BIRD SPECIES DIVERSITY AT LONG-TERM FOREST RESTORATION PLOTS IN NORTHERN THAILAND

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BACHELOR OF SCIENCE
(ENVIRONMENTAL SCIENCE)

CHIANG MAI UNIVERSITY
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I would like to dedicate this study to my family for never stopping to believe in me and for continually providing moral, emotional, and financial support.

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ABSTRACT

Tropical forest restoration aims to recover not only tree cover but also the complex ecological interactions that sustain biodiversity. Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) has widely used the Framework Species Method to restore tropical forest ecosystems in Northern Thailand for over 30 years. Birds serve as critical "mobile links" for seed dispersal and pest control, making their return a primary indicator of restoration success. However, despite research on overall bird species richness, little is known about the specific ecological requirements and timeframes needed for the return of habitat specialist bird species to restored forests in Northern Thailand. Therefore, a survey was carried out in restoration plots in Ban Mae Sa Mai, in the Doi-Suthep Pui National Park area, comparing plots where forest restoration activities had taken place to assess biodiversity recovery, particularly birds. Species accumulation curves showed a significant increase in taxonomic richness over time. The results were compared with those of the nearby natural forest to evaluate restoration success. A total of 147 bird species were found in all study habitats. The Reference Forest exhibited the highest richness (77 species), followed closely by the 24-year-old plot (71 species), which reached approximately 92% of the reference site's richness. In contrast, the 13-year-old plot (64 species) and the Control Plot (44 species) showed significantly lower diversity. This suggests that bird species richness can largely recover within 24 years using the Framework Species Method. The absence of habitat specialists in older plots highlights the need for continued structural maturation to support the full spectrum of avian ecological roles. This research underscores the importance of long-term monitoring to distinguish between restoration and a fully functional forest ecosystem.

Keywords: Forest Restoration, Northern Thailand, Bird Species Diversity, Framework Species Method, MacKinnon Species List

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LIST OF ABBREVIATIONS

FORRU-CMU	Forest Restoration Research Unit – Chiang Mai University
FSM	The Framework Species Method
ANR	Assisting Natural Regeneration
DSPNP	Doi Suthep-Pui National Park
BMSM	Ban Mae Sa Mai
BMS	Ban Mae Sa Noi
R12	12-13-year-old restoration plots in Pah Dong Saeng
R24	24-year-old restoration plots in Pah Dong Saeng
REF	Pah Dong Saeng, which served as the reference forest for this project

CHAPTER 1

Introduction

1.1 Background Introduction

Forest restoration is a critical ecological practice aimed at reversing the adverse effects of deforestation and forest degradation, which have led to significant biodiversity loss and decline in ecosystem services globally (Ciccarese et al., 2012; Raj et al., 2024; Resende et al., 2024). Restoration efforts are essential for maintaining ecological stability, enhancing biodiversity, and providing ecosystem services such as carbon sequestration, climate change mitigation, and soil restoration (Ciccarese et al., 2012; Raj et al., 2024; Resende et al., 2024). In 1950, more than 60% of Thailand's land was covered in forests, but by 1992, forest cover had been reduced to about 25% of the country's land. According to the 8th National Economic and Social Development Plan, at least 40% of Thailand should be forested (Chantong, W. 1999). It was shown that a large number of forests were rapidly destroyed in only 42 years. Although there have been many Government campaigns to reforest, the trees planted are often not adequately cared for. There is a low species richness of planted trees in reforestation areas. For example, *Pinus* spp. has been planted on a large scale in degraded mountain areas. Furthermore, exotic species such as *Eucalyptus* spp. are frequently planted. As these plantations mature, biodiversity remains lower than in primary forest.

Forest restoration encompasses various techniques and scales, including reforestation, afforestation, and rehabilitation of degraded lands (Aerts & Honnay, 2011; Ciccarese et al., 2012). The primary objectives of forest restoration are to protect forest biodiversity, enhance biomass production, and mitigate climate change (Ciccarese et al., 2012; Rayden et al., 2023). Effective Forest restoration requires well-planned policies, continuous execution, and adaptive management to address the challenges posed by past policies and ongoing environmental threats (Raj et al., 2024; Resende et al., 2024). The Forest Restoration Research Unit – Chiang Mai University (FORRU-CMU) was established to develop effective methods for restoring natural ecosystems in deforested areas. The unit has been conducting research to develop suitable methods for forest restoration using the Framework Species Method (FSM), which uses suites of carefully selected local forest tree species to accelerate natural succession. The method's success depends on the recolonization of restoration sites by seed-dispersing animals, thereby increasing tree species richness beyond the originally planted species. This method is analogous to building a house in which, once the framework has been built, the roof and furniture (e.g., in a forest, the ferns, vines, orchids, and animals) build themselves. Biodiversity recovery is also one of the 4 primary indicators of restoration success, and it is closely interdependent with the other 3 (biomass accumulation, structural diversification, and recovery of ecological functionality) (Elliott et al., 2019, 2022).

Tucker (2000) suggested using wildlife as indicators of forest recovery. Wildlife monitoring can assess a plantation's capacity to increase biodiversity and suggest ways to improve plantation methods in the future. Understanding how different restoration approaches influence faunal recovery is essential for guiding tropical forest restoration efforts and achieving desired biodiversity conservation outcomes. Birds are a key group in tropical forest restoration because they both benefit from restoration and promote forest regeneration through pollination and seed dispersal interactions. They occupy all trophic levels in food webs, including fruits, plants, seeds, herbivores, omnivores, and carnivores.

Although recovery of tree species diversity is the main objective during the first years after planting using the FSM, birds were chosen for this study because

1. Birds are wildlife that can live in deforested areas and are quite numerous.
2. Birds are easily observed and identified using "A Guide to the Birds of Thailand" by Lekagul and Round (1991).
3. There are many bird species at all trophic levels.
4. Birds are efficient seed dispersers that can disperse seeds over long distances.

Moreover, bird species and communities are often affected by changes in vegetation cover. They also disperse seeds and facilitate pollination, which can increase plant diversity in planted areas. Thus, if we can attract birds to planted areas, wildlife conservation objectives will be met, and the areas may recover more of their former biodiversity.

1.2 Objectives

- To determine the effectiveness of the Framework Species Method (FSM) in bringing back bird species diversity by direct observation
- To assess the ecological roles of birds in the trophic levels and see how they can be related to diversity

Therefore, this research monitored bird communities at plots of different restoration ages in the upper Mae Sa Valley within Doi Suthep-Pui National Park, placed in an 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. Interactions between bird communities and the restored plots were observed to determine the relative attractiveness of different-aged restoration plots. The results can be used to optimize restoration methods.

1.3 Literature review

1.3.1 Forest Restoration

Although deforestation is mainly caused by humans, forest recovery in degraded areas can be natural, 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 (Aerts & Honnay, 2011; Wunderle, 1997)). Consequently, active forest restoration is an essential key to accelerating forest recovery (Ciccarese et al., 2012; Rayden et al., 2023).

Whereas "reforestation" is a broad term meaning the reestablishment 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. In an ecological context, restoration can be defined as "returning the land to its former use and condition" (Erbaugh et al., 2020). 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 (Ciccarese et al., 2012).

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. This undisturbed or near-natural forest ecosystem 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)(Hoffmann et al., 2025). 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 increase as the severity of degradation increases (Elliott et al., 2013). Restoring a forest is more expensive and labor-intensive at a higher degradation stage than at a lower one.

The success of forest restoration can be measured through monitoring several parameters, particularly biomass (carbon storage in trees 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. So, for restoration, monitoring focuses on components related to the reestablishment of ecological functionality, particularly seed dispersal and seedling establishment of recruit tree species (i.e., incoming tree species not including those planted), especially those that indicate overall forest health (Elliott et al., 2013).

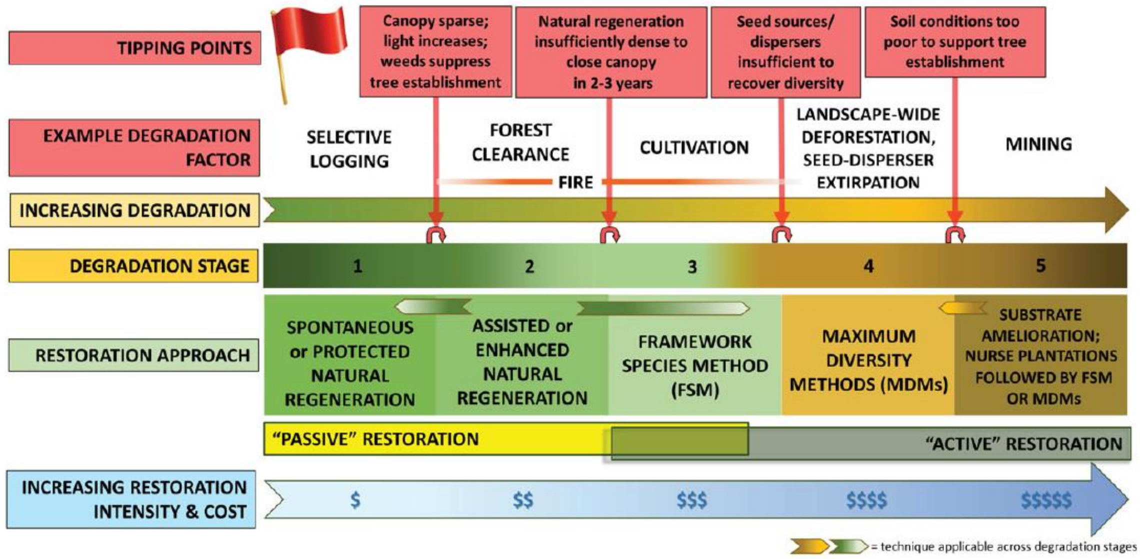

Figure 1.1 A scale of restoration interventions, which becomes more intensive and more expensive, as starting conditions become increasingly degraded (Elliott et al., 2022).

1.3.2 Framework Species Method (FSM)

Several approaches have developed, each varying in intensity from ANR with no planting to planting 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, more effective at restoring biodiversity than the former, while requiring fewer inputs than the latter (FORRU, 2005). It is also one of the least intensive of the active methods of restoration, which involves complementing natural regeneration with tree planting on moderately degraded sites located within the seed-dispersal range of remnant forests (Elliott et al., 2022).

The FSM is primarily applicable during degradation stage 3. FSM is used when the site has progressed past forest clearance into the cultivation stage. It is utilized when natural regeneration is insufficiently dense to close the canopy in 2-3 years. At this stage, the passive restoration is not fully effective, requiring a shift towards active restoration. FSM represents a moderate level of restoration intensity and cost.

The technique involves planting mixtures of 20-30 carefully selected tree species from the reference forest ecosystem and caring for them, i.e., weeding, fertilizer application, and fire prevention, for two or more years. The ecological characteristics of framework tree species are

1. High survival when planted out in deforested sites
2. Rapid growth
3. Dense, spreading crowns that shade out herbaceous weeds
4. Flowering and fruiting, or the provision of other resources, at a young age, which attract seed-dispersing wildlife. (Elliott et al, 2013; FORRU, 2005).

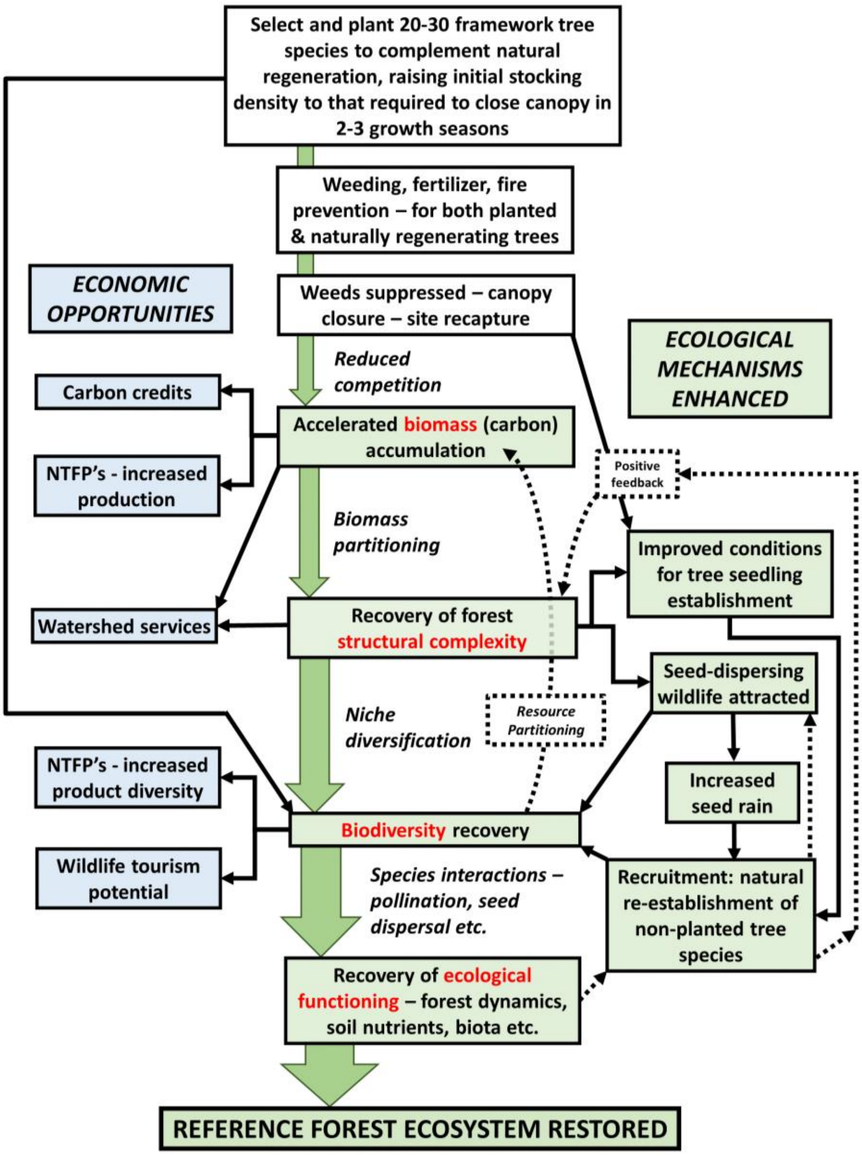

Figure 1.2 How the framework species method works (Elliott et al., 2022).

The planted trees "recapture" the degraded site by shading out weeds, reestablishing a multilayered canopy, and restoring ecosystem processes. This creates a weed-free forest floor with a cooler, more humid microclimate, thereby 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).

1.3.3 Bird communities related to forest restoration

Forest structure can greatly affect the species richness and species diversity of bird communities (Beaver and Sritasuwan, 1985). The occurrence and abundance of bird species can mirror habitat quality, which is helpful for habitat evaluation. Recently, several studies have examined the conservation value of different forest management types, such as planted and naturally regenerating forests, for bird communities. Several studies have shown that these different forest management types often retain a large proportion of forest birds. In Uganda, forest birds were best represented in scarcely logged native forests, while exotic conifer plantations had the fewest. Also, Barlow et al. (2007) reported the highest bird species richness in indigenous primary forest and the least species-rich assemblage in Eucalyptus plantations. Secondary forests harbored an intermediate number of bird species. Thus, forests that comprise a mix of forest management strategies, such as plantations with multiple tree species, monocultures, and secondary forest stands, are important for further investigations into biodiversity conservation (Hoffmann et al., 2025; Miller-ter Kuile et al., 2023).

For example, different Bulbul species on Doi Suthep-Pui are found in different forest types, depending on food resources and degree of disturbance. The Striated Bulbul (*Alcurus striatus*) can be found only in climax undisturbed evergreen forest, while the Red-whiskered Bulbul (*Pycnonotus jocosus*) often occurs near artificial habitats from 340 to 1400 meters above sea level. Thus, the Red-whiskered Bulbul (*Pycnonotus jocosus*) can be used as an indicator of disturbance (Singhakan, 1986; Portigo, 1994). Portigo (1994) studied the composition of bird communities in 4 different habitat types with differing degrees of disturbance on Doi Suthep-Pui and the ecological flexibility of the family Pycnonotidae to these habitat types. Twenty species lists were used to assess the bird communities, and the "Point Count Method" was used to determine the abundance and distribution of Bulbuls. One hundred and eighteen species were found on a demonstration farm. Undisturbed evergreen forest supported the highest species richness, and taller, denser vegetation structures were directly related to the richness of the bird community. The lowest diversity was in the demonstration farm. The Black-headed Bulbul (*Microtarsus melanocephalos*) was found only in undisturbed habitats. The Red-whiskered Bulbul (*Pycnonotus jocosus*) was found in all disturbed areas and also in the demonstration farm. Similarly, to Singhaken, she found that the Red-whiskered Bulbul (*Pycnonotus jocosus*) usually inhabited man-made habitats and suggested that this species is a good indicator of disturbance. She concluded that deleterious human activities, such as burning, habitat clearance, and poaching, threaten the diverse composition of the bird communities on Doi Suthep-Pui.

Chanthorn (2002) studied the relationship between bird communities and fellow-shifting cultivation. He studied rice fields, fellows, and mature forests. The study sites differed in age and habitat composition. One hundred and thirty-eight bird species were found in all habitats. Mature forest supported the highest bird species richness (68 species), and rice fields had the lowest. Many habitats are mosaics composed of differing microhabitats with edge effects, or ecotones, which increase the diversity of birds. He found that the composition of bird communities is specific to each habitat type and changes at ecotones or when moving from forests to the forest edge.

1.3.4 Birds as seed dispersers and forest recovery

Seed dispersers in tropical forests are mostly birds and mammal communities. These animals have the highest potential to accelerate forest recovery (Elliott et al., 2019). Trees that provide food or nesting sites can attract seed-dispersing animals for long periods, during which the animals may deposit seeds that begin the process of restoring the forest's original tree species composition. Therefore, planted framework trees act as "bait" for seed-dispersing animals. Dispersal of seeds between natural forests and planted plots is carried out by relatively few, common, fruit-eating animal species that are equally at home in forests and in deforested areas. These include small to medium-sized birds, particularly Bulbuls (*Pycnonotus* spp), fruit bats (e.g., *Cynopterus* spp), and some medium-sized mammals, including Civets, Hog Badger (*Arctonyx collaris*), Common

Wild Pig (*Sus scrofa*), Common Barking Deer (*Muntiacus muntjak*), etc. Tree species that are most likely to attract such animals produce small to medium-sized fruits or nectar-rich flowers (preferably within 3 years after planting). Insect increases in planted plots attract insectivorous and seed-dispersing birds (Toktang, 2005), as well as mammals with mixed diets. Still, little is known about the insects associated with framework tree species.

Wilson and Crome (1989) studied seed dispersal at the edge of a tropical Queensland rain forest. They found that both wind and animals (especially birds and bats) dispersed seeds from forests into degraded areas more than from degraded areas into forests, and those animals can disperse seeds farther than the wind (Willson & Crome, 1989). Habitat structure affects seed dispersal through the availability of perches, the complexity of vegetation structure, and the presence of food resources that can attract seed dispersers. Moreover, plantations that are more attractive to wildlife have a denser seed rain than those that are less attractive. In the pastureland of the Amazon basin, the majority of tree fruits are fleshy and appear to be dispersed by birds, bats, and both arboreal and ground-dwelling mammals. One hundred and fifty species of birds were identified, but fewer than 10 frugivores moved into large openings. Frugivorous bird species that are effective agents of seed dispersal in forest succession or restoration areas should be tolerant of degraded landscapes, such as Family Pycnonotidae (Bulbuls), Megalaimidae (Barbets), Zosteropidae (White-eyes), and Corvidae (Magpies). The family Pycnonotidae (Bulbuls) plays an important role in seed dispersal, especially the Black-crested Bulbul, which occurs in a wide range of habitats and eats many kinds of fruits. Amongst the birds, bulbuls are particularly important. They are common and frequent visitors to deforested sites several kilometers from natural forests. They disperse seeds of many plant species, up to 14 mm in diameter, over long distances, since they retain seeds in their digestive tracts for up to 41 minutes. Fruit bats are also important seed dispersers. However, unlike most birds, bats are nocturnal and cannot be identified using binoculars. (Chanthorn, 2002; Pattanakaew, 2002).

Parotta et al. (1997) observed animal and plant diversity while monitoring the success of reforestation in a degraded tropical forest in Brazil. An animal survey focused on birds and bats, and the plant survey focused on the floristic composition and structure of the 10-year-old reforested area. Ninety native forest tree species were planted in the area. They found that 75 species had been dispersed from the surrounding primary forest into the regenerating degraded forest. The most common dispersers were frugivorous birds and bats, which generally dispersed smaller seeds than other animals. Smaller seeds accounted for a higher proportion of colonizing species than larger seeds. In general, larger seeds were rare in the reforestation areas because the animals that typically dispersed them (such as trogons, deer, and primates) were rare there. (Parrotta et al., 1997))

Evidence from multiple continents demonstrates that native tree plantations can benefit bird recovery by providing a closed canopy and vertical stratification (Celentano et al., 2022; Eddy et al., 2021; Kukreti & Bhatt, 2014; Melkamu et al., 2025; Meng et al., 2021). However, forest-dependent birds may require specific microclimates, food items, or nest sites that can take decades to develop. Understory insectivores in particular, are sensitive to disturbance and show limited dispersal across anthropogenic matrices. The recovery of richness and composition would be greater in planted restoration treatments than in natural regeneration, because planted species would increase physical structure and provide the same resources to both treatments. Disentangling the effects of restoration treatment on avian habitat use from those of site age and context requires long-term, multi-site, and multi-treatment studies that also include reference and degraded sites surveyed multiple times to account for regional trends which may be occurring independently of local restoration efforts, for example population declines or range expansions (e.g., Blake and Loiselle, 2016; Sigel et al., 2006).

CHAPTER 2

Experimental Methods

2.1 Study Area

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 (DSPNP), in Chiang Mai Province, northern Thailand, with the Hmong hill tribe communities of Ban Mae Sa Mai (BMSM) 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. The project site was assigned to FORRU-CMU by the Doi Suthep-Pui National Authority in 1996 (Figure 2.1).

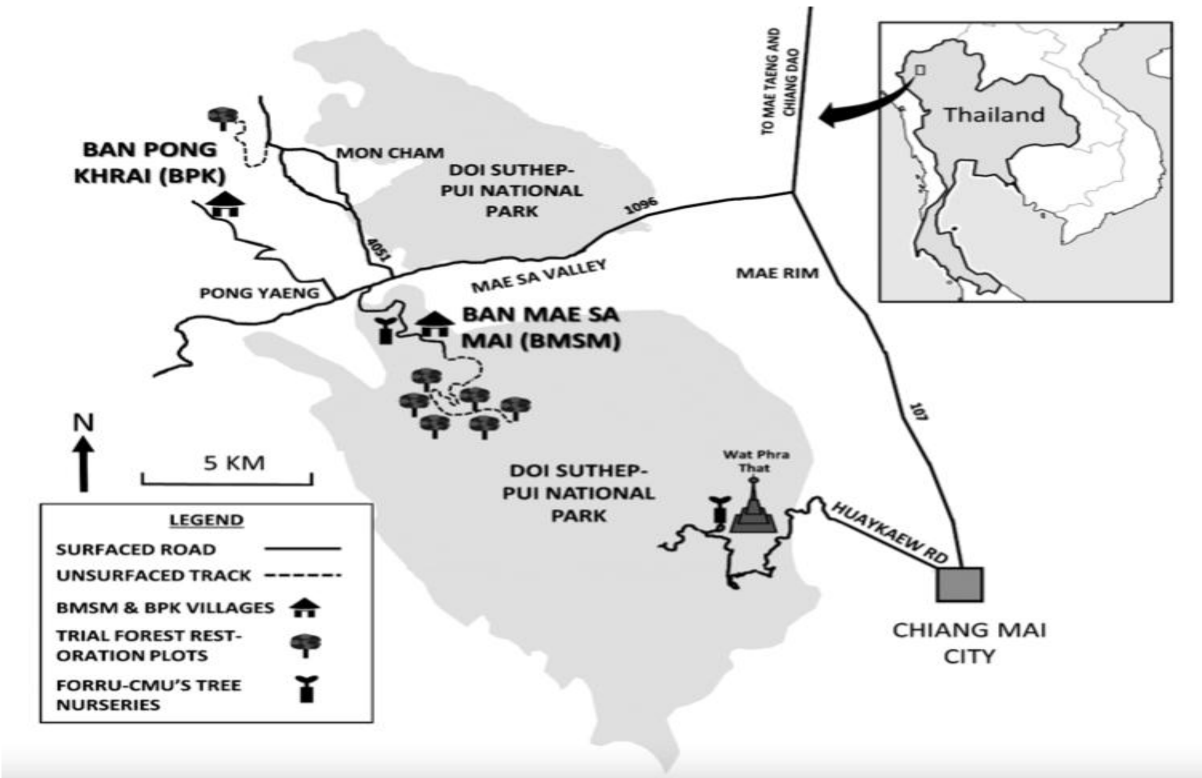

Figure 2.1 Location of the study area in relation to Chiang Mai, Doi Suthep-Pui National Park

2.2 The climate

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 (Figure 2.2). 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., 2019).

Originally, the area had been covered in "Primary, Evergreen, Seasonal Forest" (EGF), (Elliott et al., 2019), which was cleared from the 1950s to the early 80's to provide land for the cultivation of cabbage, potatoes, and other cash crops. The condition of the area was stage-3 degradation (Elliott et al., 2019), 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. A few remnant forest trees, sparsely scattered across the plot system site, provided a potential seed source for natural forest regeneration. The nearest remnant forest, "Pah Dong Saeng", lies 2–3 km from the plots (disturbed primary Evergreen Forest (EGF), 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. Potential dispersers of medium-sized seeds from that forest into the trial plots included birds (particularly bulbuls and barbets) and small mammals (civets, badgers, and small fruit bats). Most of the slopes below the plots were still cultivated for cabbage when the plot system was initiated. Litchi orchards (*Litchi chinensis* Sonn. (Sapindaceae)) lower down the valley were extensive but are now in decline and being replaced with horticultural crops, using plastic cloches (e.g., salad vegetables, cut flowers, etc.). Villagers have invested heavily in an irrigation system that delivers piped water from the upper watershed to the agricultural field lower down the valley. (Elliott et al., 2019)

This study determined to what extent restoration interventions have propelled the recovery of bird species from the starting state (abandoned agricultural land) towards reference forest conditions. Data were collected at 4 sites within the area described above: i) abandoned agricultural land (control – starting conditions) (CONTROL), ii) 12-13-year-old (R12) and iii) 24-year-old (R24) restoration plots and iv) in Pah Dong Saeng, which served as the reference forest for this project (REF) (Gann et al., 2019), being the least disturbed forest remnant in the vicinity (Figure 2.2).

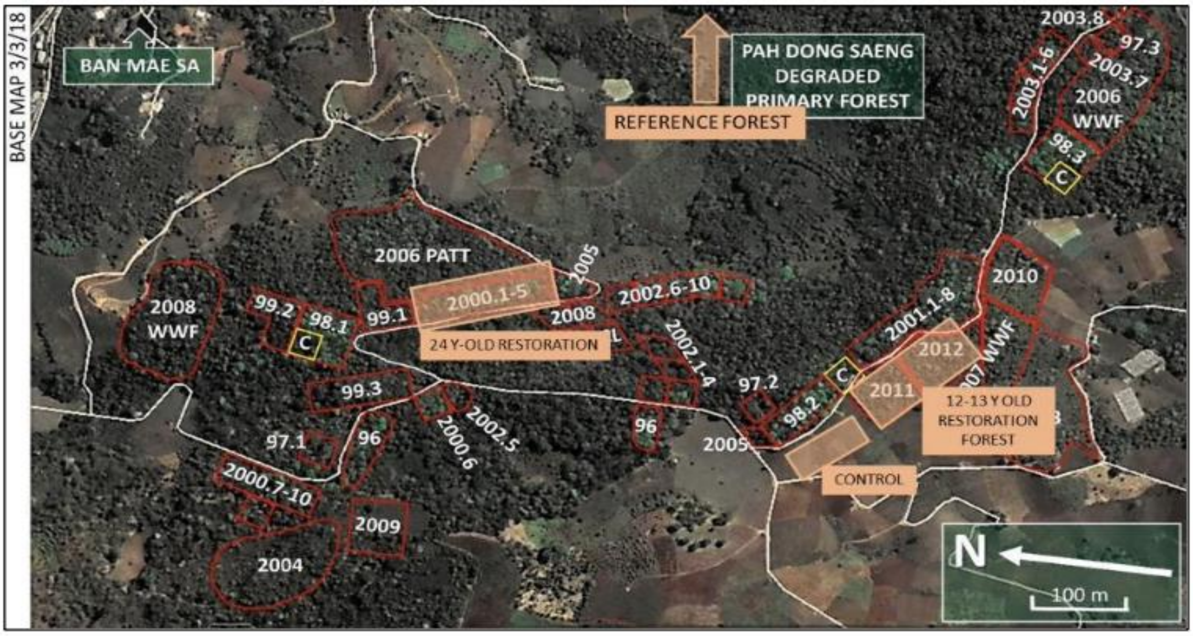

Figure 2.2 The framework species demonstration plot system in the Upper Mae Sa Valley.

2.3 Methodology

2.3.1 Field work

Bird watching was conducted by teams of 12 people staying overnight in Ban Mae Sa Mai (BMSM) village 4 times: on May 4-5, July 6-7, September 7-8, and November 2-3, 2024. Bird watchers record every bird they recognize by sight or sound, along with the time of observation, using the transect survey method. Birds were recorded for 3 hours before sunset and 3 hours after sunrise. This is the time when birds are most active. The bird watchers work in pairs: a spotter, who notes the birds seen, and a recorder, who writes down the information. Therefore, on each trip, 12 person-hours of observation time were expanded at each of the 4 sites, for a total of 48 hours per site over the four trips. The bird-watching team was split into 2-person groups, and the teams were rotated through each plot to avoid observer bias.

The MacKinnon species-list method was used to analyze the bird lists. The Mackinnon species list method is used to construct a species-discovery curve and to provide an index of relative abundance. This method differs from other techniques in that it uses the list as the unit of effort rather than time or area. This makes the method relatively insensitive to differences in observers' abilities, without affecting the results. Moreover, this method produces similar results during both high and low activity periods. For each of the four study habitats, the record sheets were arranged in time order, and a list of the first 10 different bird species observed was compiled. Continuing moving down the time record, a second list of 10 different species was compiled. Species already recorded in the first list were ticked, whilst new species were added at the bottom of the 2nd list. This process was repeated until at least ten lists had been compiled (Table 2.1). On any one list, each species occurred only once, but a single species could occur on more than one list. The list became an artificial measure of observation effort.

Table 2.1 MacKinnon species data sheet in Control Plot

Date	Time	No.	Common Name	Scientific name	Song or Sight	Number of Bird
			List 1			
04/05/2024	14.34	1	Sooty-headed Bulbul	*Pycnonotus aurigaster*	sight	2
04/05/2024	14.36	2	House Swift	*Apus nipalensis*	sight	8
04/05/2024	14.44		House Swift	*Apus nipalensis*	sight	8
04/05/2024	14.52		House Swift	*Apus nipalensis*	sight	20
04/05/2024	14.52		Sooty-headed Bulbul	*Pycnonotus aurigaster*	sight	2
04/05/2024	14.55	3	Barn Swallow	*Hirundo rustica*	sight	5
04/05/2024	14.59	4	Pied Bushchat	*Saxicola caprata*	sight	1
04/05/2024	15.02	5	Blue-throated Barbet	*Psilopogon asiaticus*	song	1
04/05/2024	15.10		House Swift	*Apus nipalensis*	sight	1
04/05/2024	15.11	6	White-rumped shama	*Copsychus malabaricus*	song	1
04/05/2024	15.11		Pied Bushchat	*Saxicola caprata*	sight	1
04/05/2024	15.14	7	Asian Brown Flycatcher	*Muscicapa dauurica*	sight	1
04/05/2024	15.17	8	Spotted Dove	*Spilopelia chinensis*	sight	1
04/05/2024	15.21	9	Greater Coucal	*Centropus sinensis*	sight	1
04/05/2024	15.25		Sooty-headed Bulbul	*Pycnonotus aurigaster*	sight	1

Date	Time	No.	Common Name	Scientific name	Song or Sight	Number of Bird
04/05/2024	15.32		House Swift	*Apus nipalensis*	sight	15
04/05/2024	15.33	10	Unidentified Munia	*Lonchura spp.*	sight	1
			List 2			
04/05/2024	15.47	1	Sooty-headed Bulbul	*Pycnonotus aurigaster*	sight	3
04/05/2024	15.48	2	Oriental Honey-buzzard	*Pernis ptilorhynchus*	sight	1
04/05/2024	15.58		Sooty-headed Bulbul	*Pycnonotus aurigaster*	sight	3
04/05/2024	16.30	3	Unidentified Munia	*Lonchura spp.*	sight	1
04/05/2024	16.33		Sooty-headed Bulbul	*Pycnonotus aurigaster*	sight	2
04/05/2024	16.39	4	Red-whiskered Bulbul	*Pycnonotus jocosus*	sight	5
04/05/2024	16.45	5	House Swift	*Apus nipalensis*	sight	3
04/05/2024	16.53		House Swift	*Apus nipalensis*	sight	30
04/05/2024	16.57	6	Spotted Dove	*Spilopelia chinensis*	song	1
04/05/2024	17.16	7	Long-tailed Shrike	*Lanius schach*	sight	1
04/05/2024	17.20	8	Blue-throated Barbet	*Psilopogon asiaticus*	song	1
05/05/2024	8.53	9	Bar-winged Flycatcher-shrike	*Hemipus picatus*	sight	1
06/07/2024	14.16	10	Rufescent Prinia	*Prinia rufescens*	sight	3

2.4 Analytical methods:

2.4.1 MacKinnon species list method

The MacKinnon species list method is a rapid, cost-effective biodiversity assessment method that involves recording species in consecutive, fixed-size lists as they are encountered in the field. It is used to estimate species richness and relative abundance based on frequency of occurrence. Bird species discovery curves were produced by plotting the cumulative total number of species observed against the number of lists made. Then, the number of bird species not seen in each survey plot was predicted by plotting the log frequency of the number of species occurring on a given number of lists against the number of lists on which each species occurs. A regression line of best fit was then extrapolated back to zero, providing an estimate of the number of species occurring on zero lists (i.e., number of species not seen). This number, when added to the number of species seen, provides a prediction of the total number of species in each area of the study plot. The advantage of the Mackinnon species list Method is that it is less sensitive to differences in observer experience and allows rapid biodiversity assessment with lower survey effort than traditional methods.

2.4.2 Sorensen's index of similarity

The Sorensen index of similarity is an ecological measure of similarity between two communities based on their species composition, calculated by the formula (Figure 2.3). It ranges from 0 to 1, with 1 indicating a perfect match between the two communities and 0 indicating no shared species.

$$S_s = 2a/(2a + b + c)$$

a = number of species common to both quadrats,

b = number of species unique to the first quradrat, and

c = number of species unique to the second quadrat

2.4.3 Mann-Whitney U test using R statistical software to measure species richness between plots

The Mann-Whitney U test is a nonparametric statistical test used to test ecological count data for a significant difference between the distributions of two independent groups. The Mann-Whitney U test is suitable for comparing two groups when sample sizes may be limited. And it is well established in the ecological literature for habitat-comparison studies. Setting the null hypothesis (H_0) for this study as "There is no difference in species richness between plots." And as the alternative hypothesis, H_1 would be "There is a difference in species richness between plots." By setting the 95% confidence interval, if the calculated "p value" is less than 0.05, the null hypothesis will be rejected, and H_1 will be accepted; Conversely, if the calculated "p value" is greater than 0.05, the null hypothesis will be accepted, and H_1 will be rejected. In the Mann-Whitney U Test, the input data were separated based on the number of species observed during a total of 8 bird-watching sessions. Analyzing how many species were observed during each bird-watching time, the species richness comparison value for each plot is calculated using R statistical software (Version 4.5.0) and compared across plots. Steps in data analysis for running the Mann-Whitney U Test include

- Data exploration
- Loading necessary packages
- Checking assumptions for hypothesis testing, parametric or non- parametric Shapiro-Wilk Test for Normality
- Test homogeneity of variance (Levene's test)
- For this research, the Mann-Whitney U test is used rather than the independent t-test because the sample size is too small to perform the independent t-test.

There will be a total of multiple tests (6 separate) pairwise comparisons for 4 habitat types.

2.4.4 Bird diet types analysis across habitat

For bird diet types analysis, the paper "BIRDBASE: A Global Dataset of Avian Biogeography, Conservation, Ecology and Life History Traits" by Çağan H. Şekercioğlu (Şekercioğlu et al., 2025) was used. Bird diets were separated into 8 types according to the paper: Invertebrate, Omnivore, Fruit, Nectar, Vertebrate, Seed, Carnivore, and Herbivore. Analyzing the bird species based on their diet list by using the Google Colab website (www.colab.research.google.com). Steps in running the code include installation and importing of required libraries, loading the file and data preparation, defining the habitat columns and filters for specific diet types, and checking to ensure all specified habitat columns exist in the data frame to create the multidimensional bubble plot.

CHAPTER 3

Results and Discussion

3.1 Results

A total of 147 bird species (including 17 unidentified species) were observed across all sites. This markedly exceeded 88 bird species, reported by Toktang working in the same plot system 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 with bi-monthly observations from June 2002 to July 2003 (Toktang, 2005). Bird species richness increased markedly from about 88 species to 147 after 22 years, representing about 59% of the birds recorded in the nearest remaining patch of climax forest. The estimated numbers of bird species not observed based on the Mackinnon list of observed species are listed and represented in Figure 3.1.

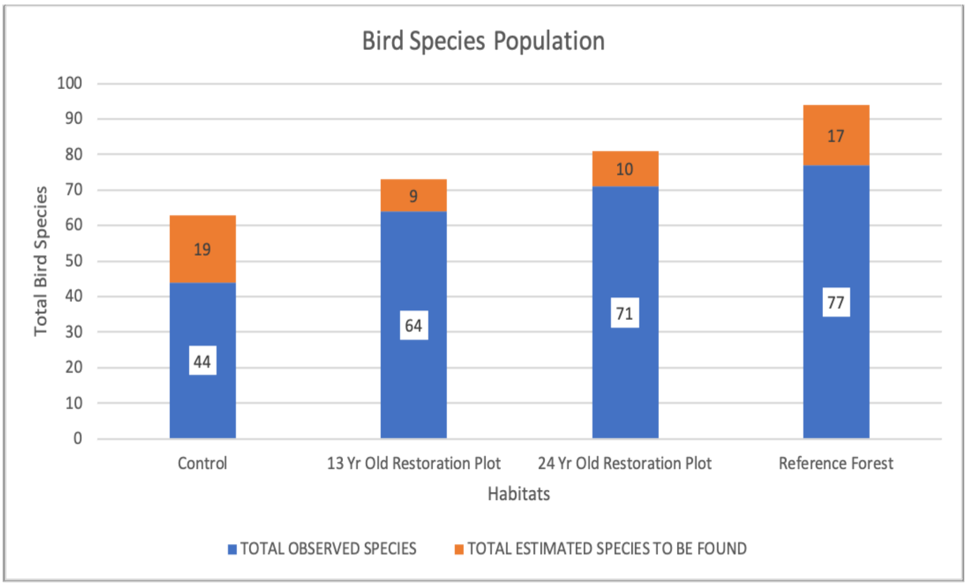

Figure 3.1 The bird species richness from all four study plots

Table 3.1 shows the common bird species found in all four habitats include a total of 14 species. All species are excellent seed dispersers in restored plots, where they thrive. Those listed as frugivores are most likely to catalyze forest regeneration and enhance restoration through natural seed dispersal from forest to open sites.

Table 3.1 Bird species recorded in all four habitats

No.	Common Name	Scientific Name	Family	Habitat	Diet
1	Bar-winged Flycatcher-shrike	*Hemipus picatus*	Vangidae	Forest edges, woodlands, gardens	Insectivore
2	Black-crested Bulbul	*Rubigula flaviventris*	Pycnonotidae	Forest edges, secondary growth, gardens	Frugivore
3	Blue-throated Barbet	*Psilopogon asiaticus*	Megalaimidae	Forests, woodlands, gardens	Frugivore
4	Common Tailorbird	*Orthotomus sutorius*	Cisticolidae	Shrublands, gardens, forests	Insectivore
5	Dark-necked Tailorbird	*Orthotomus atrogularis*	Cisticolidae	Forests, gardens, shrublands	Insectivore
6	Gray-eyed Bulbul	*Iole propinqua*	Pycnonotidae	Forests, secondary growth	Frugivore
7	Gray-headed Canary Flycatcher	*Culicicapa ceylonensis*	Stenostiridae	Forests, woodlands	Insectivore

No.	Common Name	Scientific Name	Family	Habitat	Diet
8	Indian White-eye	*Zosterops palpebrosus*	Zosteropidae	Forests, gardens, shrublands	Insectivore
9	Little Spiderhunter	*Arachnothera longirostra*	Nectariniidae	Forests, gardens, shrublands	Nectarivore
10	Puff-throated Bulbul	*Alophoixus pallidus*	Pycnonotidae	Forests, gardens, shrublands	Frugivore
11	Rufescent Prinia	*Prinia rufescens*	Cisticolidae	Grasslands, scrub, open forests	Insectivore
12	Sooty-headed Bulbul	*Pycnonotus aurigaster*	Pycnonotidae	Open woodlands, gardens, agricultural areas	Frugivore
13	White-rumped Shama	*Copsychus malabaricus*	Muscicapidae	Forests, bamboo groves, gardens	Insectivore
14	Yellow-browed Warbler	*Phylloscopus inornatus*	Phylloscopidae	Forests, woodlands, shrublands	Insectivore

Figure 3.2 Female White-rumped Shama (*Copsychus malabaricus*) (recorded in all habitats

Figure 3.3 Male White-rumped Shama (*Copsychus malabaricus*) (recorded in all habitats)

Figure 3.4 Sooty-headed Bulbul (*Pycnonotus aurigaster)* (recorded in all habitats)

3.1.2 Mackinnon species list Method

The MacKinnon species list accumulation curves reveal a clear successional trajectory in bird species richness across the four study plots (Figure 3.5). REF Forest demonstrates the highest overall richness, reaching approximately 77 species after 25 MacKinnon lists. The curve begins to plateau slightly, indicating that the sampling effort captured the majority of the resident bird community. The curve begins to rise after list 14, since winter visitors have begun to arrive in the natural forest habitat area and nearby areas. Winter visitor birds like Yellow-browed Warbler (*Phylloscopus inornatus*), Greenish Warbler(*Phylloscopus trochiloides*), Brown-cheeked Fulvetta(*Alcippe poioicephala*), and Blue-Whistling-thrush (*Myophonus caeruleus*) were found only in the Pah Dong Seng Primary Forest (Appendix A). R24 plot recorded 71 species across 22 lists. The steepness of the initial curve and the final count suggest that the bird species richness of restored plots is nearing parity with the primary forest after 24 years of forest restoration. R12 Plot as a mid-successional site recorded 64 species after 20 lists. While higher than the CONTROL, the slightly steeper end of the curve suggests that more species might still be found with increased sampling, reflecting a community in active transition toward long-term restoration. The CONTROL plot exhibited the lowest richness, with 44 species identified. The curve remains relatively linear, suggesting a simplified resident community dominated by a few abundant species.

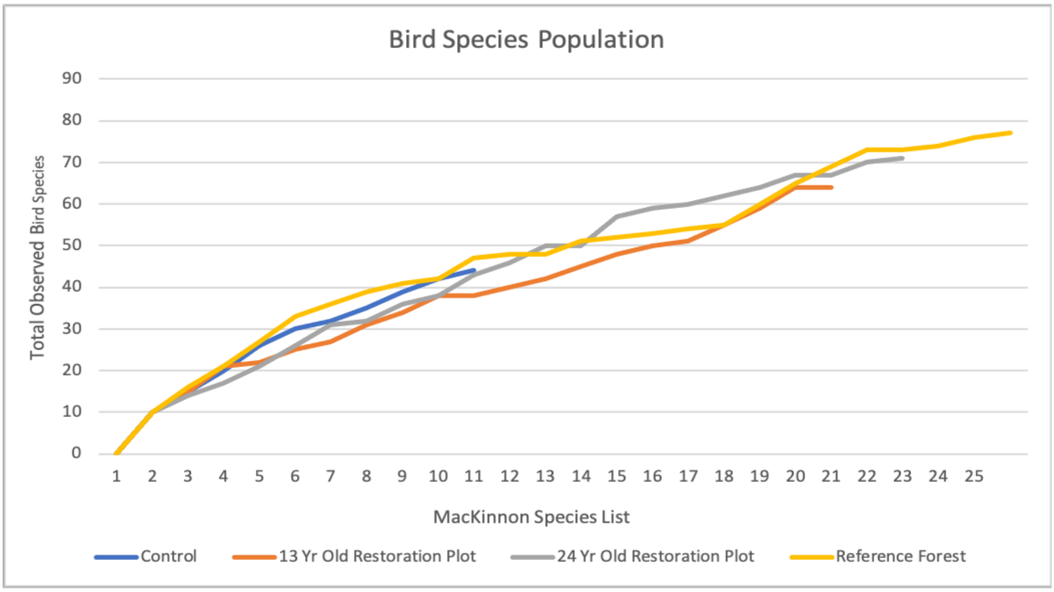

Figure 3.5 The MacKinnon species list curves of all plot

3.1.3 Sorensen's index of similarity

Table 3.2 shows Sørensen's index of similarity across all study plots. Zero indicates that they are totally different, and 1 means they are identical. R24 shows 51% similarity, indicating that the FSM restoration works on the older restoration plot, while CONTROL shows only 27% similarity. R12 shows a 44% similarity, indicating a mid-similarity rate compared to the nearby natural forest.

Table 3.2 Sørensen's index of similarity composition among all habitats.

Sørensen index of similarity				
	CONTROL	**R12**	**R24**	**REF**
CONTROL	1.00	0.44	0.35	0.27
R12		1.00	0.56	0.44
R24			1.00	0.51
REF				1.00

3.1.4 Mann-Whitney U test

To determine if the observed differences in species richness of between plots were statistically significant, a pairwise series of the Mann-Whitney U test were conducted. The results are revealed in the boxplots, showing a comparison of bird species richness across the four study plots over a total of 8 bird-watching sessions (Figure 3.6-3.11). the results reveal a significant succession in species richness, moving from the control toward the reference forest state.

Comparison with Reference Forest

Statistical testing shows a clear divergence in richness between the REF Forest and the other plots, but a convergence with the older restoration plot. Specifically, there is a highly significant difference in species richness between the REF Forest and the CONTROL Plot, where the natural forest supports nearly double the median richness. Similarly, the REF Forest exhibits a trend of higher richness compared to the R12 plot, suggesting that 12 years is insufficient for full taxonomic recovery. However, the comparison between the REF Forest and the R24 plot yielded no significant difference, indicating that after two decades, the restoration site has reached taxonomic parity with primary forest conditions.

The test indicates no significant difference in species richness between the REF Forest and the R24 plot. While the REF Forest has a maximum richness, the overlapping interquartile ranges suggest that after 24 years, the restored plot has successfully reached a taxonomic capacity statistically indifferent from primary forest.

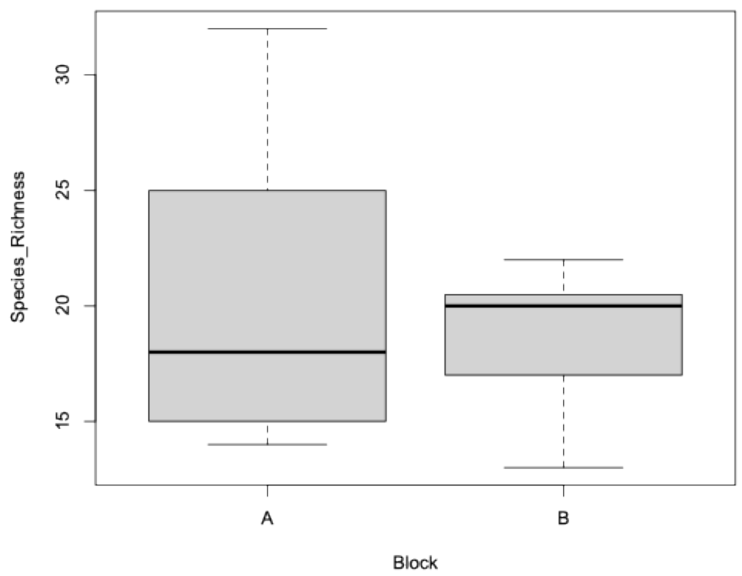

Figure 3.6 Mann Whitney U Test comparison between REF and R24 Plot (A = Reference Forest, B = 24 Year Old Restoration Plot) p = 0.9341

There is a trend showing higher richness in the REF Forest. The median for plot A is visibly higher, and the 25th percentile plot A is roughly equivalent to the median of plot C.

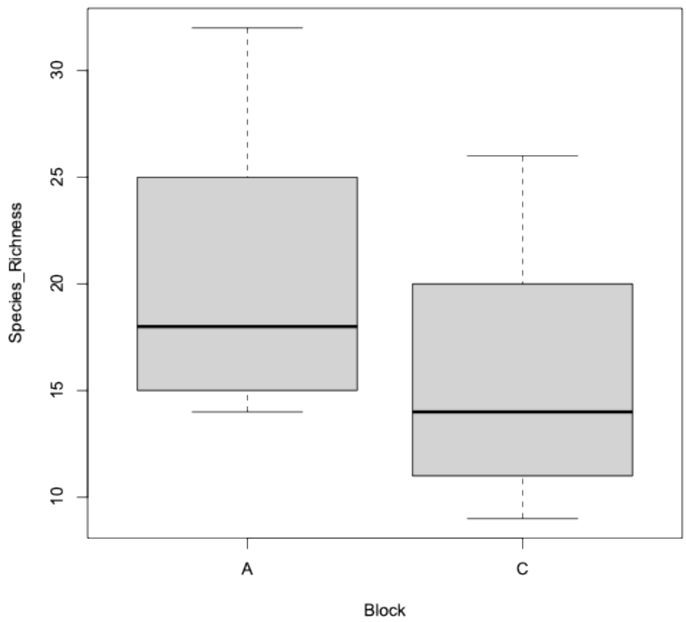

Figure 3.7 Mann Whitney U Test comparison between REF and R12 Year Old Restoration Plot (A = Reference Forest, C = 12-13 Year Old Restoration Plot) p = 0.1514

There is a highly significant difference ($p < 0.05$). The REF Forest supports a superior number of species compared to the CONTROL plot, with no overlap between the 75th percentile of the CONTROL and the median of the REF.

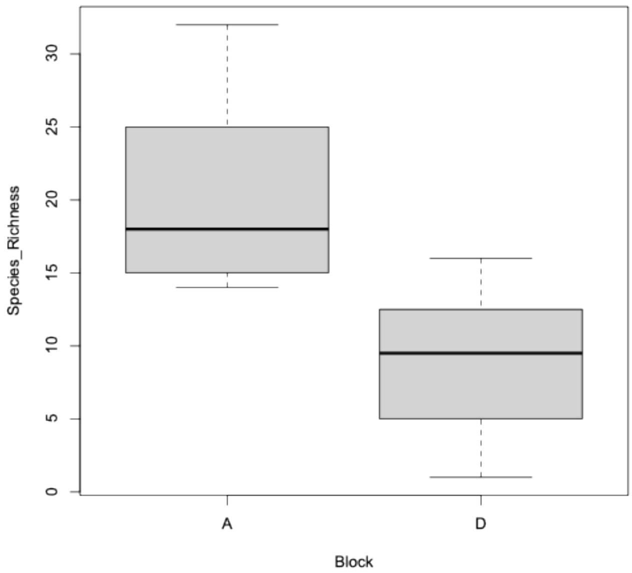

Figure 3.8 Mann-Whitney U Test comparison between REF and CONTROL (A = Reference Forest, D = Control Plot). The p-value is 0.0014, indicating a difference in species richness between plots.

Comparison between Restoration Chronosequence Stages

The recovery trajectory within the restoration plots themselves highlights critical developmental windows. A significant increase in species richness was observed between R24 and R12 plots, demonstrating that a decade of additional growth significantly enhances the site's capacity to support diverse bird communities. While the R12 plot shows a significant improvement over the CONTROL Plot, its richness remains highly variable, reflecting a mid-successional state of ecological recovery.

The analysis shows an increase in species richness as restoration age progresses from 13 to 24 years. The median richness in Block B (24-year) is notably higher and exhibits less variance than Block C, indicating that the bird community becomes both richer and more stable over time.

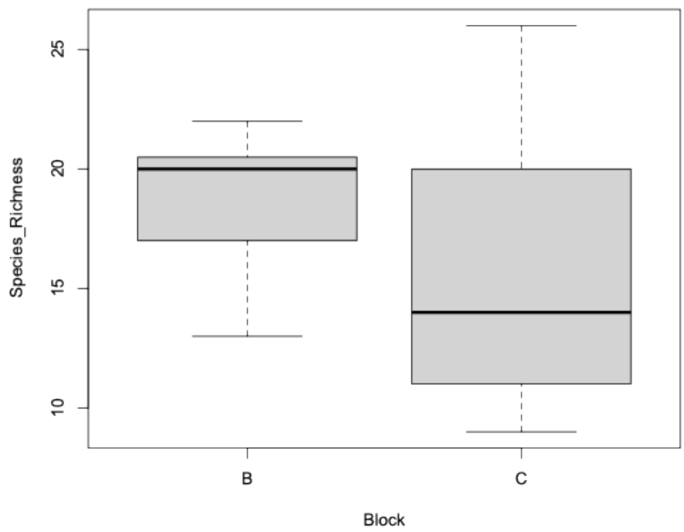

Figure 3.9 Mann Whitney U Test comparison between R24 and R12 Year Old Plot(B = 24 Year Old Restoratio Plot , C = 12-13 Year Old Restoration Plot) p = 0.2019

This comparison yields the most significant difference among restoration sites. The R24 plot has completely diverged from the CONTROL plot, supporting nearly double the median species richness.

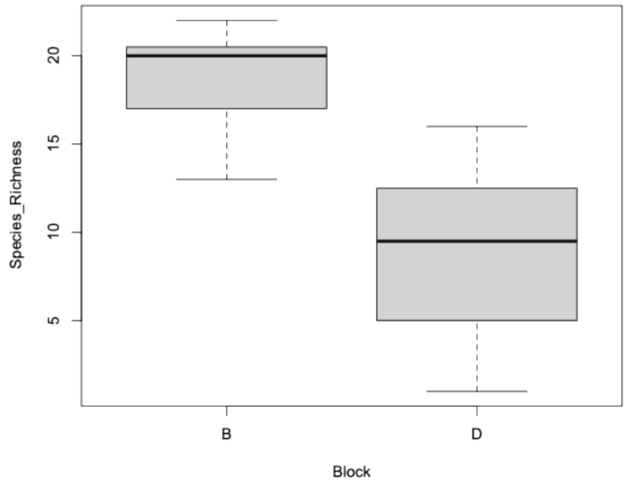

Figure 3.10 Mann Whitney U Test comparison between R24 and CONTROL Plot (B = 24 Year Old Restoration Plot, D = Control Plot). The p value is 0.0008, meaning there is a difference in species richness between plots.

While the R12 plot (Block C) has a higher median than the CONTROL, the test may indicate only moderate significance due to the wide variance in Block C. This suggests that at 13 years, restoration plots are in a highly volatile transition state where species richness fluctuates significantly.

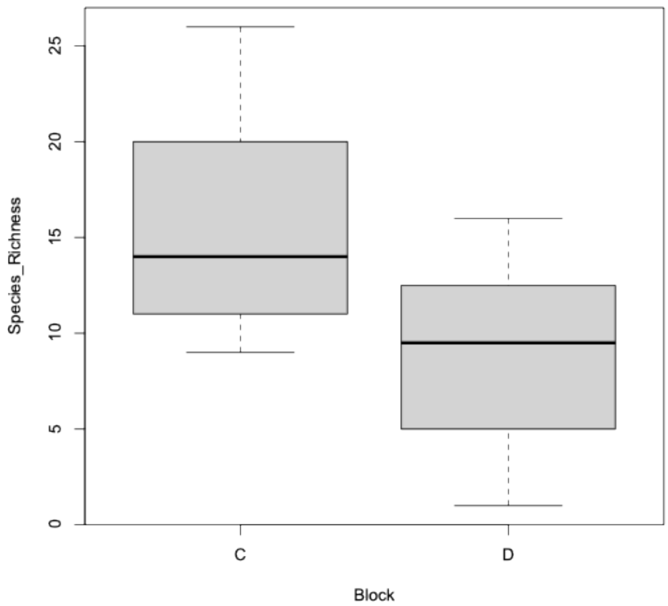

Figure 3.11 Mann Whitney U Test comparison between R12 and CONTROL Plot (C = 12-13 Year Old Restoration Plot, D = Control Plot) p = 0.0527

3.1.5 Bird diet types analysis across habitat

The distribution of dietary types across all habitats further clarifies the "functional filling" of the restoration plots. Invertebrate Feeders: This is the dominant guild across all habitats, showing a linear increase with forest age: from 28 species in the CONTROL Plot to 53 species in REF. R24 plot (40 species) significantly outperforms the R12 plot (39 species) in this category. Frugivores: Fruit-eating species increased from 5 species in the CONTROL and R12 plots to 8 species in both R24 plot and REF. This suggests that after 24 years, the restoration area provides sufficient fruiting resources to support a community with frugivore richness identical to that of a primary forest. Omnivores: Interestingly, omnivore richness peaked in R24 plot (15 species) compared to REF (9 species), likely reflecting an "edge effect" where species utilize both the maturing restoration plot and adjacent open areas. Specialist Guilds: Carnivores, Nectarivores, and Vertebrate-eaters remained consistently low across all plots (1–3 species), indicating that high-trophic-level or highly specialized roles are the slowest to recover.

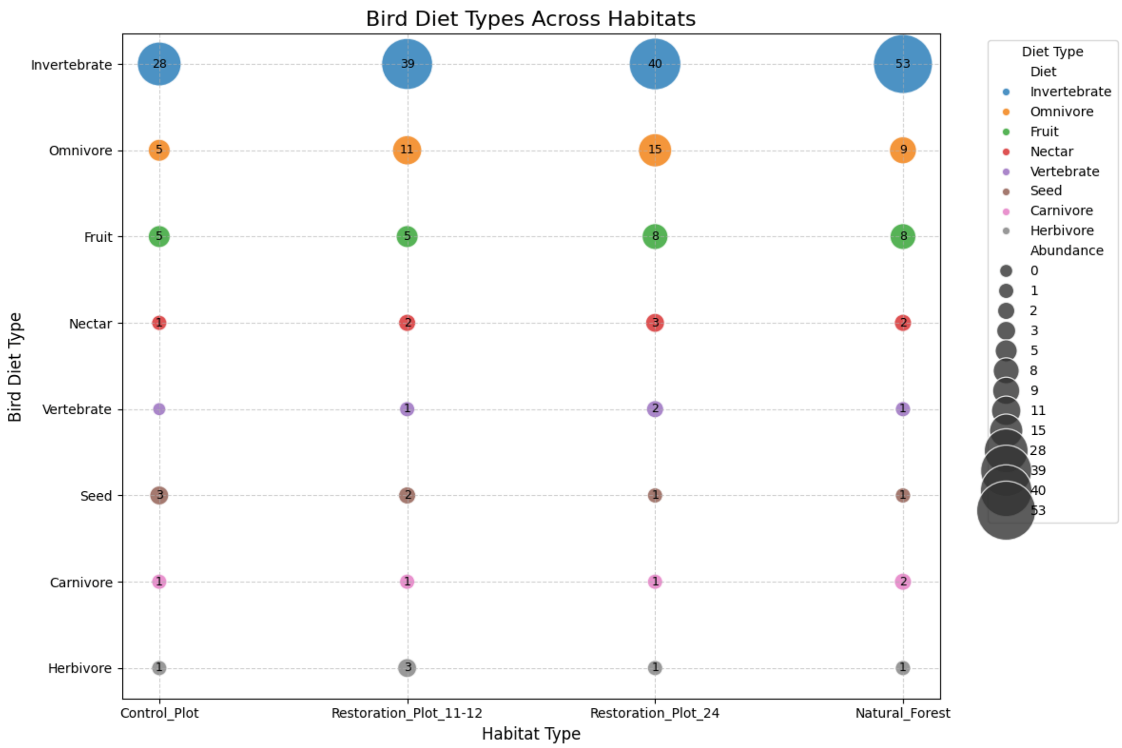

Figure 3.12 Bird diet types across habitats

Table 3.3 lists the unique species in each habitat, which are likely habitat specialists. The numbers of such species were 17, 15, 20 & 32 in CONTROL, R12, R24, and REF, respectively, suggesting that the number of specialists increases as restoration proceeds. As restoration advances, bird communities become less similar to the control habitat and more similar to the reference forest. This supports the hypothesis that as restoration progresses, more bird species recognize the developing forest as suitable habitat, with similar provision of food, nesting sites, and other essential resources. Birds' eyes are more critical than human eyes for recognizing if restoration is achieving its ultimate goal of recreating the ecological functionality of the original forest.

Table 3.3 - Unique species found only in each habitat.

CONTROL	R12	R24	REF
Bright-headed Cisticola	Arctic Warbler	Ashy Minivet	Ashy Bulbul
Dusky Warbler	Asian Barred Owlet	Collared Owlet	Ashy Drongo
Eastern Stonechat	Asian stubtail	Crested Serpent Eagle	Ashy Woodswallow
Eurasian Hoopoe	Black-naped Oriole	Eurasian Tree Sparrow	Asian Fairy Bluebird
Eurasian Skylark	Booted Eagle	Flavescent Bulbul	Asian Paradise Flycatcher
Grey Bushchat	Greater Racket-tailed Drongo	Grey-capped Pygmy Woodpecker	Banded Kingfisher
Grey-breasted Prinia	Large-billed Crow	Lesser Racket-tailed Drongo	Blue-throated Flycatcher
Long-tailed Shrike	Olive-backed Pipit	Lesser Yellownape	Blue Whistling-thrush
Oriental Honey-buzzard	Pale-legged Leaf Warbler	Orange-bellied Leafbird	Brown-cheeked Fulvetta
Rufous-corgeated Flycatcher	Plain Prinia	Racket-tailed Treepie	Great Spotted Woodpecker
Unidentified Barbet	Pygmy Cupwing	Red-billed Blue-Magpie	Greater Flameback
Unidentified Bushchat	Scarlet-backed Flowerpecker	Silver Pheasant	Grey Wagtail
Unidentified Munia	Swinhoe's White-eye	Small Minivet	Grey-throated Babbler
Unidentified Spiderhunter	Unidentified Tailorbird	Speckled Piculet	Indian Paradise-Flycatcher
Unidentified Swift	Unidentifitied Bulbul	Stripe-throated Bulbul	Little Pied Flycatcher

CONTROL	R12	R24	REF
Wood Sandpiper		Unidentified Oriole	Orange-headed Thrush
Zitting Cisticola		Unidentified White-eye	Oriental Dollarbird
		White-browed shrike Bubbler	Rufous Treepie
		White-crested Laughing Thrush	Rufous-throated Fulvetta
		White-throated Fantail	Shikra
			Slaty-backed Forktail
			Spotted Owlet
			Straited Bulbul
			Tickell's Blue Flycatcher
			Unidentified Eagle
			Unidentified Swallow
			Verditer Flycatcher
			Violet Cuckoo
			White-bellied Erpornis
			White-browned Piculet
			White-rumped Munia

CONTROL	R12	R24	REF
			Yellow-bellied Warbler
17	15	20	32

3.2 Discussion

The results of this study underscore the efficacy of the FSM in catalyzing the result of avian biodiversity to degraded landscapes in Northern Thailand. Both R12 and R24 supported significantly higher bird species richness than recorded in the CONTROL habitat and more than half of those recorded in the REF forest (Figure 3.1). This strongly demonstrates that forest-structure diversification, as restoration proceedes, increase diversity of habitats, which are then occupied by a greater diversity of bird species. And the communities in both R12 and R24 restoration habitat sites are far along a trajectory toward a bird species richness similar to that of the nearby natural REF forest. This was further supported by Sørensen's index of similarity, applied to all habitats (Table 3.2). Sørensen's index of similarity increase from 44% in R12 to 51% in R24 relative of the reference forest, indicating a steady increase in the bird community as restoration progresses. The CONTROL plot had the lowest similarity index number to the reference forest. Toktang's (2005) study of bird communities (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 the birds recorded within just five years of planting at Ban Mae Sa Mai. While Toktang's study captured the rapid initial colonization phase, the current data from R12 and R24 confirms that this momentum is maintained over decades, eventually overcoming the initial community simplifies found in degraded control plots (Toktang, 2005).

Bird species richness often increases in restored areas compared to degraded or agricultural landscapes. For example, in Mexican temperate forests, restoration treatments attracted higher bird species richness compared to cropfields, with species composition resembling native forests. (MacGregor-Fors et al., 2010) Similarly, in Beijing, long-term afforestation efforts led to an increase in bird species from 344 in 1987 to 430 in 2014, highlighting the positive impact of forest coverage expansion(Pei et al., 2018). In Ecuadorian Amazon restoration sites, bird species richness was similar across manually restored and naturally revegetated forests, but species composition varied slightly, with forest-dependent groups showing differences in occupancy(Bare & Danner, 2017). In contrast, restored grasslands in Brazil showed higher bird richness and abundance compared to native grasslands, suggesting rapid recovery(da Silva & Fontana, 2020).

The growing forest will provide greater niche space as the canopy develops several layers. In addition, the trees will provide food resources, such as fruit and nectar, as well as perches and nesting sites. The Mackinnon method is more accurate when species diversity is high, and for predicting the expected bird species in each plot. In this study, 14 bird species were found over all plots. Primary Forest consistently support the highest bird species richness due to the structural complexity and habitat diversity(Ghadiri Khanaposhtani et al., 2012; Rurangwa et al., 2021; Zhang et al., 2024). For example, primary forests in Rwanda and Iran showed significant higher species richness compared to restored or degraded areas(Ghadiri Khanaposhtani et al., 2012; Rurangwa et al., 2021). Restored forests approached the species of richness of natural forests but may still differ in species composition(Latja et al., 2016; Rey-Benayas et al., 2010; Standish et al., 2021). In tropical dry forests, 20 year old plots supported similar richness to older forests, but structural differences persisted(Hilje et al., 2020). Younger restoration plots typically show moderate recovery in species richness , with fewer forest specialists compared to older plots(Latja et al., 2016; Rey-Benayas et al., 2010; Zhang et al., 2024). For example, bird richness in 13 year old plantations was lower than in older or primary forests in China (Zhang et al., 2024). Abandoned agricultural lands generally support lower species richness compared to restored or natural forests(Bowen et al., 2009; Rey-Benayas et al., 2010; Salaverri et al., 2019). In Spain, abandoned fields had fewer species than restored plots, with open-habitat speciealsts dominating(Razola & Rey Benayas, 2009).

Functional diversity in restored forests often lags behind primary forests. Structural attributes like canopy cover and vegetation complexity strongly influence bird diversity. For example, higher canopy cover in subtropical rainforests positively correlated with rainforest-dependent species richness(Borrow et al., 2025). It is expected that, as the forest recovers, bird species richness will increase in the long term. The observed increase in bird diversity is intrinsically linked to the structural maturation of the forest. As the canopy develops multiple strata, it creates a vertical mosaic of niche spaces that accommodate specialized foraging and nesting behaviors. In the long term, the transition from open-canopy to a closed-canopy system provides essential resources, including perches for hunting, nectar for pollinators, and fruits for seed dispersers.

The findings from this study highlight that resident birds play a more pivotal role in this restoration process than winter visitors, primarily due to their consistent presence and year-round interaction with the flora. Furthermore, frugivorous and omnivorous birds, especially Bulbuls (Family Pycnonotidae) emerge as the most critical functional species in this ecosystem. With 13 species recorded at high population densities, Bulbuls act as the primary seed dispersers of the restoration plots, facilitating the influx of seeds from neighboring REF forest and ensuring the long-term genetic diversity of the restored plots. 17 unidentified observed species can be explained by difficulty of observation in the dense forest or lack of distinguishing physical characteristics. In REF, low light or long distances between observer and the bird can affect bird identification. Behavioural constraints like rapid movement, secretive behaviour and insufficient evidence notes for later verification need further practices to get better bird species identification.

While frugivores drive seed dispersal, the return of specialized insectivores is an equally vital indicator of ecosystem. Future research should place a greater emphasis on the insect-bird nexus. In tropical forests, many birds such as flycatchers and babblers are strict insectivores that rely on specific micro-habitats (e.g., leaf litter, deadwood, or epiphytes). A lack of certain insectivorous guilds in younger plots may be attributed to a lag in entomological recovery. If the restored forest has not yet recruited the specific beetle, caterpillar, or ant populations found in primary forests, the bird species dependent on them will remain absent. Future studies should include simultaneous insect sampling to determine if "empty" niches in the bird community are caused by a lack of food resources. Furthermore, comparing different diet types such as nectarivores, which were found in low numbers can reveal if the current tree species mix at R12 and R24 provides enough year-round floral resources or if additional framework species are needed to support these specialized pollinators.

While the MacKinnon method is robust, several limitations must be acknowledged. First, the seasonal variation in bird presence particularly the influx of winter visitors can temporarily inflate richness numbers without necessarily reflecting long-term habitat suitability. Second, the edge effect in restoration plots may lead to an over-representation of generalist species from surroundings, potentially masking the absence of natural forest habitat specialists. This study focuses primarily on taxonomic richness; however, the functional redundancy of these communities remains under explored. Knowing that 77 species are present is valuable, but understanding whether they are all performing the same ecological role is essential for assessing true ecosystem resilience.

CHAPTER 4

Conclusions

This study evaluated bird species diversity and functional community assembly across a chronosequence of restored plots by planting FSM comparing against CONTROL site and REF forest at the landscape level. The study focused on the recovery of species richness and the shift in dietery guilds as a measure of ecological success. As restored plots mature, the avian community undergoes a fundamental shift from open areas generalists to forest birds specialists. While species richness in the R24 plot reached nearly 92% of the REF, the composition remains distinct. Insectivores and frugivores return quickly, while specialized guilds such as Carnivores, Nectarivores, and Vertebrate-eaters remain low even after two decades. This indicates that while species numbers can be restored within 24 years, the full functional complexity of a climax forest community require a longer timeframe to stabilize. This study is limited by its primary focus on daytime visual surveys. Furthermore, species richness alone does not account for reproductive success; it remains unclear if the birds recorded are successfully breeding in the plots or merely using them for foraging. Further studies are essential to determine whether these hypothesized changes specifically the recruitment of rare forest specialists actually occur as the forest enters into its third and fourth decades. Future research should also integrate Insect Diversity Surveys to correlate the return of specialized insectivorous birds with their food sources

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BirdLife DataZone www.datazone.birdlife.org

APPENDIX A

Bird species - number of records and records per observation person-hour in all four habitats (totally 48 h person-hours observation effort per site) landscape chnage

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Arctic Warbler			1	0.02				
Ashy Bulbul							1	0.02
Ashy Drongo							4	0.08
Ashy Minivet					1	0.02		
Ashy Woodswallow							1	0.02
Asian Barred Owlet			1	0.02				
Asian Brown Flycatcher	2	0.042	5	0.1	1	0.02		
Asian Fairy Bluebird							2	0.04
Asian Green Bee-eater			3	0.06	1	0.02		
Asian Palm Swift	2	0.042					1	0.02
Asian Paradise Flycatcher							1	0.02
Asian stubtail			1	0.02				
Banded Kingfisher							1	0.02
Bar-winged Flycatcher-shrike	1	0.021	1	0.02	1	0.02	1	0.02
Barn Swallow	1	0.021	1	0.02				
Black naped Oriole			1	0.02				
Black-crested Bulbul	3	0.063	13	0.27	13	0.27	7	0.15
Black-headed Bulbul					1	0.02	5	0.10
Black-naped Monarch					3	0.06	4	0.08
Black-throated Sunbird			2	0.04	4	0.08	3	0.06
Blue-throated Barbet	2	0.042	12	0.25	15	0.31	16	0.33
Blue-throated Bulbul								
Blue-throated Flycatcher							2	0.04
Blue Whistling-thrush							1	0.02
Blue-winged Leafbird			1	0.02	1	0.02	1	0.02
Blyth's leaf Warbler			1	0.02	1	0.02	2	0.04
Booted Eagle			1	0.02				
Bright-headed Cisticola	1	0.021						
Bronzed Drongo					2	0.04	7	0.15
Brown-cheeked Fulvetta							2	0.04
Buff-breasted Babbler			2	0.04	3	0.06	4	0.08
Collared Owlet					1	0.02		

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Common Green-Magpie	1	0.021					1	0.02
Common Iora			1	0.02			1	0.02
Common Tailorbird	4	0.083	10	0.21	13	0.27	10	0.21
Crested Serpent Eagle					1	0.02		
Dark-necked Tailorbird	3	0.063	1	0.02	3	0.06	3	0.06
Dark-sided Flycatcher			1	0.02	3	0.06		
Davison's leaf Warbler					1	0.02	1	0.02
Dusky Warbler	1	0.021						
Eastern Stonechat	1	0.021						
Eurasian Hoopoe	1	0.021						
Eurasian Skylark	1	0.021						
Eurasian Tree Sparrow					1	0.02		
Ferrugious Flycatcher			1	0.02			3	0.06
Fire-breasted Flowerpecker			2	0.04	1	0.02		
Flavescent Bulbul					1	0.02		
Great Barbet			6	0.13	4	0.08	9	0.19
Great Spotted Woodpecker							1	0.02
Greater Coucal	2	0.042	3	0.06	3	0.06		
Greater Flameback							1	0.02
Greater Racket-tailed Drongo			1	0.02				
Green-billed Malkoha					1	0.02	1	0.02
Greenish Warbler			8	0.17	2	0.04	2	0.04
Grey Bushchat	3	0.063						
Grey Wagtail							1	0.02
Grey-throated Babbler							4	0.08
Grey Treepie			1	0.02	1	0.02		
Grey-breasted Prinia	5	0.104						
Grey-capped Pygmy Woodpecker					1	0.02		
Grey-eyed Bulbul	1	0.021	12	0.25	15	0.31	13	0.27
Grey-headed Canary Flycatcher	1	0.021	10	0.21	11	0.23	10	0.21
Hainan blue Flycatcher			1	0.02	1	0.02	2	0.04
Hair-Crested Drongo			3	0.06	3	0.06		
Hill Blue Flycatcher			1	0.02	7	0.15	5	0.10
House Swift	6	0.125	2	0.04	3	0.06		
Indian Paradise-Flycatcher							1	0.02
Indian White-eye	2	0.042	5	0.1	5	0.1	3	0.06
Larged-billed Crown			1	0.02				

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Lesser Racket-tailed Drongo					1	0.02		
Lesser Yellownape					1	0.02		
Little Spiderhunter	3	0.063	2	0.04	11	0.23	12	0.25
Little Pied Flycatcher							2	0.04
Long-tailed Shrike	1	0.021						
Mountain Bulbul			1	0.02	6	0.13	5	0.10
Olive-backed Pipit			2	0.04				
Olive-backed Sunbird			2	0.04			1	0.02
Orange-bellied Leafbird					1	0.02		
Orange-headed Thrush							3	0.06
Oriental Dollarbird							1	0.02
Oriental Honey-buzzard	1	0.021						
Oriental Magpie-Robin	2	0.042	2	0.04	1	0.02		
Pale-legged Leaf Warbler			1	0.02				
Pied Bushchat	6	0.125	1	0.02				
Pin-striped Tit-Babbler			2	0.04	1	0.02	6	0.13
Plain Prinia			1	0.02				
Plaintive Cuckoo			1	0.02	1	0.02		
Puff-throated Babbler			8	0.17	4	0.08	3	0.06
Puff-throated Bulbul	1	0.021	3	0.06	6	0.13	8	0.17
Pygmy Cupwing			1	0.02				
Racket-tailed Treepie					1	0.02		
Red-billed Blue-Magpie					1	0.02		
Red-whiskered Bulbul	3	0.063	3	0.06	2	0.04		
Rufescent Prinia	2	0.042	2	0.04	2	0.04	1	0.02
Rufous Treepie							1	0.02
Rufous-throated Fulvetta							1	0.02
Rufous-corgeated Flycatcher	1	0.021						
Scaly-breasted Munia	2	0.042	1	0.02				
Scarlet Minivet					3	0.06	6	0.13
Scarlet-backed Flowerpecker			3	0.06				
Shikra							1	0.02
Silver Pheasant					1	0.02		
Silver-breasted Broadbill					2	0.04	4	0.08
Slaty-backed Forktail							1	0.02
Small Minivet					1	0.02		
Sooty-headed Bulbul	8	0.167	8	0.17	1	0.02	2	0.04

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Speckled Piculet				0	1	0.02		
Spotted Dove	7	0.146	3	0.06				
Spotted Owlet							1	0.02
Streaked Spiderhunter			5	0.1	6	0.13	3	0.06
Straited Bulbul							1	0.02
Stripe-throated Bulbul					1	0.02		
Swinhoe's White-eye			1	0.02				
Taiga Flycatcher			3	0.06	4	0.08		
Tickell's Blue Flycatcher							2	0.04
Unidentified Barbet	1	0.021						
Unidentified Bulbul			1	0.02	1	0.02	3	0.06
Unidentified Bushchat	1	0.021						
Unidentified Eagle							1	0.02
Unidentified Flycatcher			1	0.02			1	0.02
Unidentified Minivet			1	0.02	1	0.02	3	0.06
Unidentified Munia	2	0.042						
Unidentified Oriole					1	0.02		
Unidentified Spiderhunter	1	0.021						
Unidentified Sunbird	2	0.042			1	0.02		
Unidentified Swallow							1	0.02
Unidentified Swift	2	0.042						
Unidentified Tailorbird			1	0.02				
Unidentified Warbler	1	0.021	3	0.06	1	0.02	1	0.02
Unidentified White-eye					1	0.02		
Unidentified Woodpecker					1	0.02	2	0.04
Velvet-fronted Nuthatch					1	0.02	3	0.06
Verditer Flycatcher							1	0.02
Violet Cuckoo							1	0.02
White-bellied Erpornis							1	0.02
White-browed scimitar-Babbler			2	0.04			2	0.04
White-browed shrike Bubbler					1	0.02		
White-browned Piculet							1	0.02
White-crested Laughing Thrush					1	0.02		
White-rumped Shama	1	0.021	7	0.15	15	0.31	13	0.27
White-rumped Munia							1	0.02
White-throated Fantail					2	0.04		
Wood Sandpiper	1	0.021						

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Yellow-bellied Warbler							3	0.06
Yellow-browed Warbler	3	0.063	6	0.13	4	0.08	5	0.1
Zitting Cisticola	1	0.021						
TOTAL OBSERVATIONS	97		194		219		246	
TOTAL OBSERVED SECIES	44		64		71		77	

APPENDIX B

Observed bird photos and Unobserved bird species found from camera traps of mammal project

Figure 5.1 – Ashy Drongo (observed only in REF)

Figure 5.2 – Common Tailorbird (observed in all habitats)

Figure 5.3 – Female Ashy Minivet (observed only in R24)

Figure 5.4 – Green-billed Malkoha (observed in R24 and REF)

Figure 5.5 – Tickell's Blue Flycatcher (observed only in REF)

Figure 5.6 – Silver Pheasant in R12 captured from camera trap (observed only once in R24 – Appendix A)

Figure 5.7 – Asian Emerald Dove in R24 from Camera Trap (didn't record during observation)

Figure 5.8 – Mrs. Hume's Pheasant in REFRENCE from Camera Trap (didn't record during observation)

Figure 5.9 – Silver Pheasant in REFRENCE from Camera Trap (didn't record during observation, observed only once in R24 – Appendix A)

Figure 5.10 – 4 Mrs. Hume's Pheasant and 1 Silver Pheasant in R24 from Camera Trap (didn't record during observation, Silver Pheasant observed only once in R24 – Appendix A)

Figure 5.11 – Blue Pitta in R24 from Camera Trap (didn't record during observation)

Figure 5.12 – Asian Emerald Dove in R24 from Camera Trap (didn't record during observation)

Figure 5.13 – Blue Pitta in R12 from Camera Trap (didn't record during observation)

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