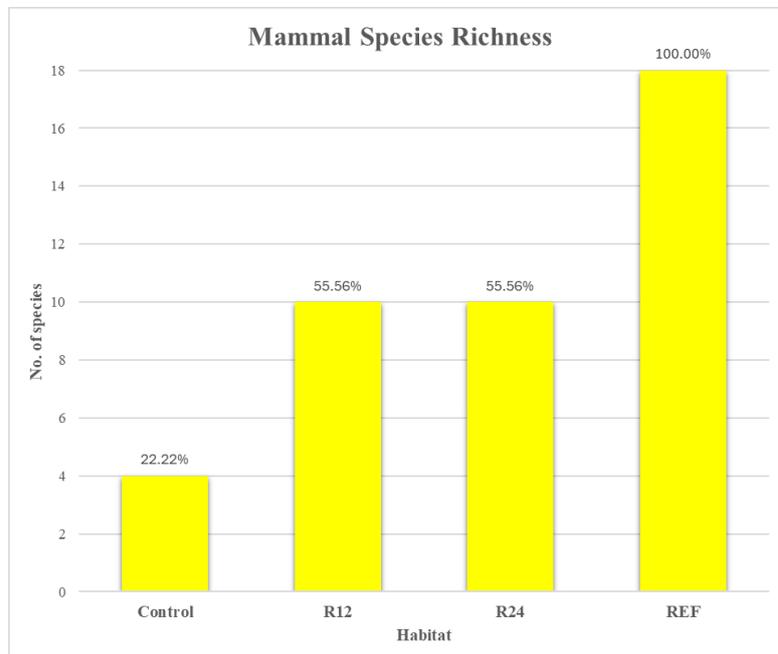
Figure 3.1 Mammal Species Richness in all 4 habitats. Percent values are per cent of the reference forest value.

The species list included 1 critically endangered species: the Sunda Pangolin (*Manis javanica*) (in R12 and REF) (Figure B.8) and 1 vulnerable species: the Hog Badger (*Arctonyx collaris*) (Figure B.5) (in all plots except CON), according to the IUCN Red List. All others were considered of least concern, in terms of their conservation status (IUCN, 2025).

The Large Indian Civet (*Viverra zibetha*) (Figure B.2), the Common Palm Civet (*Paradoxurus hermaphroditus*) (Figure B.1) and the Crab-eating Mongoose (*Herpestes urva*) (Figure B.4) were recorded in all 4 habitats. Hog Badger (*Arctonyx collaris*), the Leopard Cat (*Prionailurus bengalensis*) (Figure B.6) and rodents (unidentified species of rats (Figure B.15) and squirrels), were detected in all habitats except in CON. The Large-toothed Ferret Badger (*Melogale personata*) (Figure B.7) was found in R24 and REF, while Sunda Pangolin (*Manis javanica*) (Figure B.8) and the Eurasian Wild Pig (*Sus scrofa*) (Figure B.9) were recorded in R12 and REF. The Burmese Hare (*Lepus peguensis*) was found only in CON. The Western Striped Squirrel (*Tamiops mcclellandii*) (Figure B.11) was restricted to R24 only, whereas the Red Muntjac (*Muntiacus muntjak*) (Figure B.10), Red-cheeked Squirrel (*Dremomys rufigenis*) (Figure B.12), Variable Squirrel (*Callosciurus finlaysonii*) (Figure B.13), Northern Tree Shrew (*Tupaia belangeri*) (Figure B.14), and an unidentified bat species were recorded only in the reference forest. No species were uniquely restricted to the R12 plot. The similarity of mammal species found in two restored forests was 80%. Although mammal species similarity between REF and R12 was 71.43%, there was only 64.29% similarity between REF and R24. The control site (CON) only displayed 27.27% of the reference forest's richness and 42.86% of that of each restoration plot (Table 3.2).

Table 3.1 Mammal species found in all four habitats. Green cells = species detected in only 1 habitat (specialists); Orange cells = species detected in all habitats (generalists).

ENGLISH NAME	SPECIES NAME	FAMILY	CONSERVATION STATUS	DIET	PREFERRED HABITAT	RECORDED IN			
						CON	R12	R24	REF
Common palm civet	*Paradoxurus hermaphroditus*	Viverridae	LC	Omni	Forests, plantations, urban areas	✓	✓	✓	✓
Large Indian civet	*Viverra zibetha*	Viverridae	LC	Carn	Forests, grasslands, agricultural areas	✓	✓	✓	✓
Crab-eating mongoose	*Herpestes urva*	Herpestidae	LC	Carn	Riversides, forests, wetlands	✓	✓	✓	✓
Burmese hare	*Lepus peguensis*	Leporidae	LC	Herb	Grasslands, open forests	✓			
Hog badger	*Arctonyx collaris*	Mustelidae	V	Omni	Forests, grasslands		✓	✓	✓
Leopard cat	*Prionailurus bengalensis*	Felidae	LC	Carn	Forests, grasslands, agricultural areas		✓	✓	✓
Large-toothed ferret-badger	*Melogale personata*	Mustelidae	LC	Omni	Forests, grasslands			✓	✓
Sunda pangolin	*Manis javanica*	Manidae	CE	Inse	Forests, grasslands		✓		✓
Eurasian wild pig	*Sus scrofa*	Suidae	LC	Omni	Forests, grasslands, agricultural areas		✓		✓
Western striped squirrel	*Tamiops mcclellandii*	Sciuridae	LC	Herb	Forests			✓	
Red muntjac	*Muntiacus muntjak*	Cervidae	LC	Herb	Forests, grasslands				✓
Red-cheeked squirrel	*Dremomys rufigenis*	Sciuridae	LC	Herb	Forests				✓
Variable squirrel	*Callosciurus finlaysonii*	Sciuridae	LC	Herb	Forests, gardens				✓
Nothern treeshrew	*Tupaia belangeri*	Tupaiidae	LC	Omni	Forests, plantations				✓
Unidentifed bat									✓
Unidentifed squirrel							✓	✓	✓
Unidentified rat							✓	✓	✓
Unidentifed species							1	1	3
Total no. of species						4	10	10	18
Carn=carnivore; Herb=herbivore; Omni=omnivore; Inse=insectivore									
LC=least concern;V=vulnerable;CE=critically endangered									

Table 3.2 Similarities of mammal species between habitats.

Similarity index (Sorensen index) (%)				
	CON	R12	R24	REF
CON	100.00	42.86	42.86	27.27
R12		100.00	80.00	71.43
R24			100.00	64.29
REF				100.00

3.1.2 Frequency of Detection

Total FD value across all study habitats was 87.22 (unit = "%"). Highest mammal activity was recorded in reference forest (FD = 42.94) and the lowest in control habitat (FD = 1.96) (Figure 3.2). FD values in R12 and R24 were 18.58 and 23.75 respectively (Figure 3.2). The Common Palm Civet (*Paradoxurus hermaphroditus*) was the most frequently detected mammal species over the entire study with an FD of 29.24 (Figure 3.3). The Large Indian Civet (*Viverra zibetha*) was the second most frequently detected mammal species with 17.19 FD value (Figure 3.3). The least detected species (FD <1%) included the Large-toothed ferret-badger (*Melogale personata*), the Sunda pangolin (*Manis javanica*), the Red muntjac (*Muntiacus muntjak*), the Northern tree shrew (*Tupaia belangeri*), the Burmese hare (*Lepus peguensis*), the Western striped squirrel (*Tamiops mcclellandii*) and 1 unidentified bat species (Figure 3.3). FD of all mammals detected in CON were less than 1. In both restoration plots, two civet species were the most common species. Common Palm Civet was so the most common species in the reference forest (Figure 3.4). FD of the reference forest is regarded as a target value for restoration. Therefore, R12 and R24 have already reached 43.26% and 55.30 % of the target FD value respectively (Figure 3.2).
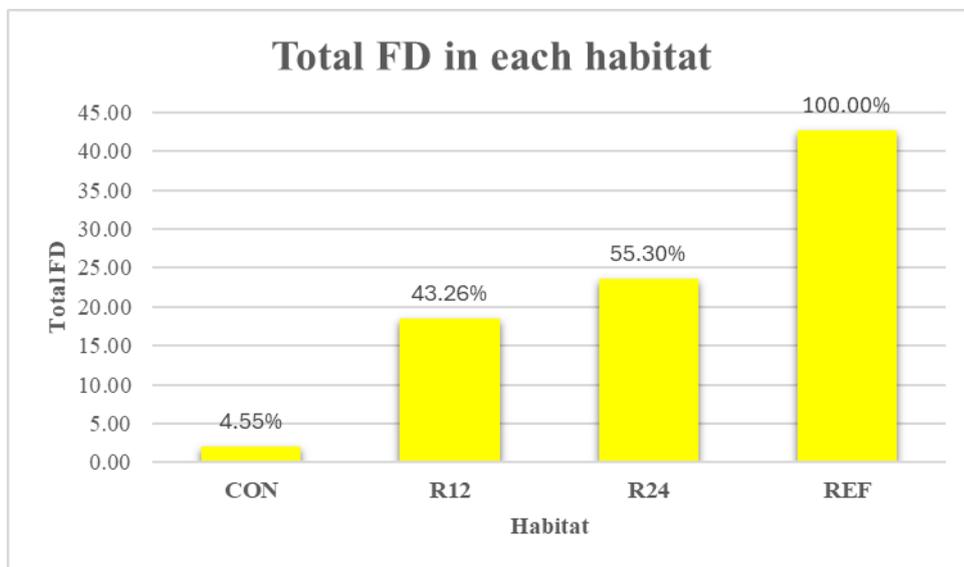
Figure 3.2 Total Frequency of Detection in all 4 habitats. Percent values are per cent of the reference forest value.
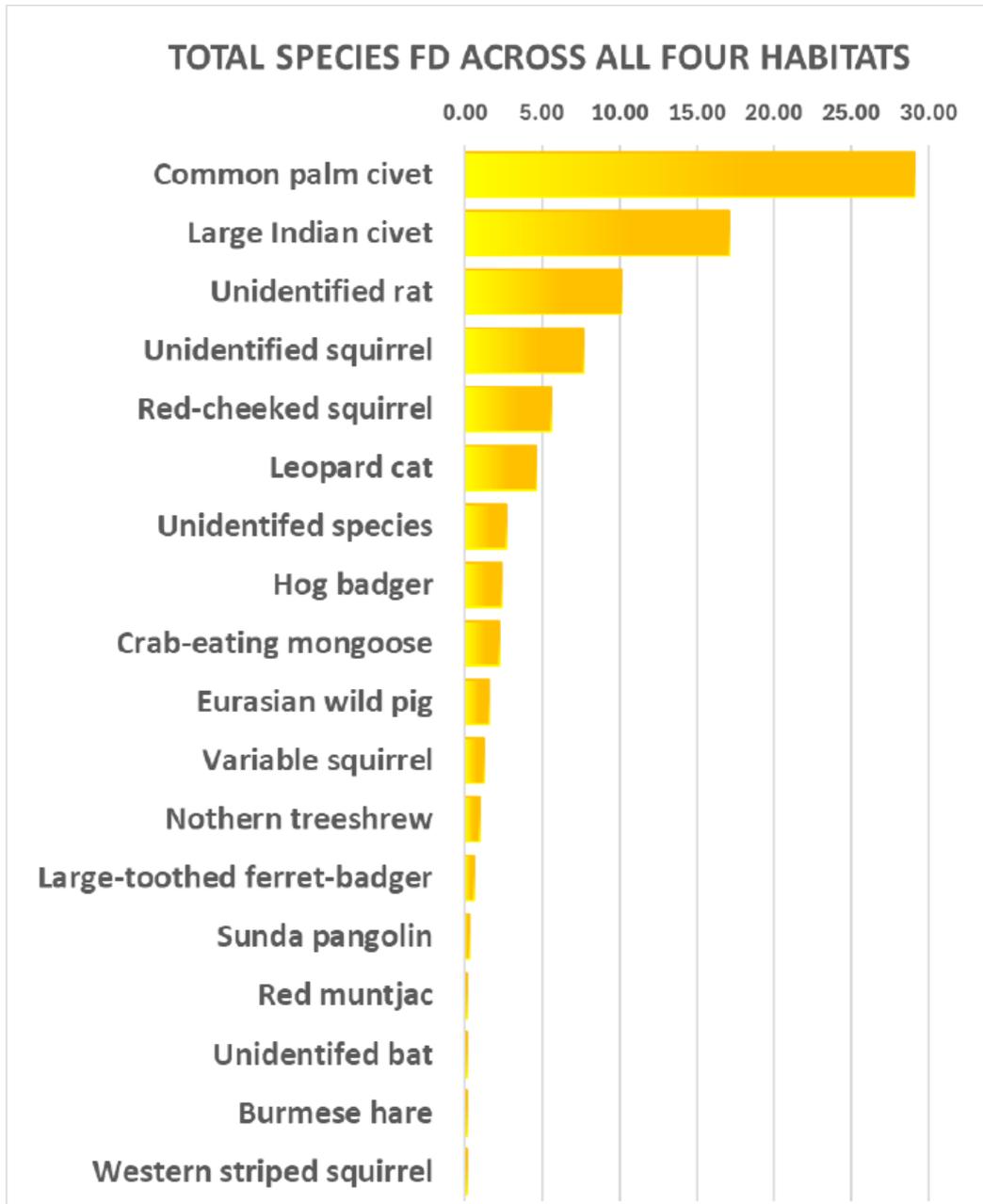
Figure 3.3 Total Frequency of Detection for each species across all 4 habitats.
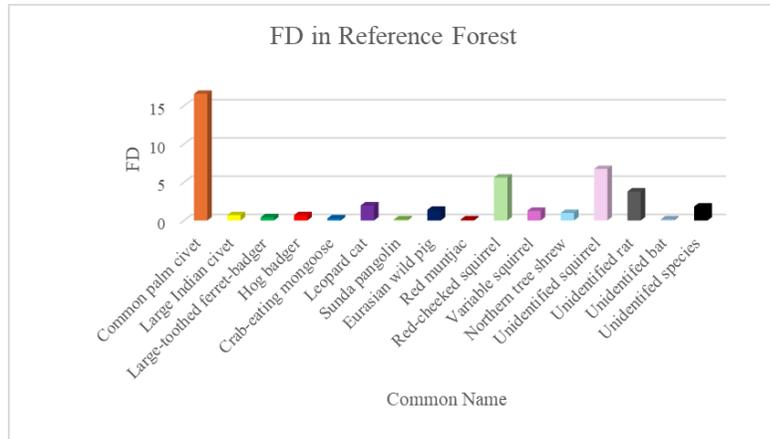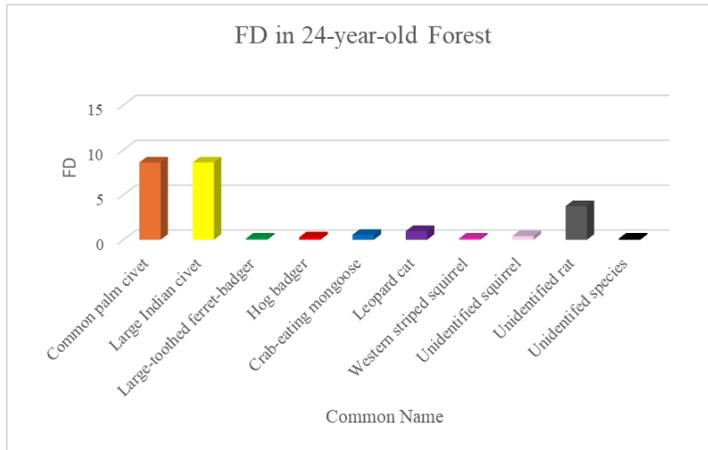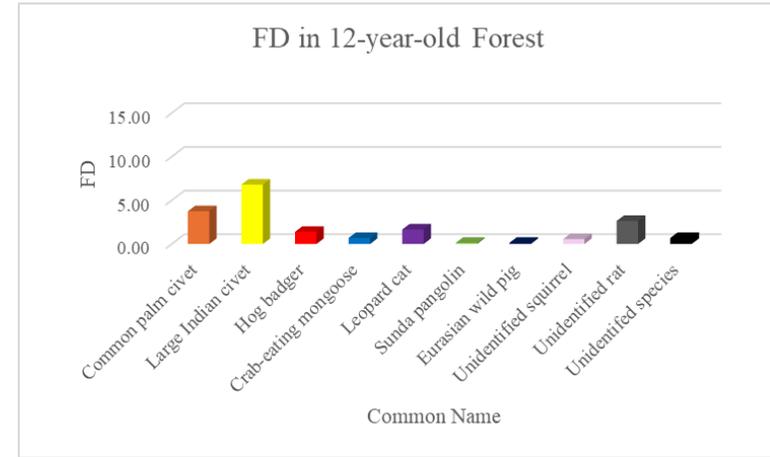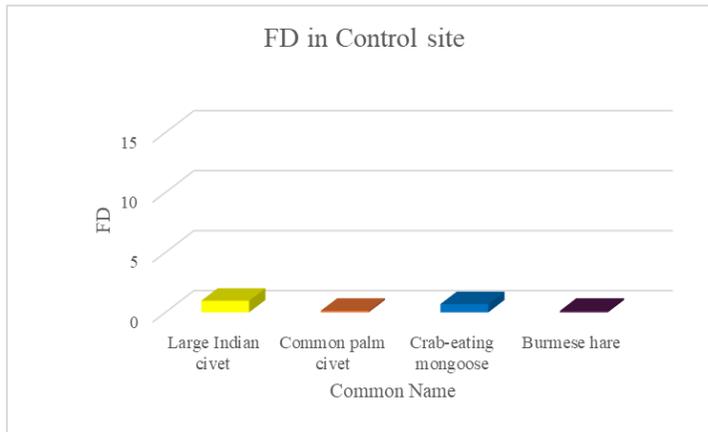
Figure 3.4 Frequency of Detection (FD) of each species in each habitat.

3.1.3 Dispersal mechanisms of trees species in old restoration plot (R24)

From Tun (2025)'s study, list of the tree species present in the 24-year-old forest (R24) was assessed (Table 5.6 & 5.7). Of the 41 tree species recorded in Tun's sample plots (8 circles, 10m diameter) only 15 (37%) had been planted; the rest had established naturally, probably via seed dispersal from nearby remnant forest.

All remaining planted framework tree species produced fruits known to attract seed-dispersing animals (Table 3.3). Most produced fleshy fruits such as *Balakata baccata* (Figure C.1)*, Choerospondias axillaris* (Figure C.2), *Gmelina arborea* (Figure C.3), *Helicia nilagirica* (Figure C.4), *Prunus cerasoides* (Figure C.5) and *Sapindus rarak* (Figure C.6), whilst others produced nuts attractive to scatter hoarding rodents, such as *Castanopsis acuminatissima* (Figure C.7)*, Castanopsis tribuloides* (Figure C.8) and *Lithocarpus elegans* (Figure C.9). Eight out of ten species produce fruits eaten by seed-dispersing mammals.

Table 3.3 No. of remaining planted framework species recorded in a sample survey of the 24-year-old forest (R24) and their dispersal agents.

Main dispersal agent	No. of species	%
Wind	0	0.0
Mammals	4	26.7
Birds	3	20.0
Both mammals & birds	8	53.3
Total no. of mammal-dispersed species	12	80.0
Total no. of species	15	

Considering the 26 incoming recruit tree species in Tun's sample (Figure C.10 – C.16), more than 75% of them were dispersed by mammals and/or birds. Mammals might be responsible for dispersal of 58% of the animal-dispersed species (Table 3.4). Full details of tree names and fruits/seed details of each are presented in the appendix (Table A.6 and A.7).

Table 3.4 Dispersal agents of recruit tree species found in 24-year-old forest (R24).

Main dispersal agent	No. of species	%
Wind	6	23.1
Mammals	5	19.2
Birds	5	19.2
Both mammals & birds	10	38.5
Total no. of mammal-dispersed species	15	57.7
Total no. of species	26	

3.2 Discussion

3.2.1 Species richness and Frequency of Detection

In this study, both R12 and R24 supported more than double the number of mammal species recorded in the control habitat and more than half of the number of mammal species recorded in the reference forest (Figure 3.2). This strongly suggests that forest restoration by the framework species method promotes recovery of small and medium sized mammal communities and that such communities in the R12 and R24 sites are well along a trajectory towards attaining a high species richness similar to that of reference forest. This was further supported by the mammal activity data (frequency of detection) (Figure 3.1). Reference forest had the highest FD while the control site had the lowest. FD values in R12 and R24 were 43% and 55% of the reference forest value, indicating steady increase in mammal activity as restoration progresses.

The results of the present study were very similar to those of a previous study (Feb-Dec 2021) (Kunchorn, 2022), which compared mammal communities in 7-year-old restoration at Mon Long (R7) and 9-year-old restoration at Mon Cham (R9) with reference evergreen forest; totally 1,026 camera-trap nights per habitat. Twelve species were recorded in the natural forest. The Large Indian Civet (*Viverra zibetha*) had the highest FD value of 4.09. R7 supported 7 recorded species, with the Northern Treeshrew (*Tupaia belangeri*) having the highest FD (0.39). Six species were recorded in R9 with the Leopard Cat (*Prionailurus bengalensis*) having the highest frequency (FD 0.88). The similarity of mammal species between R9 and REF was 67%, between R7 and REF 32% and between R7 and R9, 46%. That study also confirmed that restoration provides habitats for local mammals and attracts seed dispersers which can contribute towards natural regeneration via seed dispersal.

3.2.2 Similarity between habitats

The mammal communities found in two restoration plots were very similar to each other (80% similarity) despite their 12 years difference in age. This could be explained by Derhé et al. (2017)'s study where mammal communities shifted from mostly small, invasive, terrestrial open-environment specialist species in young restoration sites

(1-5 years old) to communities of larger, arboreal, rainforest species in the mid-age (6-12 years old) and old-restoration sites (13-17 years old). This shift began to occur approximately 5 years after planting, corresponding with the age at which canopy closure begins to occur (Goosem and Tucker 2013). This is also supported by low similarities between CON and all the other habitats (<50%). Hence, there were less differences (only 20%) in mammal communities between mid-age (R12) and old-restoration (R24) plots.

Furthermore, both mammal species in both restored forests shared more than 60% of the reference forest (REF)'s species. Like mammals, birds are also efficient seed dispersers and restoration success heavily depends on their availability and abundance (FORRU, 2005). Previous study of bird communities by Toktang (2005) (June 2002-July 2003) also showed similar results, where the species richness, diversity, abundance and density of birds in non-planted control plots and planted plots of different ages: recently planted, 2-year-old and 4-year-old plots at Ban Mae Sa Mai in Suthep-Pui National Park, were compared. Bird species richness increased markedly from about 34 species before planting to 88 after 5 years, representing about 54% of birds recorded in the nearest remaining patch of climax forest.

However, mammal communities in older R24 plot were less similar to REF's communities (64%) than younger R12 plot did (71%). By comparison, R12 shared 10 species with REF while R24 shared only 9 species. The Western Striped Squirrel (*Tamiops mcclellandii*) (Figure B.11) found only in R24 could be one of the unidentified squirrel species in REF. Thus, the species similarity between R24 and REF could be higher than 64%. The 2 remarkable species that were detected in R12 but not in R24 were the Sunda Pangolin (*Manis javanica*) (Figure B.8) and the Eurasian Wild Pig (*Sus scrofa*) (Figure B.9).

This difference in mammal communities may be explained by the forest structure and the surrounding habitats of R12. It is more open compared to older R24 plot. In semi-open R12 plot, primary productivity is more concentrated at the ground level in gaps since more sunlight can reach the floor (Sharp, 1995). Therefore, forest gaps can promote a higher density of ground-dwelling arthropods like ants and termites which are the major diet of pangolins (Francis, 2008). This is supported by Hethcoat et al. (2019) who showed

that more open and warmer habitats often support more ants than closed-canopy forests. Uno et al. (2010) also found that although ants species' richness was higher in the forests than in less-forested gardens, ants were more active and abundant in gardens than in the forests. Furthermore, Tamang et al. (2022)'s study showed that the occurrence of pangolin foraging burrows was greater nearer to agricultural areas since these areas are abundant with ants and termites due to the presence of plant debris and animal dung (Richer et al, 1997). We also encountered many ant colonies nesting inside the camera boxes whenever we checked the camera traps in CON, which is an abandoned agricultural land. In fact, R12 is adjacent to CON and is in close vicinity with other active plantations in the area. On the other hand, R24 is completely sandwiched between other restoration plots and has no connection to any agricultural areas (Figure 2.1). Pangolins are known to inhabit secondary forests as well as cultivated areas, including gardens (Francis, 2008). So, it was possible that the pangolin was roaming around between R12 and CON and the surrounding agricultural sites. This difference in food availability (ants and termites), may explain why insectivores like the Sunda Pangolin preferred R12 over R24 in this study.

Wild pigs can be found in a wide variety of habitats from mature forests to disturbed areas, gardens and plantations (Francis, 2008). Thurfjell et al, (2009) found that wild pigs often prefer to forage close to forest edges because edges can act as potential escape cover, providing them safe shelter while foraging in open fields. They are also known for causing damage to growing crops in gardens and plantations (Francis, 2008). R12 can be regarded as the forest edge since it is surrounded by other restoration plots on one side and agricultural sites on the other (Figure 2.1). This may explain why the wild pig was present in R12 but not in R24.

3.2.3 Dispersal mechanisms of trees species in old restoration plot (R24)

We found that fruits of 80% of the framework tree species planted in 24-year-old forest (R24) were attractive to seed-dispersing mammals, which might be responsible for the dispersal of 58% of the recruit/naturally established tree species in the plot. Therefore, it is likely that the planted framework tree species attracted mammals into the restoration plot (R24), which brought in more seeds from nearby forests into R24, thus accelerating recovery of tree-species richness during restoration. This indicates that restoration by the

FSM promotes seed dispersal into restoration plots by attracting frugivorous animals and thus encouraging a steady recovery of ecological functionality by creating a self-sustaining ecosystem over time. This is further supported by the behavioral observations from Toktang (2005) which showed 22 framework tree species planted were used by frugivorous birds. One planted framework tree species in R24, *Prunus cerasoides,* produces nutritious nectar and fruit and was found to be one of the most attractive species in Toktang (2005)'s study.

3.2.4 Ecological roles of mammal species in restoration plots

The most important detected mammal species for forest restoration was the common palm civet (*Paradoxurus hermaphroditus*) (Figure B.1). It was the most frequently detected mammal species over the entire study area (Figure 3.3) and its FD increased with restoration age, peaking in reference forest from where it could disperse seeds to the other sites (Figure 3.4). It is highly frugivorous and ranges widely across both forested and open habitats and is known to survive well in human-modified areas (Corlett, 1998). Unlike large frugivores such as hornbills, elephants, or primates, which are highly vulnerable to habitat fragmentation or hunting, and have been typically rare or eliminated from disturbed habitats (Sodhi et al. 2004; Cardillo et al. 2005), civets are more disturbance tolerant and can persist in largely deforested landscapes (Corlett and Hau, 2000). Compared with other frugivores, civets are highly capable of swallowing large seeds despite their relatively small body mass, swallowing seeds up to 20.3 mm in width (Nakashima et al, 2010), and defecating seeds intact (Mudappa, 2001). The size of the seeds swallowed by the civet is equivalent to those swallowed by larger frugivores such as orangutans or gibbons (Nakashima et al, 2010). The species plays an important and unique role in the dispersal of large-seeded plants as a long-distance disperser in degraded forests due to its long seed retention time (mean retention time = 2.6 hours) and dispersal distance (mean distance = 216 m) (Nakashima et al, 2010). Studies in Africa also report that many tree seeds have a higher germination rate after passing through the gut of a civet (Bekele et al., 2008). Therefore, it is likely to be the most prolific seed-dispersing mammal species in the area, catalyzing natural forest regeneration on open sites and adding to tree-species richness in restoration plots. In addition, the common palm civet could be responsible for dispersal of large seeds in the study area and should be

considered as one of the major restoration "engineers". This species is so important that hunting of it should be completely banned in restoration areas.

A close relative of the Common Palm Civet, the Large Indian Civet (*Viverra zibetha*) (Figure B.2) was the second most frequently detected mammal species (Figure 3.3). *V. zibetha* has a diverse diet and, like many other civets, plays a multifunctional role as an omnivore, seed disperser and consumer of significant diversity of arthropods and mammals. Thus, it has a potential role as an important bioindicator of forest ecosystems. Although fruits are occasionally part of its diet, the species is mostly carnivorous, preying on a wide range of invertebrates and vertebrates (Simcharoen et al, 2020). Therefore, it may not disperse seeds as prolifically as its smaller relative, the common palm civet.

The abundance of other carnivores e.g. Crab-eating Mongoose (*Herpestes urva*) (Figure B.4) and Leopard Cat (*Prionailurus bengalensis*) (Figure B.6) in all three forested habitats, may also support restoration. Although these predators are not seed-dispersers, they prey on rodents, which are mainly seed predators. By helping to control the populations of seed predators (mostly rodents) (Elliott et al, 2013), predators may increase the probability that incoming seeds will germinate. The camera traps also captured evidence that the Large Indian Civet may play a similar ecological role (Figure B.3).

The occurrence of omnivores such as the Hog Badger (*Arctonyx collaris*) (Figure B.5), the Large-toothed Ferret Badger (*Melogale personata*) (Figure B.7), and the Eurasian Wild Pig (*Sus scrofa*) (Figure B.9), whose diet ranges from plants and fruits to worms, insects and small mammals (Zhou et al, 2015; Koju et al, 2022; Schley et al, 2003), in restored forests might have positive impact on restoration as well, since they can act as both seed dispersers and predators, controlling the populations of seed predators. Diverse fruit diets, multi-hour gut-passage times, gentle treatment of seeds, and large home ranges of mustelids (badgers and ferret badgers) mean that seeds are widely dispersed. Thus, they are probably more important as seed dispersal agents than was concluded then (Corlett, 2017).

Small mammals like squirrels (Figure B.11-B.13) and rats (Figure B.15) can have both positive and negative impacts towards restoration. Many tree squirrels and terrestrial

rodents are usually seed predators, even though, rarely, they may act as dispersers of very small seeds (Datta and Rawatt, 2008). Squirrels are among animals that have evolved food-hoarding strategies to ensure a reliable food supply in the face of energy shortages (Vander Wall 1990; Yi et al. 2012; Wang et al. 2014). Thus, they also disperse seeds through their scatter hoarding or caching behavior i.e., burying small caches (seeds and nuts) at different sites within their home ranges for future consumption. On the other hand, trees which are dispersed by squirrels must pay a high cost in terms of a number of seeds eaten by the dispersal agents (Allen, 1942; Brown and Yeager, 1945; Stapanian and Smith, 1978). Rats often display caching behavior as well. Although most cached seeds are eventually retrieved and eaten, enough survive for this to be a very effective means of dispersal (Vander Wall, 2010).

Among the recorded mammal species, the Sunda Pangolin (*Manis javanica*) (Figure B.8) is a highly valuable species. Pangolins are much prized as their scales being an important ingredient in Traditional Chinese Medicine, and consequently they are the most trafficked mammals in the world (Gomez et al, 2026). Pangolins can be considered as keystone species for ecological restoration since they can promote the recovery of plant diversity and richness in burned forest sites through their burrowing activities (Song Sun et al, 2025). The species is thought to regulate insect populations as well (Challender et al, 2019).

Most of the species found in 2 restoration plots have a critical role in forest restoration, especially seed dispersal species. Predators also contribute towards restoration by preying on seed predator populations. Majority of mammal species found have individual roles that accelerate the restoration process and hunting of such species should be banned in restoration areas. Fortunately, the presence of pangolin, deer (only found in REF) (Figure B.10) and wild pig – prized species for hunters – indicates that hunter pressure is not particularly high in the study area. When camera traps were first set up in Pah Dong Saeng 10 years ago, they often detected men carrying guns (Elliott et al, 2024), whereas in the present survey, no hunters were photographed. Therefore, hunting may not be as frequent as it was in the past and currently in decline there.

3.2.5 Camera trapping versus live trapping

We found that the carnivores, the Large Indian Civet and the Crab-eating Mongoose, were more active than the frugivores in the degraded control site, probably due to the greater abundance of prey species (i.e. rodents) in open areas than in the closed forest. Although no rodents were recorded in the control site, Sharp (1995) and Thaiying (2003), reported higher densities of rodents in open areas, nearby the study site, compared with forest and restoration sites using live trapping, due to food resources at ground level and the protection from predators afforded by dense vegetation. Such dense vegetation (grasses and shrubs) also obscured such small animals from camera traps and may explain why no small rodents were detected. This probably means that camera traps are not so good for rodents as low ground vegetation obscures them but does not affect live trapping.

CHAPTER 4

Conclusions

The study supports validity of one of the central pillars of the framework species method (FSM) – planting a limited number of trees to attract seed-dispersers of a large number of the tree species and strengthens validation of the hypothesis that the FSM promotes seed dispersal into restoration plots by attracting frugivorous mammals. The results strongly suggest that forest restoration by the Framework Species Method (FSM) promotes recovery of mammal communities and steady recovery of ecological functionality over time and creates habitat attractive to predators (Large Indian Civet and Leopard Cat), which may help to control populations of seed predators (particularly rats). Furthermore, the results showed that cameras worked well for identification of medium sized mammals but for studies of small mammals (particularly rodents), live trapping remains the better methodology option. We also found that the Common Palm Civets are identified as critical seed dispersers, especially for large-seeded tree species, to support forest ecosystem restoration in northern Thailand's fragment upland areas and prevention of hunting of them is important for the success for forest ecosystem restoration. However, we studied presence of mammals only and the role of small to medium sized mammals has yet to be systematically elucidated. Therefore, in the future, we suggest studying seed-dispersal by small-medium sized mammals in forests undergoing restoration by the FSM by identifying the seeds/fruits found in the diet (via scat analysis).

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Data

Table A.1 Mammal species Frequency of Detection in all 4 habitats.

English Name	Frequency of Detection (FD)				
	CON	R12	R24	REF	Total
Common palm civet	0.14	3.77	8.66	16.67	29.24
Large Indian civet	0.98	6.84	8.66	0.71	17.19
Large-toothed ferret-badger	0.00	0.00	0.14	0.42	0.56
Hog badger	0.00	1.40	0.28	0.71	2.39
Crab-eating mongoose	0.70	0.70	0.56	0.28	2.24
Leopard cat	0.00	1.68	0.98	1.98	4.64
Sunda pangolin	0.00	0.14	0.00	0.14	0.28
Eurasian wild pig	0.00	0.14	0.00	1.41	1.55
Red muntjac	0.00	0.00	0.00	0.14	0.14
Red-cheeked squirrel	0.00	0.00	0.00	5.65	5.65
Variable squirrel	0.00	0.00	0.00	1.27	1.27
Northern tree shrew	0.00	0.00	0.00	0.99	0.99
Burmese hare	0.14	0.00	0.00	0.00	0.14
Western striped squirrel	0.00	0.00	0.14	0.00	0.14
Unidentified squirrel	0.00	0.56	0.42	6.78	7.76
Unidentified rat	0.00	2.65	3.77	3.81	10.23
Unidentified bat	0.00	0.00	0.00	0.14	0.14
Unidentified species	0.00	0.70	0.14	1.84	2.68
Total	1.96	18.58	23.75	42.94	87.22

Table A.2 & A.3 Mammal species no. of encounters, Frequency of Detection and trap nights in the control site (CON) and the 12-year-old restored forest (R12).

CON			
Species	Encounters	FD	Trap nights
Large Indian civet	7	0.98	716
Common palm civet	1	0.14	716
Crab-eating mongoose	5	0.70	716
Burmese hare	1	0.14	716
Total	14	1.96	716

R12			
Species	Encounters	FD	Trap nights
Common palm civet	27	3.77	716
Large Indian civet	49	6.84	716
Hog badger	10	1.40	716
Crab-eating mongoose	5	0.70	716
Leopard cat	12	1.68	716
Sunda pangolin	1	0.14	716
Eurasian wild pig	1	0.14	716
Unidentified squirrel	4	0.56	716
Unidentified rat	19	2.65	716
Unidentifed species	5	0.70	716
Total	133	18.58	716

Table A.4 & A.5 Mammal species no. of encounters, Frequency of Detection and trap nights in the 24-year-old restored forest (R24) and the reference forest (REF).

R24			
Species	Encounters	FD	Trap nights
Common palm civet	62	8.66	716
Large Indian civet	62	8.66	716
Large-toothed ferret-badger	1	0.14	716
Hog badger	2	0.28	716
Crab-eating mongoose	4	0.56	716
Leopard cat	7	0.98	716
Western striped squirrel	1	0.14	716
Unidentjfied squirrel	3	0.42	716
Unidentified rat	27	3.77	716
Unidentifed species	1	0.14	716
Total	170	23.75	716

REF			
Species	Encounters	FD	Trap nights
Common palm civet	118	16.67	708
Large Indian civet	5	0.71	708
Large-toothed ferret-badger	3	0.42	708
Hog badger	5	0.71	708
Crab-eating mongoose	2	0.28	708
Leopard cat	14	1.98	708
Sunda pangolin	1	0.14	708
Eurasian wild pig	10	1.41	708
Red muntjac	1	0.14	708
Red-cheeked squirrel	40	5.65	708
Variable squirrel	9	1.27	708
Northern tree shrew	7	0.99	708
Unidentified squirrel	48	6.78	708
Unidentified rat	27	3.81	708
Unidentifed bat	1	0.14	708
Unidentifed species	13	1.84	708
Total	304	42.94	708

Table A.6 Planted framework species recorded in 24-year-old forest (R24) and their dispersal mechanism.

Species	Seed dispersal mode	Main dispersal agent	Known consumers and/or dispersers	Fruit type	Avg Seed diameter/width (mm)	Seed size
Balakata baccata	Zoochory	Birds, mammals	Birds, squirrels, civets	Drupe	4.22	Medium
Castanopsis acuminatissima	Zoochory	Birds, mammals	Squirrels, civets, macaque, bulbuls	Nut	10.99	Large
Castanopsis tribuloides	Zoochory	Mammals	Civets	Nut	6.39	Large
Choerospondias axillaris	Zoochory	Mammals	Ungulates, elephant, Malayan giant squirrel, civets	Drupe	14.32	Large
Ficus benjamina	Zoochory	Birds, mammals	Birds, bats, primates, civets, squirrels, bears, deer, wild pig	Fig	1.00	Small
Ficus glaberrima	Zoochory	Birds, mammals	Birds, bats, primates, civets, squirrels, bears, deer, wild pig	Fig	2.00	Small
Gmelina arborea	Zoochory	Birds, mammals	Birds, deer, wild pig, primates, civets	Drupe	8.00	Large
Helicia nilagirica	Zoochory	Birds	Birds	Berry	19.95	Large
Heynea trijuga	Zoochory	Birds	Southern Hill Myna	Aril	13.00	Large
Hovenia dulcis	Zoochory	Birds	Pigeons	Aepticidal capsule	5.37	Large
Lithocarpus elegans	Zoochory	Mammals	Squirrels, wild pigs, civets	Nut	9.31	Large
Machilus bombycina	Zoochory	Birds, mammals	Birds, civets, other mammals	Drupe	-	-
Nyssa javanica	Zoochory	Birds, mammals	Birds, civets, other mammals	Drupe	7.99	Large
Prunus cerasoides	Zoochory	Birds, mammals	Bulbuls, squirrels, civets, small mammals	Drupe	7.47	Large
Sapindus rarak	Zoochory	Mammals	Wild pigs, deer, civets	Drupe	15.91	Large

References; Datta and Rawatt (2008); FORRU (2005); FORRU (n.d.); Ganesh et al. (2001); Gopal et al. (2020); Junsongduang et al. (2014); Tun (2025).

Seed size classification	
Small	< 2.0 mm
Medium	2.0 mm – 5.0 mm
Large	> 5.0 mm

Table A.7 Recruit tree species recorded in 24-year-old forest (R24) and their dispersal mechanism.

Species	Seed dispersal mode	Main dispersal agent	Known consumers and/or dispersers	Fruit type	Avg Seed diameter/width (mm)	Seed size
Albizia chinensis	Anemochory	Wind	-	Pod/legume	7.63	Large
Albizia odoratissima	Anemochory	Wind	-	Pod/legume	5.78	Large
Artocarpus lanceolata	Zoochory	Mammals	Monkeys, squirrels, civets	Syncarp	10.55	Large
Artocarpus lakoocha	Zoochory	Birds, mammals	Hornbills, monkeys, squirrels, civets	Syncarp	9.14	Large
Baccaurea ramiflora	Zoochory	Mammals	Deer, wild pigs, primates, civets	Loculicidal capsule	8.59	Large
Dalbergia ovata	Anemochory	Wind	-	Legume	-	-
Dillenia parviflora	Zoochory	Birds, mammals?	Birds, mammals?	Berry	3.59	Medium
Eugenia claviflora	Zoochory	Birds, mammals	Birds, civets, other mammals	Berry	4.00	Medium
Ficus fistulosa	Zoochory	Birds, mammals	Birds, bats, primates, civets, squirrels, bears, deer, wild pig	Fig	1.00	Small
Ficus superba	Zoochory	Birds, mammals	Birds, bats, primates, civets, squirrels, bears, deer, wild pig	Fig	1.00	Small
Garuga pinnata	Zoochory	Birds, mammals	Macaques, parakeets, civets	drupe	6.46	Large
Kydia calycina	Anemochory	Wind	-	Winged	1.50	Small
Lannea coromandelica	Zoochory	Birds	Birds	drupe	-	-
Lithocarpus garrettianus	Zoochory	Mammals?	Mammals?	Nut	14.20	Large
Litsea glutinosa	Zoochory	Birds?	Birds?	drupe	6.65	Large
Litsea salicifolia	Zoochory	Birds?	Birds?	Berry	7.18	Large
Magnolia liliifera	Zoochory	Birds?	Birds?	Capsule	-	-
Markhamia stipulata	Anemochory	Wind	-	Loculicidal capsule	11.93	Large
Measa ramenta	Zoochory	Birds, mammals	Birds, civets, other mammals	Berry	-	-
Miliusa velutina	Zoochory	Birds, mammals?	Birds, mammals?	Drupe	8.18	Large
Phoebe lanceolata	Zoochory	Birds	Hornbills, other birds	Drupe	6.44	Large
Prunus arborea	Zoochory	Mammals	Gibbons	Drupe	-	-
Sarcosperma arboreum	Zoochory	Birds, Mammals?	Birds, mammals?	Berry	11.77	Large
Trevesia palmata	Zoochory	Birds, mammals?	Birds, bats?	Drupe	-	-
Turpinia pomifera	Zoochory	Mammals	Deer, wild pig, civets	Berry	6.85	Large
Wendlandia paniculata	Anemochory	Wind?	-	Capsules, globose or subglobose, glabrous	-	-

References; Aluri et al. (2013), Chase et al. (2016); Datta and Rawat (2008); FORRU (2005); FORRU (n.d.); Ganesh et al. (2001); Gopal et al. (2020); Junsongduang et al. (2014); McConkey et al. (2002); Orwa et al. (2009); Ridley (1930); Tun (2025); Van Valkenburg (n.d.).

APPENDIX B

Mammal photos from camera trap

Figure B.1 Common Palm Civet (*Paradoxurus hermaphroditus*) (recorded in all habitats).

Figure B.2 Large Indian Civet (*Viverra zibetha*) (recorded in all habitats).

Figure B.3 Large Indian Civet preying on a seed predator (likely a rat) in R12.

Figure B.4 Crab-eating Mongoose (*Herpestes urva*) (recorded in all habitats).

Figure B.5 Hog Badger (*Arctonyx collaris*) (recorded in all habitats except CON).

Figure B.6 Leopard Cat (*Prionailurus bengalensis*) (recorded in all habitats except CON).

Figure B.7 Large-toothed Ferret-Badger (*Melogale personata*) (recorded in R24 & REF).

Figure B.8 Sunda Pangolin (*Manis javanica*) (recorded in R12 & REF).

Figure B.9 Eurasian Wild Pig (*Sus scrofa*) (recorded in R12 & REF).

Figure B.10 Red Muntjac (*Muntiacus muntjak*) (recorded only in REF).

Figure B.11 Western striped squirrel (*Tamiops mcclellandii*) (recorded only in R24).

Figure B.12 Red-cheeked Squirrel (*Dremomys rufigenis*) (recorded only in REF).

Figure B.13 Variable Squirrel (*Callosciurus finlaysonii*) (recorded only in REF).

Figure B.14 Northern Tree Shrew (*Tupaia belangeri*) (recorded only in REF).

Figure B.15 An unidentified Rat (recorded in all habitats except CON).

APPENDIX C

Fruit Photos and Fruit Types

Framework Tree Species

Figure C.1 *Balakata baccata* (Drupe)

Photo by Mark Francis Watson (2008)

Figure C.2 *Choerospondias axillaris* (Drupe)

Photo by Etsy (n.d.)

Figure C.3 *Gmelina arborea* (Drupe)

Photo by Trade Wind Fruits (n.d.)

Figure C.4 *Helicia nilagirica* (Berry)

Photo by POWO (Plants of World Online) (n.d.)

Figure C.5 *Prunus cerasoides* (Drupe)

Photo by Top Tropicals (n.d.)

Figure C.6 *Sapindus rarak* (Drupe)

Photo by FORRU (n.d.)

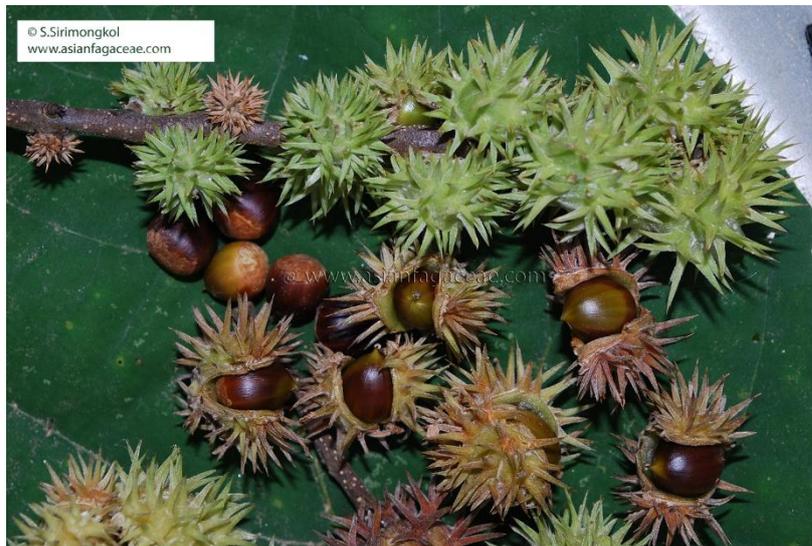**Figure C.7** *Castanopsis acuminatissima* (Nut)

Photo by Flora of Thailand (n.d.)

Figure C.8 *Castanopsis tribuloides* (Nut)

Photo by Sirimongkol (n.d.)

Figure C.9 *Lithocarpus elegans* (Nut)

Photo by Sawmliana (2018)

Recruit Tree Species

Figure C.10 *Ficus fistulosa* (Fig)

Photo by Jircas (n.d.)

Figure C.11 *Garuga pinnata* (Drupe)

Photo by Flowers of India (n.d.)

Figure C.12 *Measa ramenta* (Berry)

Photo by Medthai (n.d.).

Figure C.13 *Prunus arborea* (Drupe)

Photo by Martin W. Callmander (n.d.)

Figure C.14 *Turpinia pomifera* (Berry)

Photo by Flora of Thailand (n.d.)

Figure C.15 *Artocarpus lakoocha* (Syncarp)

Photo by India Biodiversity Portal (n.d.)

Figure C.16 *Eugenia claviflora* (Berry)

Synonym: *Syzygium claviflorum*

Photo by Commonwealth Scientific and Industrial Research Organization (CSIRO)
(2020)

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