

Use of the Framework Species Method to Restore Carbon Flow via Litterfall and Decomposition in an Evergreen Tropical Forest Ecosystem, Northern Thailand

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ABSTRACT

If forest restoration is to play a significant role in mitigating climate change, greater knowledge is needed of how quickly the process can restore carbon flows to levels typical of natural forest. Litterfall and its decomposition are two important components of the carbon cycle of tropical forest ecosystems. This paper quantified the balance between these two processes in experimental plots undergoing restoration of upland evergreen forest by the framework species method in the upper watershed of the Mae Sa Valley, Chiang Mai province, northern Thailand. Restoration plots had been planted with 20–30 indigenous forest tree species at an average initial density of 3,100 trees.ha⁻¹ in 1998, 2002 and 2007 (at 11, 7 and 2 yr, respectively, before the study commenced). Carbon flow measurements in these plots were compared with identical measurements in relatively intact mature forest and nonplanted control sites. Measurements were litterfall dry mass (from litterfall traps emptied monthly), percentage carbon content (using the Walkley-Black method) and decomposition rates (using litterbags). Net inputs of carbon into the soil pool via litterfall declined below control levels for at least 7 yr after tree planting (probably due to fire and weeding), but increased rapidly thereafter, reaching 61% of natural forest levels by 11 yr and are projected to reach natural forest levels (1.33 t.ha⁻¹.yr⁻¹ carbon) in 14–16 yr after tree planting. Therefore, the framework species method appears to be an efficient mechanism for restoring carbon flow through forest ecosystems and should be considered for forest restoration projects where carbon sequestration is included among the objectives.

Keywords: carbon sequestration, climate change, forest restoration, framework species method

INTRODUCTION

Forest degradation and deforestation are major contributors to global climate change, accounting for at least 15% of total anthropogenic

CO₂ emissions (Boucher, 2008). On the other hand, forest restoration can provide a carbon sink (Kanowski and Catterall, 2010). The role of tropical forests in carbon sequestration and global climate change mitigation was recognized in the

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Kyoto Protocol and has become increasingly more important, as carbon trading mechanisms develop and since the inclusion of “enhancement of carbon stocks” (that is, forest restoration) within REDD+ (a set of policies and incentives being developed under the UN Framework Convention on Climate Change (UNFCCC) to “Reduce Emissions from Deforestation and forest Degradation”) (Meridian Institute, 2011). Once established, this international framework will provide approved funding and monitoring mechanisms for both forest conservation and restoration projects, which enhance the net global forest “sink” for carbon dioxide, whilst also conserving biodiversity and benefiting local people.

Inputs of carbon into the soil pool through litterfall are closely related to tree species composition and growth rates as well as forest age, structure and ecosystem productivity (Scherer-Lorenzen *et al.*, 2007), although, surprisingly Ostertag *et al.* (2008) could not find an obvious trend in litter production with increasing stand age. Litter decomposition is also correlated closely with plant species composition and plant species traits (Cornwell *et al.*, 2008) and is influenced by the microclimate, as it affects physical forces such as leaching and fragmentation. Biotic factors affecting decomposition include plant species interactions, plant-decomposer interaction and the species composition of the soil microbial fauna (Vivanco and Austin, 2008).

An increased understanding of the dynamics of litterfall, and its decomposition could ultimately lead to better forest restoration strategies.

Therefore, the current research focused on litterfall and its decomposition in forest restoration plots, established by the framework species method. The restoration method has been adapted by the Forest Restoration Research Unit of Chiang Mai University to restore forest ecosystems in northern Thailand and neighboring regions for environmental protection and biodiversity recovery. It involves planting a mixture of 20–30

pioneer and climax native tree species (Elliott *et al.*, 2003). Essential characteristics of framework species are: 1) high survival and growth rates on open degraded sites; 2) dense, spreading crowns that shade out herbaceous weeds; and 3) provision of resources, at a young age, which attract seed-dispersing wildlife for fruits, nectar and nesting sites among other uses (Goosem and Tucker, 1995). The objectives of the current research were to quantify litterfall and decomposition in forest restoration plots of different ages compared with both nonplanted control sites and near-natural forest. Litter accumulation and decomposition are two of several ecosystem functions that can be used to determine the progression and ultimate success of forest restoration projects.

MATERIALS AND METHODS

Study site

The study made use of a field trial plot system set up to develop and test a framework species approach for restoring evergreen tropical forest in northern Thailand. Plots had been established annually since 1997 using planting various combinations of 20–30 candidate framework tree species, in the Upper Mae Sa valley (18°52'N, 98°51'E, 1,207–1,310 m above sea level, m asl) of the Doi Suthep-Pui National Park (Elliott *et al.*, 2012).

Three replicate subplots (each 40 × 40 m²) were established in each of the following sites: non-planted control sites (C), mature natural forest (NF) and forest restoration sites of three different ages (at the start of this study), since planting: 2 (R2), 7 (R7), and 11 (R11) yr, planted in 2007, 2002 and 1998, respectively. The control plots were deforested sites dominated by grasses such as *Imperata cylindrica*. The mature natural forest plots were located in the nearest intact forest remnant as the closest approximation to primary forest. Although never clear cut, the area had been disturbed by local villagers, including selective tree felling and clearance of small patches for

opium cultivation about 40–50 yr previously. Throughout this paper it is referred to as “natural forest” (NF) to distinguish it from “restored forest”. Situated at 1,300 m asl, the forest was dominated by *Castanopsis diversifolia* (family Fagaceae), according to Jinto (2009).

Litterfall and litter carbon

Six litter traps, made of plastic mesh, 1 × 1 m², were suspended 15 cm above the ground in each of 15 subplots resulting in 90 traps overall. The traps were cleared of litter monthly for 2 yr from June 2009 to May 2011. Collected litter was oven-dried at 80 °C to constant weight (Weerakkody and Parkinson, 2006), and then analyzed for organic carbon, using the standard technique of Walkley and Black (1934).

Decomposition of natural litter using litterbags

Samples of approximately 500 g (wet weight) of leaf litter were carefully transferred into mesh bags (50 × 50 cm²), under natural conditions, using a shovel to minimize disturbance of the litter as much as possible. Twelve such bags were placed back into the litter layer of each subplot. A subsample of about 10% of the litter in each bag was collected at the start of the experiment (April 2011), and then at the end of the rainy season (August 2011), cool season (November 2011) and cool dry season (February 2012) for moisture content determination. Each time the bags were weighed and the remaining dry mass of litter was used to derive the decomposition rate using Equation 1:

$$\% \text{ mass loss} = (W1 - W2) / W1 \times 100 \quad (1)$$

where W1 is the original dry mass of litter, W2 is the dry mass of litter after time t and % mass remaining = 100 - % mass loss

Statistical analyses

Litterfall and carbon content in litter

The amounts of litterfall and soil carbon were analyzed for differences among the study sites and differences between the two years, using one-way analysis of variance (ANOVA; Guo *et*

al., 2004). Tukey’s test was used in conjunction with ANOVA to determine significant differences among means. The relationships between total litter (t.ha⁻¹.yr⁻¹) and age since planting were determined, using correlation analysis.

Litter decomposition of mixed species

Tukey’s test was used to determine differences in decay rates among the study sites and in different periods. Linear regression and the correlation coefficient (R^2) of data from all study sites were used to provide suitable equations for predicting the percentage mass of litter remaining after 1 yr.

RESULTS

Litterfall

Initially, litterfall declined below control levels during the first 2 yr of restoration operations. A fire in early March 2010 in the R2 plots considerably reduced litterfall from February to September that year, but weeding operations, to protect the young planted trees, may also have contributed to the reduction. In older restoration plots, litterfall rose substantially above control levels, such that by 11 yr after tree planting, it was more than double that of the control site and had increased to about 72% of the value measured in NF (Table 1). Monthly litterfall varied greatly across seasons (Figure 1), peaking in the hottest months of the dry season and falling to a minimum in the mid-wet-season.

Carbon flow through litterfall

The organic carbon content ranged from 32.97 to 38.72% of the litter mass (Table 1) across the sites. Litter from NF had a significantly ($P < 0.05$) higher carbon content (38.72%) than that from the R7 and control sites, but other differences in the carbon content among the plots were not significant. Estimated carbon flow through litterfall, derived from these values, is shown in Table 1. The average annual carbon input to soil via litterfall in the 11 year-old restoration plot had risen to 66 % of that recorded in the NF plots.

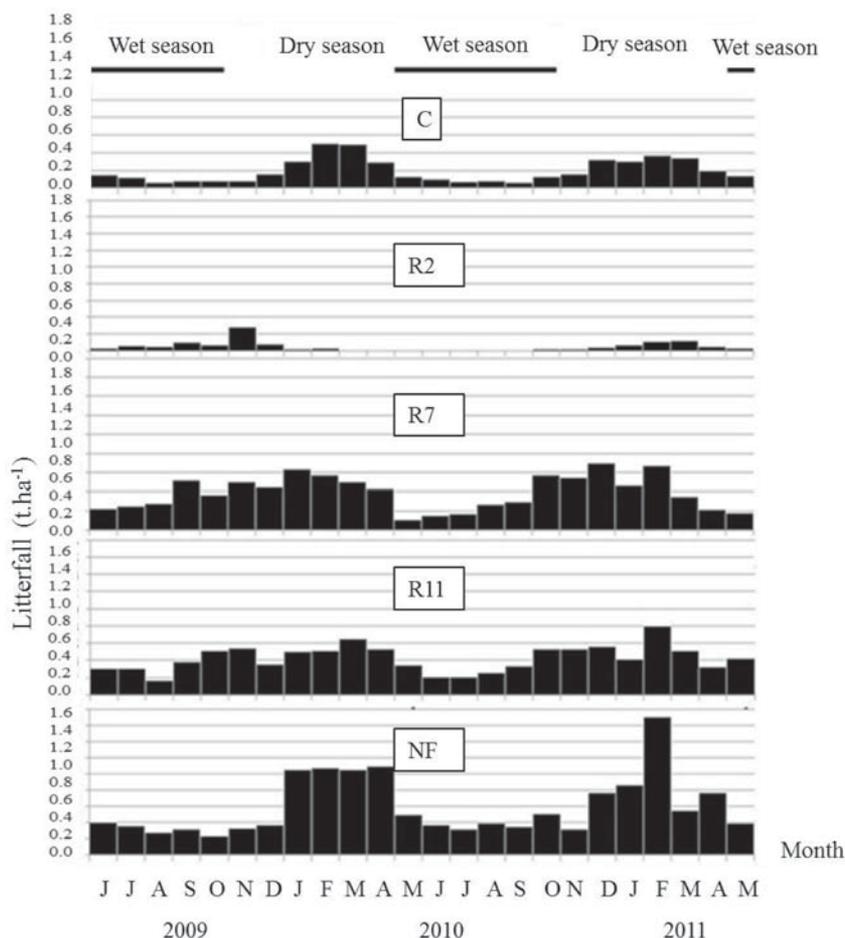


Figure 1 Seasonal variation in litterfall in year 1 (June 2009–May 2010) and year 2 (June 2010–May 2011). (C = Non-planted control sites; NF = Mature natural forest; and R2, R7 and R11 = Forest restoration sites (at the start of this study) at age 2, 7 and 11, respectively, since planting.)

Table 1 Carbon flow via litterfall (n=3, averaged over 2 yr \pm SD).

Site	Annual dry mass of litterfall (t.ha ⁻¹ yr ⁻¹)	Carbon content of litterfall %	Carbon flow via litter fall (t.ha ⁻¹ yr ⁻¹)	%NF	% left after 1 yr	Net input of carbon into soil (t.ha ⁻¹ .yr ⁻¹)	%NF
C	2.36	33.29 \pm 1.95 ^b	0.79 ^{cd}	28.6	65.5	0.51	38.7
R2	0.59	34.74 \pm 2.13 ^{ab}	0.20 ^d	7.2	64.5	0.13	9.9
R7	4.72	32.97 \pm 2.74 ^b	1.56 ^{bc}	56.5	25.7	0.40	30.0
R11	5.11	35.50 \pm 1.50 ^{ab}	1.81 ^{ab}	65.6	44.6	0.81	60.9
NF	7.13	38.72 \pm 0.39 ^a	2.76 ^a	100.0	48.2	1.33	100.0

Three replicates were performed.

C = Non-planted control sites; NF = Mature natural forest; and R2, R7 and R11 = Forest restoration sites (at the start of this study) at age 2, 7 and 11, respectively, since planting.

^{a-d} = Values with the same lower case superscript letters are significantly different ($P < 0.05$).

Litter decomposition

The decline in the mass of litter remaining in the mesh bags over time is shown in Figure 2, from which the percentage mass remaining after 1 yr was projected using the equations from the trend lines (Table 2). The derived decomposition rates in the oldest restoration plots (R11 and NF) were very similar (55.37 and 51.81% yr⁻¹, respectively), and higher than the other plots, indicating that the conditions that promote decomposition (such as microclimate and soil microfauna recovery) in the R11 plots had reached similar levels to those of the NF plots. In contrast, decomposition

occurred much more slowly in the control plots and the youngest restoration plots (34.55 and 35.53% yr⁻¹, respectively), perhaps reflecting a drier microclimate and poor micro-fauna recovery. Decomposition in the R7 plots was anomalously high. Many studies (Gartner and Cardon, 2004; Rahman and Motiur, 2012; Song *et al.*, 2013) have reported a direct influence of litter chemistry and physical properties of the leaves on litter decomposition rates. So in the current study, the effect of site and litter quality were combined and dominated the decomposition rates. However, the initial mixed litter in older restored sites was

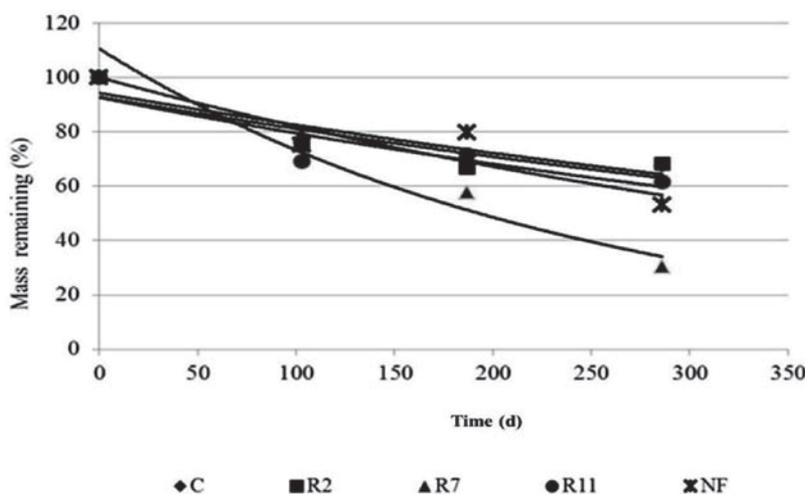


Figure 2 Litter mass remaining with trend line in different periods. (C = Non-planted control sites; NF = Mature natural forest; and R2, R7 and R11 = Forest restoration sites (at the start of this study) at age 2, 7 and 11 , respectively, since planting.)

Table 2 Regression equation and correlation coefficient (*R*²) for all study sites.

Site	Equation	R ²	Predicted mass remaining (%) in 1 year	k
C	$y = 94.287e^{-0.001x}$	0.87	65.45	1.20 ± 0.88 ^b
R2	$y = 92.863e^{-0.001x}$	0.78	64.47	1.08 ± 0.78 ^b
R7	$y = 110.53e^{-0.004x}$	0.94	25.67	2.85 ± 1.10 ^a
R11	$y = 92.608e^{-0.002x}$	0.80	44.63	1.27 ± 0.40 ^b
NF	$y = 99.996e^{-0.002x}$	0.85	48.19	1.12 ± 0.29 ^b

Three replicates were performed.

k = Litter decomposition constant± SD.

C = Non-planted control sites; NF = Mature natural forest; and R2, R7 and R11 = Forest restoration sites (at the start of this study) at age 2, 7 and 11 , respectively, since planting.

^{a,b} = Significantly different (*P* < 0.05).

not different in terms of plant species. Thus, the decomposition rate was dominated by other factors such as microclimate which is the primary influence on the understory composition due to the many biogeochemical processes including humidity and warm weather (Heal *et al.*, 1997) and the aspect was most likely the main reason for the high decomposition in the R7 plot.

Addition to soil carbon pool

The annual addition of carbon to the soil carbon pool, via litterfall, can be derived by multiplying the litter carbon flow by the percentage remaining after 1 yr (from the decomposition study). Figure 3 shows that the net carbon available to the soil carbon pool via litter initially fell below the control levels, taking around 8–9 yr to recover above these levels, but thereafter approaching natural forest levels in 14–16 yr.

DISCUSSION

Litterfall

Litterfall in the restored forest increased with site age (Figure 3). Even though the R11 site was still quite young (11 yr), litterfall over the two

years of the study was quite high compared to NF. The significant relationship between annual litter (y) and age (x) since planting was determined using Equation 2:

$$y = 2.5718\ln(x) - 0.9188 \quad (R^2 = 0.97) \quad (2)$$

and was used for estimating the age at which the litter would equal the amount of litter in NF. The result (22.65 yr) was much lower than the age for NF (25 yr).

Litterfall in R11 and R7 in the present study was close to the values for teak plantation species (Sumantakul and Viriyabuncha, 2007) but less than that of fast-growing plantation trees such as *Eucalyptus* spp. and *Acacia* spp. (Tanavat *et al.*, 2011) as shown in Table 3. It was generally less than that of mature forest ecosystems in Asia (Table 4). The annual pattern of litterfall was similar to that reported by others. High amounts of litter were recorded during the dry season (December to April). The study by Visaratana and Chernkhuntod (2005) in dry evergreen forest at the Sakaerat Environmental Research Station, Nakhon Ratchasima province, Northeastern Thailand reported $7.66 \text{ t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ which was a similar amount of litter to that from the natural forest site in the current study but the highest peak was found

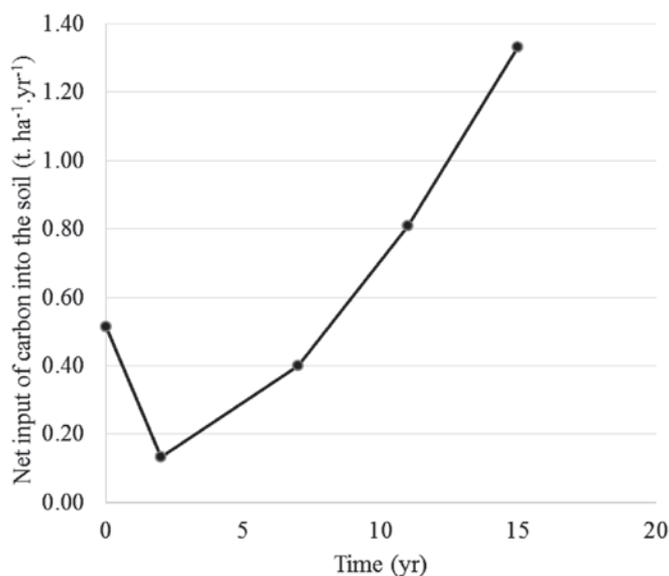


Figure 3 Relationship between litterfall and restored forest age.

in June. However, litterfall is variable, depending on various factors, such as soil type, weather and the age of the plant community (Martius *et al.*, 2004), as well as planting density (Dickens *et al.*, 2004), tree growth rates (Xu *et al.*, 2004), and site preparation and management (Toit, 2008). The planting density at each site in the current study was around 3,000 trees.ha⁻¹ compared with 10,000 trees.ha⁻¹ in Tanavat *et al.* (2011).

Primary productivity increases with increasing precipitation (Grosso *et al.*, 2008). The high rainfall in Eastern and Western Thailand might contribute to the high litterfall recorded in the studies there compared with Northern Thailand

(Table 3). Hence, the low litter production in the NF (natural forest) plot in the current study compared with other forest studies (Table 4), may be due to the variation in the mean annual rainfall at each specific study site and other factors such as the age of forest.

Organic carbon return through litterfall

Most researchers normally use a conversion factor of 0.50 to provide an estimate of carbon pools (IPCC, 2006; Lewis *et al.*, 2009). However, the carbon concentration of litter in the present study was lower than such typical values. In the present study, the organic carbon

Table 3 Comparison of litter production between the present study and other plantation studies.

Location	Plantation	Litter production (t.ha ⁻¹ .yr ⁻¹)	Mean Annual rainfall (mm)	Elevation (m asl)	Reference
Prachin Buri, Western Thailand,	Plantation (3-year-old)				
	- <i>Eucalyptus camaldulensis</i>	11.43			Tanavat <i>et al.</i> 2011
	- <i>Acacia hybrid (mangium × auriculaemis)</i>	13.67	1,540		
- <i>Leucaena leucecephala</i>	10.56				
Kanchanaburi Western Thailand,	Unthinned teak plantation				
	-6-year-old	4.45		400	Sumantakul and Viriyabuncha, 2007
	-14-year-old	5.65	1,655		
-27-year-old	6.69				
Chachoengsao, Eastern Thailand,	-6-year-old	10.37			
	<i>Eucalyptus camadulensis</i>				
	-6-year-old	8.29			
	-14-year-old	8.97	-		
Southern Costa Rica	Plantation site with two native timber and two nitrogen fixing species	6.3	3,500	1,000 1,300	Augusto, 2010
FORRU, Chiang Mai, Northern Thailand	Forest restoration plot				
	-R11 (11 yr)	5.09–5.13	1,154	1,207	– Present study
	-R7 (7 yr)	4.60–4.85		1,310	
	-R2 (2 yr)	0.46–0.71			
	-Control plot	2.27–2.46			
Manipur, India	Plantation site with <i>Quercus serrata</i>	4.20	1,384	790	Pandey <i>et al.</i> 2007

FORRU = Forest Restoration Research Unit.

content of litter varied among the site types, being highest for NF, medium for the restored sites and lowest for the control site (38.72, 34.40 and 33.29%, respectively), with the percentage carbon values averaging 35.47%. This result agreed with several other studies from China (45%) in natural *Castanopsis kawakamii* forest and monoculture plantations of *C. kawakamii* and Chinese fir (Guo *et al.*, 2004) and 39.4–45.8% in *Cunninghamia lanceolata* and *Michelia macclurei* plantations (Niu *et al.*, 2009).

The organic carbon in primary forest, secondary forest, rubber plantation and lychee orchard in northern Thailand was in the ranges 27.47–31.56, 27.72–29.42, 20.98–33.25 and 30.39–32.52%, respectively (unpublished data). Jain *et al.* (2010) stated that carbon concentration varies, depending on the tree species, substrate, and the location and variability in the carbon content as a function of forest type.

In the present study, the high carbon content found at the natural forest site (38.72%) was greater than at the restored (34.40%) and control (33.29%) sites, perhaps because the litter

quality in terms of the carbon content varied with tree species (Chandrashekar, 2011).

Litter decomposition of mixed species

After 286 d, the litter decomposition constant or k value in R7 was significantly ($P < 0.05$) higher than for other sites ($k = 2.85$). Martínez-Yrizar *et al.* (2007) proposed that decomposition rates vary among litter types differing in structural or nutritional quality. The litter types used in their experiment significantly differed in initial quality and annual decomposition rates. However, the initial mixed litter on older restored sites was not different in terms of plant species, so the decomposition rate was dominated by other factors possibly the microclimate which is the primary influence on the understory composition for many biogeochemical processes due to humidity and warm weather (Heal *et al.*, 1997) which may have been due to the different aspect and the high decomposition in R7.

The k values from previous studies in different types of forest in Thailand were quite

Table 4 Comparison of litter production between the present study and other forest studies.

Location	Forest type	Litter production (t.ha ⁻¹ .yr ⁻¹)	Mean annual rainfall (mm)	Elevation (m asl)	Reference
Sakaerat Environmental Research Station, Nakhon Ratchasima, Thailand	Dry evergreen forest	7.66	1,000–1,500	300–600	Visaratana and Chernkhuntod, 2005
Southern Costa Rica	Secondary forest (7–9 yr)	7.3	3,500	1,000–1,300	Augusto, 2010
FORRU, Chiang Mai, Northern Thailand	Hill evergreen forest (NF plot)	7.01–7.26	1,154	1,300	Present study
Manipur, India	Natural oak forest dominated with <i>Quercus serrata</i>	5.48	1,384	840	Pandey <i>et al.</i> 2007

FORRU = Forest Restoration Research Unit; NF = Native forest; asl = Above sea level.

varied (Table 5). Compared with previous studies, the k values in the present study were quite high ($k = 1.08\text{--}2.85$), whereas, for the litter decomposition studies at the Sakaerat Environmental Research Station, in the Kog-ma watershed in the Doi Suthep-pui National Park and in the Kaeng krachan National Park, in Petchaburi and Prachuab Kiri Khan provinces the respective values were 1.62, 0.05–1.05 and 0.03–0.11. Litter decomposition is also correlated closely with the plant species composition and plant species traits (Scherer-Lorenzen *et al.*, 2007; Vivanco and Austin, 2008). Plant species and their associated community have the potential to influence the decomposition process through altering plant species interactions, plant-decomposer interactions and biotic factors such as bacteria and fungi as well as the abiotic

environment such as the microclimate Vivanco and Austin, 2008). Litter decomposition constant or k values of the study sites less than one indicate that the turnover time for leaf litter is longer than one year (Melvin *et al.*, 2011) and this indicates that the litter on the current study sites had a fast turnover rate (shorter than 1 yr).

CONCLUSION

Forest restoration using the framework species method appears to substantially increase carbon inputs into the upper layers of the soil by litterfall. The study showed that framework species can produce high quality litter that can be the major input of carbon through litterfall, which was a new finding from this study.

Table 5 Decay rates of variety plant species in different forest type of Thailand.

Location	Forest type	Dominant species	k	Reference
FORRU, Chiang Mai, Northern Thailand	Forest restoration site			
	Planted 1997	Mixture of two species	2.07	Gavinjan, 2005
	1999	<i>Prunus cerasoides</i> and <i>Ficus altissima</i>	2.40	
	2001	<i>altissima</i>	3.14	
	control		2.69	
FORRU, Chiang Mai Northern Thailand	Control site	Grass	1.20	Present study
	2-year-old site	Grass + mixed framework species	1.08	
	7-year-old site	Mixed framework species	2.85	
	11-year-old site	Mixed framework species	1.27	
	Natural forest	Mixed species dominated by <i>Castanopsis diversifolia</i>	1.12	
Sakaerat Environmental Research Station, Nakhon Ratchasima, Thailand	Dry evergreen forest	<i>Hopea ferrea</i>	1.62	Boonriam, 2010
Kog-ma watershed research area, Doi Suthep-Pui National Park, Chiang Mai, Thailand	Hill evergreen forest	<i>Castanopsis accumunatissima</i>	0.99–1.05	Torreta and Takeda, 1999
		<i>Schima wallichii</i>		
Kaeng krachan National Park, Petchaburi and Prachuap Khiri Khan, Thailand	Mixed deciduous forest	<i>Alchornea tiliifolia</i>	0.07–0.11	Jampanin, 2004
	Dry evergreen forest	<i>Blachia siamensis</i> <i>Bhesa robusta</i>	0.03–0.07	
	Hill evergreen forest	<i>Castanopsis diversifolia</i>	0.04	
		<i>Quercus lamellosa</i>		

FORRU = Forest Restoration Research Unit; k = Litter decomposition constant.

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