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Bird communities and seedling recruitment in restoring seasonally dry forest using the framework species method in Northern Thailand

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Abstract This study examined the effects of framework trees, planted in 1998, and bird community on the natural recruitment of tree seedling species in a forest restoration experiment designed to test the framework species method of forest restoration established by Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU). Tree seedlings establishing beneath five framework tree species: *Erythrina subumbrans* (Hassk.) Merr., *Hovenia dulcis* Thunb., *Melia toosendan* Sieb. & Zucc., *Prunus cerasoides* D.Don and *Spondias axillaries* Roxb., were surveyed. Five trees of each species were selected in the 8-year-old trial plots. Birds visiting each tree were observed to determine possible seed dispersal activities. Thirty-six tree seedling species were found beneath the selected trees, of which 11 were wind-dispersed and 25 were animal-dispersed. The population density of animal-dispersed tree seedlings was higher than the wind-dispersed seedlings beneath all selected framework trees. The sample plots beneath *P. cerasoides* supported the highest population density of tree seedlings. Forty-nine bird species were recorded visiting the framework trees between July 2006 and June 2007. Non-frugivorous birds were recorded more frequently than the frugivorous birds. The effects of birds on seedling recruitment were different among each of the selected framework tree. Bigger trees, which attracted high number of birds by providing food resources, roosting and nesting sites may increase the seed deposition more than smaller trees with fewer attractants.

Keywords Birds · Forest restoration · Seed dispersal · Thailand

Introduction

Thailand has experienced serious deforestation in recent decades, like most tropical countries, with adverse consequences for biodiversity loss, flooding, soil erosion and climate change (Houghton 2005; Schlamadinger et al. 2005). The well known main causes of

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deforestation are illegal logging, intensive agricultural expansion, forests fires and infrastructure development (Alencar et al. 2005; Delang 2002; RFD 2007).

Many forest planting campaigns have been initiated to restore natural forests throughout the tropics (Lamb and Gilmour 2003; Otsamo 2002). In Thailand, reforestation projects, using fast-growing monoculture plantations of eucalyptus (*Eucalyptus camaldulensis* var. *camaldulensis* Dehnh.), pine (*Pinus kesiya* Royle *ex* Gordon.), teak (*Tectona grandis* L. f.) and other broadleaf species have been implemented by the Royal Forestry Department (RFD) since 1994 (FAO 2001). However, plantations support low biodiversity and are not self-supporting ecosystems (Ruiz-Jaen and Aide 2005; Society for Ecological Restoration International Science and Policy Working Group 2004; Urbanska et al. 1997). For biodiversity conservation, reforestation should promote biodiversity recovery by re-establishing the original ecosystem, based on vegetation structure, species diversity and ecosystem processes (McCoy and Mushinsky 2002; Montagnini and Cusack 2004; Wilkins et al. 2003). This is "forest restoration", defined as "re-establishment of the original forest ecosystem that was present before deforestation occurred". Forest restoration involves planting tree species that play a vital role in forest recovery, such as those that create a multi-layered canopy, restore the soil ecosystem and accelerate biodiversity (Elliott et al. 2000).

The Forest Restoration Research Unit (FORRU) (http://www.forru.org) at Chiang Mai University has been carrying out research on forest restoration since 1994. The unit has modified the framework species method of forest restoration firstly developed in Queensland, Australia (Goosem and Tucker 1995; Lamb et al. 1997; Tucker 2000; Tucker and Murphy 1997). An important characteristic of framework tree species is the provision of resources (e.g., fruits, nectar, nesting sites, etc.) that attract seed-dispersing wildlife, such as birds and mammals. This promotes recovery of the tree species composition of the original forest ecosystem, by establishment of "recruit" tree species (i.e., non-planted tree species growing from incoming seeds) (Chanthorn 1999; Clark et al. 2001; Corlett 1998a, b; Corlett and Hau 2000; Donath et al. 2003; Holbrook et al. 2002; Ingle 2003; Pakkad et al. 2008; Sinhaseni 2008; Toktang 2005; White et al. 2004; Wunderle 1997). However, tree species recruitment in this way can be limited by a lack of natural seed sources in the landscape, a scarcity of seed dispersal animals, and also by the conditions prevalent beneath the planted tree species that affect seed germination and seedling establishment.

The research reported here examined the effects of planted framework trees, and the birds attract to them, on recruitment of tree seedling species in a forest restoration experiment, established to test framework species method. The following hypotheses were tested:

1. Different characteristics of each selected framework tree species attract different bird species, depending on the resources provided to the birds.
2. Natural seedling recruitment beneath the framework trees depends on the species of the framework tree.
3. High bird density, species richness and species diversity will increase the natural tree seedling recruitment rate beneath framework tree species.

Materials and methods

Study site

The study site was three experimental plots, planted in 1998 (8 years old at the start of this study in March 2006) to test the framework species method of forest restoration in the north of Doi Suthep-Pui National Park, Chiang Mai Province of northern Thailand. The plots were positioned in a degraded watershed area, 3–5 km from the village of Mae Sa Mai (18°52′N, 98°51′E) at 1,207–1,310 m elevation. The plots had originally been covered with evergreen forests, cleared approximately 20 years previously to provide land for crops (Elliott et al. 2000; Khopai 2000). Some remnant trees, which provide the seed sources for natural forest regeneration, were scattered sparsely across the area. A degraded primary forest area provided habitat of seed-dispersing animals such as fruit bats and birds, 2–3 km away from the planted plots (Navakitbumrung 2003).

The plots were planted with 29 framework tree species in 1998, including *Albizia chinensis* (Osb.) Merr., *Erythrina subumbrans* (Hassk.) Merr., *Pterocarpus macrocarpus* Kurz. (all Leguminosae), *Castanopsis tribuloides* A. DC., *Lithocarpus elegans* (Blume) Hatus. *ex* Soepadmo var. *collettii* (King *ex* Hook.f.) HB. Naithani & S. Biswas, *Quercus semiserrata* Roxb. (all Fagaceae), *Ficus altissima* Blume, *Ficus microcarpa* var. *microcarpa* L.f., *Ficus subincisa* Buch.-Ham. ex Sm. var. *trachycarpa* (Miq.) Corner *ex* Chater (all Moraceae), *Balakata baccata* (Roxb.) Esser (Euphorbiaceae), *Cinnamomum iners* Reinw. *ex* Bl (Lauraceae), *Rhus rhetsoides* Craib and *Spondias axillaries* Roxb. (Anacardiaceae). The tallest planted trees were *E. subumbrans*, and *S. axillaris*, growing up to 25 m tall. The trees had been randomly planted as 30–50 cm tall saplings, at a density of 3,125/ha (averaging 1.8 m apart) to bring about rapid shading out of weeds and canopy closure. By the start of the study described here, a dense 2-layered canopy had been achieved and most tree species had reached maturity with flowering and fruiting has been observed (FORRU 2005).

Framework tree selection

Five species of framework trees, which have different abilities based on their attractiveness to birds were selected for this study. The five framework tree species were: *Erythrina subumbrans* (Hassk.) Merr. (Family Leguminosae), *Hovenia dulcis* Thunb. (Family Rhamnaceae), *Melia toosendan* Sieb.& Zucc. (Family Meliaceae), *Prunus cerasoides* D.Don (Family Rosaceae) and *Spondias axillaris* Roxb. (Family Anacardiaceae). Five individuals of each species were selected (25 trees) from the three replicated planted plots in 1998 (Five trees in 1998-1, 10 trees in 1998-2 and 10 trees in 1998-3). Circular plots were laid out to match the maximum crown width. Flowering and fruiting phenology of each trees species with mean tree size (GBH) and circular plots areas are listed in Table 1.

Bird surveys

Bird observations were carried out on each framework tree crowns once a month for 12 months during July 2006–June 2007 using binoculars (8 × 32 mm). Each tree crown was observed for 20 min/time for bird visitations. Random walks after every 5 min of observation from tree to tree were used to avoid time bias. The observation periods for all selected trees were between 6:30 and 8:30 in the mornings and between 14:30 and 18:00 in the afternoons. Bird species, number of birds, duration of visit, behaviors (e.g., perching; feeding on fruits, insect, nectars; and/or defecation) were recorded. The observed birds were classified according to their diet (e.g., frugivore and non-frugivore; Kopkate 2001) and the parts of the tree used by them (e.g., crown, ground, or understorey user).

Table 1 Flowering and fruiting phenology (FORRU 2005) of each selected framework tree species with mean tree size (GBH; cm) and sample plot areas (m^2)

Framework species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Erythrina subumbrans	Flowering	Flowering	Fruiting	Fruiting								Flowering
GBH 114.80; Plot area 24.62	Observed											Observed
Hovenia dulcis	Fruiting	Fruiting	Flowering	Flowering	Flowering			Fruiting	Fruiting	Fruiting	Fruiting	Fruiting
GBH 20.40; Plot area 15.26												
Melia toosendan	Fruiting	Fruiting	Fruiting							Flowering	Flowering	Flowering
GBH 71.40; Plot area 25.44												
Prunus cerasoides	Flowering		Fruiting	Fruiting	Fruiting							Flowering
GBH 68.60; Plot area 21.98	Observed											
Spondias axillaris	Flowering	Flowering	Flowering			Fruiting	Fruiting	Fruiting				
GBH 101; Plot area 35.79												

Flowering period (FORRU 2005)

Fruiting period (FORRU 2005)

Flowering to fruiting period observed during the research

Seedling surveys

All natural tree seedlings presented in each plot were labeled, identified, and classified according to their seed-dispersal mechanism (FORRU 2005). Root collar diameter and height of every seedling were recorded to determine average relative growth rates (% per year). Percentages of seedling survival were calculated. The first seedling survey was done during the dry season, between March and April, 2006, and monitored after the rainy season in November 2006. The final seedling survey was done in July 2007. Percent estimation of ground vegetation (Goldsmith et al. 1986) and measurements of light intensity using Lux/Fc light meter (TENMARS, Model: DL-204) were carried out beneath each of the selected tree in July 2007.

Data analyses

Communities of natural tree seedlings were analyzed using species richness indices by N0 (total number of seedling/bird species), species diversity indices by N1 ($e^{H'}$, where $H' =$ Shannon–Wiener's index), N2 ($1/\lambda$, where $\lambda =$ Simpson's index) and evenness by E5 (modified Hill's index) by MVSP 3.1®, a multivariate statistical package programs (Kovach computing services 2000). Relative growth rates of each seedling which survived the entire project period were calculated using both height (Relative Growth Rate of Height, RHGR) and root collar diameter (Relative Growth Rate of Root Collar Diameter, RRGR). Survival percentages of all natural tree seedlings were calculated. Differences among the framework tree species in the bird and seedling communities they supported were tested by using ANOVA and two-tailed *t*-test. A linear comparison analysis using correlation was used to detect a relationship between seedlings and bird communities.

Results

Bird surveys

A total of 49 bird species was recorded visiting the selected framework tree species. The bird species were divided into two groups: frugivorous birds (birds feeding mainly on fruits) which are likely to be seed dispersers (17 species) and non-frugivorous bird (birds not feeding mainly on fruits, including carnivores, insectivores and nectarivores) which are unlikely to be seed dispersers (up to 32 species). The most abundant bird species recorded was *Copsychus malabaricus* followed by *Pycnonotus jocosus*, *Zosterops japonicus*, *Pycnonotus melanicterus*, *Hemipus picatus*, *Pericrocotus flammeus*, *Aethopyga saturate*, and *Pycnonotus aurigaster* (Table 2).

Non-frugivorous birds visited the selected framework trees more frequently than frugivorous birds, except for *E. subumbrans* (Table 3). The population density (no./m^2) and species richness (no. of species/m^2) of visiting birds were highest in *P. cerasoides* crowns, whilst *H. dulcis* crowns supported the lowest numbers and species of birds (Table 4). The population density of the frugivorous birds was higher than that of the non-frugivorous bird species only in *E. subumbrans* crowns. The species richness of non-frugivorous birds was higher than that of frugivorous bird in all selected tree species (Table 4).

Table 2 Most abundant bird species, their diet (Kopkate 2001), and total minutes observed using each selected tree species

Bird species	Common name	Diet	No. of birds	ER	HO	ME	PR	SP
Copsychus malabaricus	White-rumped Shama	Non-frugivore	18	1.16	1.38	0.23	1.07	4.28
Pycnonotus jocosus	Red-whiskered Bulbul	Frugivore	16	0.48	–	0.17	0.04	0.39
Zosterops japonicus	Japanese White-eye	Frugivore	13	0.18	–	0.32	1.43	–
Pycnonotus melanicterus	Black-crested Bulbul	Frugivore	11	0.18	–	–	0.18	0.53
Hemipus picatus	Bar-winged Flycatcher-shrike	Non-frugivore	11	0.11	0.03	0.24	–	0.10
Pericrocotus flammeus	Scarlet Minivet	Non-frugivore	11	0.20	–	2.34	–	0.06
Aethopyga saturata	Black-throated Sunbird	Non-frugivore	11	0.32	0.12	–	1.04	0.11
Pycnonotus aurigaster	Sooty-headed Bulbul	Frugivore	10	0.18	–	0.12	–	1.12

Abbreviations: ER, *Erythrina subumbrans*; HO, *Hovenia dulcis*; ME, *Melia toosendan*; PR, *Prunus cerasoides*; SP, *Spondias axillaris*

Table 3 The means number (±standard deviation) of birds of each group using the selected tree species

Bird group	*Erythrina subumbrans*	*Hovenia dulcis*	*Melia toosendan*	*Prunus cerasoides*	*Spondias axillaris*
Frugivore	4.4 ± 3.0^{a}	0.6 ± 0.8^{b}	2.8 ± 3.4^{ab}	5.4 ± 2.2^{ab}	5.4 ± 3.1^{ab}
Non-frugivore^{NS}	3.4 ± 1.4	1.8 ± 2.2	6.6 ± 2.4	7.8 ± 2.3	7.0 ± 1.3
Total^{NS}	7.8 ± 2.1	2.4 ± 2.2	9.8 ± 5.2	13.2 ± 2.1	12.4 ± 3.5

Note: Different superscript alphabets in the same row = significant differences ($P \le 0.05$). NS = no significant difference

Table 4 Population density and species richness (±standard deviation) of each bird group at the sampling tree plots

Bird group	*Erythrina subumbrans*	*Hovenia Dulcis*	*Melia toosendan*	*Prunus cerasoides*	*Spondias axillaris*
Population density (no./m^2)					
Frugivore	0.17 ± 0.08^{a}	0.02 ± 0.03^{b}	0.10 ± 0.10^{ab}	0.34 ± 0.32^{ab}	0.15 ± 0.10^{ab}
Non-frugivore^{NS}	0.16 ± 0.07	0.12 ± 0.18	0.32 ± 0.17	0.47 ± 0.25	0.20 ± 0.03
Total^{NS}	0.33 ± 0.06	0.15 ± 0.18	0.44 ± 0.20	0.82 ± 0.52	0.35 ± 0.09
Species richness (no. of species/m^2)					
Frugivore	0.10 ± 0.06^{a}	0.02 ± 0.02^{b}	0.07 ± 0.06^{ab}	0.17 ± 0.16^{ab}	0.07 ± 0.05^{ab}
Non-frugivore^{NS}	0.13 ± 0.06^{ab}	0.07 ± 0.07^{a}	0.20 ± 0.11^{ab}	0.33 ± 0.18^{b}	0.16 ± 0.03^{b}
Total	0.23 ± 0.08^{a}	0.09 ± 0.10^{b}	0.27 ± 0.12^{a}	0.50 ± 0.32^{a}	0.23 ± 0.06^{a}

Note: Different superscript alphabets in the same row = significant differences ($P \leq 0.05$). NS no significant difference

Table 5 Number of birds, species richness (N0), ecological indices (Shannon–Wiener's index; N1, Simpson's index; N2) and the evenness (E5) of bird communities in each selected framework tree species

Tree plot	No. of birds	Richness (N0)	Species diversity		Evenness
			(N1)	(N2)	(E5)
Erythrina subumbrans	39	19	15.753	1.054	0.004
Hovenia dulcis	12	8	7.236	1.082	0.013
Melia toosendan	49	23	18.412	1.050	0.003
Prunus cerasoides	66	25	20.573	1.045	0.002
Spondias axillaris	62	28	21.413	1.046	0.002

Highest species richness of the birds was recorded in *P. cerasoides* crowns and *S. axillaris* crowns (Table 5). Bird diversity was highest in *S. axillaris* crowns (N1 = 21.41), whilst lowest species diversity was in *H. dulcis* crowns (N1 = 7.24). Highest evenness was in *H. dulcis* crowns (E5 = 0.01), whilst lowest was in *P. cerasoides* crowns and *S. axillaris* crowns (E5 = 0.002).

Bird behavior and their usage sites on the selected framework tree species

Most birds perched on the trees and then flew away. Feeding on insects was observed more frequently than feeding on fruits and nectar. Feeding on fruits and nectars were observed only for *P. cerasoides* in January 2007 and *E. subumbrans* from December 2006 to January 2007 (Table 1).

Defecation was observed in *M. toosendan*, *P. cerasoides* and *S. axillaris*. Most bird species visited only one part of the tree, whilst a few birds used more than one part of the tree. The tree trunk and branches under the tree crowns were most frequently used by visiting birds followed by the tree crowns and the ground under the tree crowns. The highest number of birds visiting the tree crown was observed in *P. cerasoides*, whilst the

Table 6 Number of bird and bird species using the selected framework trees

Tree plots	No. of birds (No. of species)	No. of bird using the sites (No. of species)		
		Crown user	Understorey user	Ground user
Erythrina subumbrans	39 (19)	29 (12)	8 (7)	2 (2)
Hovenia dulcis	12 (8)	2 (2)	8 (5)	2 (2)
Melia toosendan	49 (23)	18 (11)	30 (14)	1 (1)
Prunus cerasoides	66 (25)	25 (7)	33 (20)	8 (3)
Spondias axillaris	62 (28)	30 (13)	30 (14)	3 (3)

highest numbers of birds using the understorey and the ground beneath the crown were observed in *S. axillaris* (Table 6).

Tree seedling surveys

A total of 36 species of 436 seedlings was found beneath all selected trees between April 2006 and July 2007. Ten species (203 individuals) were the same as the planted framework tree species were regarded as "non-recruited species", whilst 26 species (233 individuals) were considered to be incoming "recruited species" (Table 7). Eleven species were wind-dispersed (55 individuals) and 25 species were animal-dispersed (381 individuals). Both population density (no./m^2) and species richness (no. of species/m^2) of seedling communities (Table 8) were highest in the *P. cerasoides* crowns, whilst *H. dulcis* crowns supported the sparsest seedling communities. Considering dispersal mechanisms, population density and species richness of wind-dispersed seedling species were highest in *P. cerasoides* crowns, whilst species richness of animal-dispersed seedling species were highest in *E. subumbrans* and *P. cerasoides* crowns. The most abundant seedling species in all the sample plots were *Litsea monopetala* (Roxb.) Pers. (Family Lauraceae), *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (Family Fagaceae), *Phoebe lanceolata* (Wall *ex* Nees) Nees (Family Lauraceae), *Eugenia albiflora* Duth. *ex* Kurz (Family Myrtaceae), *Aporusa octandra* (Buch.-Ham. *ex* D. Don) (Family Euphorbiaceae), *Schima wallichii*

Table 7 The means number (±standard deviation) of non-recruited and recruited seedlings beneath the planted tree crowns

Dispersal mode (FORRU 2005)	*Erythrina subumbrans*	*Hovenia dulcis*	*Melia toosendan*	*Prunus cerasoides*	*Spondias axillaris*
Non-recruited species: 10 species (203 individuals)					
Wind	0.60 ± 0.49^{a}	0.60 ± 1.20^{b}	1.20 ± 2.40^{ab}	1.60 ± 1.85^{ab}	0.20 ± 0.40^{b}
Animal	8.60 ± 8.40^{a}	1.00 ± 0.63^{b}	8.60 ± 12.22^{ab}	16.00 ± 19.39^{ab}	2.00 ± 1.26^{ab}
Total	9.20 ± 8.03^{a}	1.60 ± 0.80^{b}	9.80 ± 11.81^{ab}	17.60 ± 19.03^{ab}	2.20 ± 1.17^{b}
Recruited species: 26 species (233 individuals)					
Wind	3.40 ± 1.50^{a}	0.40 ± 0.80^{ab}	1.00 ± 0.63^{ab}	1.60 ± 1.02^{ab}	0.40 ± 0.49^{b}
Animal	15.80 ± 10.23^{a}	2.00 ± 1.67^{ab}	9.00 ± 8.10^{ab}	7.40 ± 2.65^{a}	5.80 ± 4.58^{b}
Total	19.20 ± 10.68^{a}	2.40 ± 1.85^{ab}	10.00 ± 8.37^{ab}	9.00 ± 2.61^{ab}	6.20 ± 4.96^{b}

Note: Different superscript alphabets in the same row = significant differences ($P \leq 0.05$)

Table 8 Population density and species richness (±standard deviation) of seedlings divided by dispersal mode in each sampling tree plots

Dispersal mode (FORRU 2005)	*Erythrina subumbrans*	*Hovenia dulcis*	*Melia toosendan*	*Prunus cerasoides*	*Spondias axillaris*
Population density (no./m^2)					
Wind	0.19 ± 0.07^{a}	0.04 ± 0.10^{b}	0.08 ± 0.09^{ab}	0.23 ± 0.24^{ab}	0.02 ± 0.03^{b}
Animal	1.15 ± 0.68^{a}	0.26 ± 0.17^{b}	1.11 ± 1.59^{ab}	1.29 ± 1.04^{ab}	0.23 ± 0.14^{ab}
Total	1.33 ± 0.72^{a}	0.30 ± 0.14^{b}	1.20 ± 1.59^{ab}	1.52 ± 1.14^{ab}	0.25 ± 0.17^{b}
Species richness (no. of species/m^2)					
Wind	0.11 ± 0.05^{a}	0.03 ± 0.05^{ab}	0.05 ± 0.04^{ab}	0.13 ± 0.12^{ab}	0.02 ± 0.03^{b}
Animal	0.26 ± 0.13^{a}	0.18 ± 0.11^{ab}	0.25 ± 0.17^{ab}	0.25 ± 0.11^{a}	0.09 ± 0.05^{b}
Total	0.35 ± 0.15^{a}	0.21 ± 0.10^{ab}	0.30 ± 0.20^{ab}	0.38 ± 0.23^{ab}	0.11 ± 0.07^{b}

Note: Different superscript alphabets in the same row = significant differences ($P \leq 0.05$)

Table 9 Abundant seedlings in all the sampling plots beneath all selected framework trees

Species	Non-recruited/Recruited (Elliott et al. 2000)	Family	Dispersal mechanism (FORRU 2005)	Total no. of seedlings
Litsea monopetala	Recruited	Lauraceae	Animal	148
Castanopsis cerebrina	Non-recruited	Fagaceae	Animal	84
Phoebe lanceolata	Non-recruited	Lauraceae	Animal	61
Eugenia albiflora	Non-recruited	Myrtaceae	Animal	21
Aporusa octandra	Recruited	Euphorbiaceae	Animal	17
Schima wallichii	Recruited	Theaceae	Wind	13
Archidendron clypearia	Non-recruited	Leguminosae, Mimosaceae	Wind	12
Ficus hirta	Recruited	Moraceae	Animal	11

(DC.) Korth. (Family Theaceae), *Archidendron clypearia* (Jack) I. C. Nielsen ssp. *clypearia* var. *clypearia* (Family Leguminosae), and *Ficus hirta* Vahl. var. *hirta* (Family Moraceae) (Table 9).

Species richness of seedlings beneath *E. subumbrans* crowns was highest, whilst it was lowest beneath *H. dulcis* crowns (Fig. 1). Seedling species diversity was highest beneath *E. subumbrans* crowns (Shannon's index, N1 = 8.39) and *S. axillaris* crowns (Simpson's index, N2 = 1.50), whilst the lowest seedling diversity was calculated for *H. dulcis* crowns (N1 = 6.07, N2 = 1.20). Highest evenness was found beneath *S. axillaris* crowns (modified Hill's index, E5 = 0.12), whilst the most uneven seedling community was found beneath *P. cerasoides* crowns (E5 = 0.03; Fig. 1).

Relative growth rate and survival rate of seedlings

RRGR of the seedlings was highest beneath *P. cerasoides* crowns (44%/year), RHGR of the seedlings was highest beneath *E. subumbrans* crowns (20%/year) (Table 10). Survival of the seedlings beneath framework tree species crowns was generally very high with 28 of

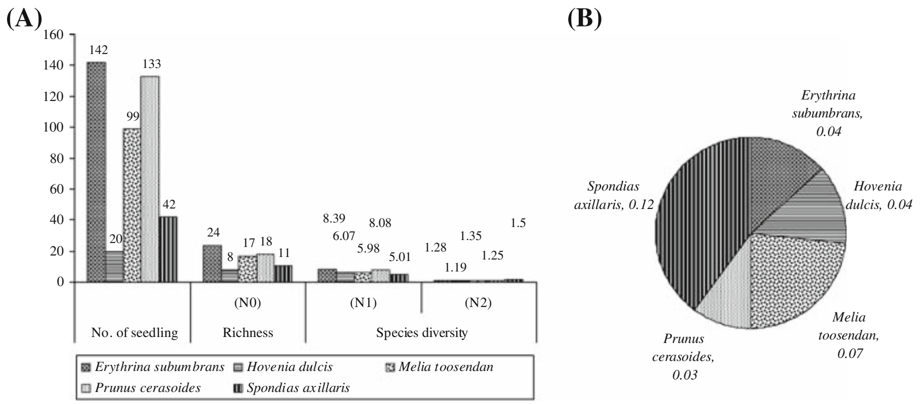

Fig. 1 **a** Number, species richness (N0), Shannon–Wiener's index (N1), Simpson's index (N2) of natural tree seedlings. **b** Evenness (E5) of seedlings beneath each selected framework tree species

Table 10 Relative growth rate of root collar diameter (RRGR), relative growth rate of height (RHGR), and survival percentage of natural tree seedlings (±standard deviation)

Tree plot	No. of seedlings	RRGR (%/year)^{NS}	RHGR (%/year)^{NS}	Remaining seedlings	Survival (%)
Erythrina subumbrans	142	26.0 ± 45.2	20.3 ± 26.6	135	95.0
Hovenia dulcis	20	41.1 ± 56.6	16.8 ± 21.9	19	95.0
Melia toosendan	99	16.2 ± 35.3	16.3 ± 12.5	97	97.9
Prunus cerasoides	133	44.1 ± 46.2	14.0 ± 11.1	127	95.4
Spondias axillaris	42	22.2 ± 37.9	19.3 ± 40.0	41	97.6
Total	436	35.2 ± 50.0	18.4 ± 21.3	419	96.1

Note: NS, no significant difference between each framework tree plot ($P \geq 0.05$)

the 36 seedling species recorded, achieving 100% survival. The average survival rate beneath all trees is 96.1% (from 20 April 2006 to 21 July 2007, totally 458 days).

Correlations between the natural tree seedlings and the conditions below tree canopies

Light intensity was strongly positively correlated with population density and species richness of establishing seedlings (Fig. 2a, b), but was very weak positively correlated with RHGR (Fig. 2c). Percentage of ground cover showed low correlations with population density (Fig. 2d) and species richness of seedlings (Fig. 1e) and very weak positive with RHGR (Fig. 2f).

Correlations between bird and seedling communities

The population density and species richness of crown-user (Fig. 3a) and ground-user birds (Fig. 3c) were moderately correlated with the population density of recruited

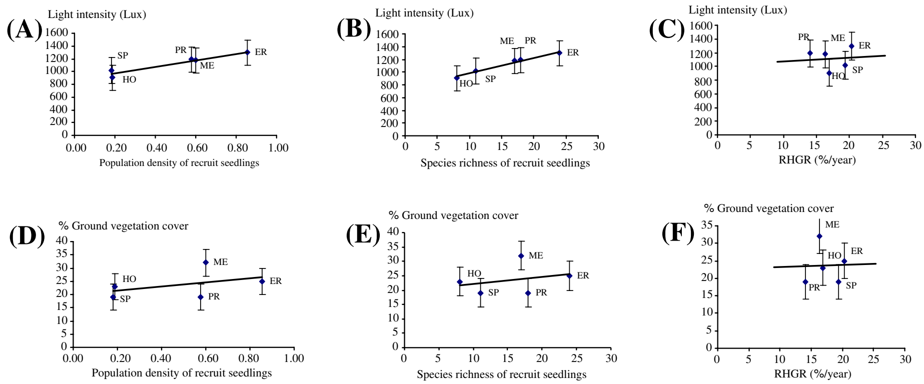

Fig. 2 Correlations between the recruited tree seedlings and the conditions below tree canopies. **a** Light intensity and population density ($y = 510.85x + 870.24$, $r^2 = 0.9253$), **b** species richness ($y = 24.403x + 735.15$, $r^2 = 0.9764$), and **c** RHGR ($y = 5.1991x + 1025.4$, $r^2 = 0.0071$) of recruit seedlings. Percentage ground vegetation and **d** population density ($y = 7.7597x + 19.869$, $r^2 = 0.1777$), **e** species richness ($y = 0.243x + 19.809$, $r^2 = 0.0806$) and **f** RHGR ($y = 0.0585x + 22.582$, $r^2 = 0.0007$) of recruited seedlings. (Abbreviations: ER, *Erythrina subumbrans*; HO, *Hovenia dulcis*; ME, *Melia toosendan*; PR, *Prunus cerasoides*; SP, *Spondias axillaris*)

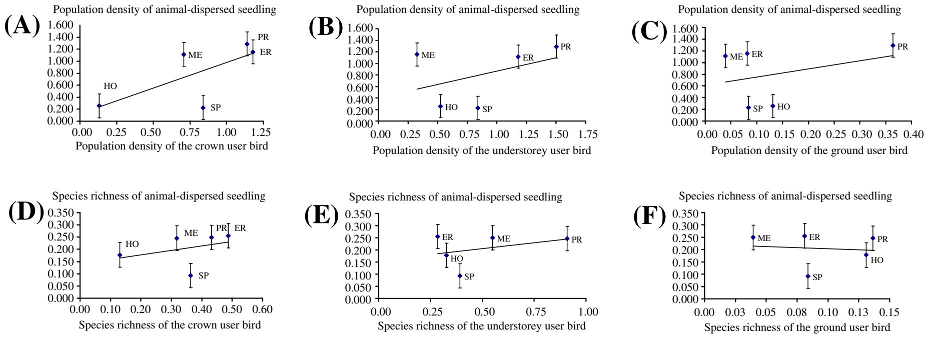

Fig. 3 Correlation of the population density of recruited animal-dispersed seedlings and **a** population density of the crown user ($y = 0.8573x + 0.1233$, $r^2 = 0.4822$), **b** understorey user ($y = 0.4596x + 0.4064$, $r^2 = 0.1769$), and **c** ground user ($y = 1.4056x + 0.6112$, $r^2 = 0.1216$). Correlation of the species richness of recruited animal-dispersed seedlings and **d** species richness of the crown user ($y = 0.1846x + 0.1402$, $r^2 = 0.1296$), **e** understorey user ($y = 0.0972x + 0.1562$, $r^2 = 0.1242$) and **f** ground user ($y = -0.1843x + 0.2215$, $r^2 = 0.0111$) (Abbreviations: ER, *Erythrina subumbrans*; HO, *Hovenia dulcis*; ME, *Melia toosendan*; PR, *Prunus cerasoides*; SP, *Spondias axillaris*)

animal-dispersed seedlings, whilst the population density and species richness of understorey-user birds (Fig. 3b) was weakly correlated. The crown-user (Fig. 3d) and understorey-user birds (Fig. 3e) showed weak correlation with species richness of recruited animal-dispersed seedlings, whilst the ground user birds (Fig. 3f) showed very weak negative correlation. The population of seedlings, which were the same species of planted trees in 1998 plots, was subtracted from this analysis, to focus only in the recruit seedling species and birds which were assumed to affect natural tree seedling recruitment.

Discussion

This research was designed to answer the following questions.

Do selected framework tree species attracted different bird species, depending on the different characteristics and resources provided to the birds?

Frugivorous bird species were observed frequently on *P. cerasoides* and *E. subumbrans* due to their higher provision of flowers and fruits for bird species compared with *S. axillaris*, *M. toosendan* and *H. dulcis*. *P. cerasoides* supported the highest abundance of birds even though the trees were smaller in size than *E. subumbrans*, *M. toosendan* and *S. axillaris*. The dense branching structure of *P. cerasoides* crowns provided lots of perching sites for the birds. Black-throated sunbird (*Aethopyga saturate*), Japanese White-eye (*Zosterops japonicus*), used *P. cerasoides* frequently to fed on the nectar. White-rumped Shama and other insectivores spent most time under the tree crown, gleaning insects from the leaves and on the ground under the trees. Bulbuls, which are common in the forest and occur in a wide range of habitats (Chanthorn 2002; Corlett et al. 2008; Green et al. 2008; Pattanakaew 2002; Scott et al. 2000; Weir and Corlett 2007), feed on *P. cerasoides* fruits.

E. subumbrans produces bright red color flowers, when they are leafless, which provide high quantities of nectar as a food sources for many birds species such as Black-throated sunbird. Many birds search for insects in the *E. subumbrans* flowers. Potential seed dispersing birds such as Red-Whiskered Bulbul (*Pycnonotus jocosus*) and Sooty-headed Bulbul (*P. aurigaster*) were observed frequently on the tree tops.

Although, flowering and fruiting were not recorded in the tall tree species (*M. toosendan* and *S. axillaris*) observed, during this study period (Table 1), these trees were used frequently by crown users as perching sites. Tree crowns provided ideal points for birds to perch and look out for food, since they were taller than the other species in the planted plots. Toktang (2005) recorded 24 bird species as regular visitors to *M. toosendan*, including five bulbul species, which are important seed dispersing agents. *S. axillaris* supported the highest species richness of birds, which used their multiple crowns in search for food or as perch sites. One bird nest was found in the "basket-shaped" cavity formed by multiple-secondary stems of a *S. axillaris* tree in 1998-1 plot in August 2006. The multiple crowns of *S. axillaris* supported nesting birds from the 5th year after planting (FORRU 2005). Voysey (1999) also reported that animal-dispersed seeds might be deposited more frequently in nesting or roosting sites.

H. dulcis supported the lowest richness, diversity and abundance of birds. Similarity coefficients of *H. dulcis*-bird communities compared with other species were low. This tree was the smallest selected framework species in this study. Their crowns were not large enough to support high number of birds. One important thing to consider is that *H. dulcis* has not yet flowered and provided fruit since planting. Therefore, resources to attract birds were not present.

Does natural seedling recruitment beneath the framework trees depend on the species of the framework tree?

Seedling surveys beneath the tree crowns resulted in higher species richness and abundance of animal-dispersed tree seedling species more than those of wind-dispersed tree seedling species, suggesting that seed dispersal by birds and small mammals significantly affects tropical forest regenerations (Corlett 1998a, b; Wunderle 1997).

The characteristics of each selected framework trees such as tree height, canopy width and denseness affect seedling communities. *E. subumbrans* had large mean crown width which determines shade and influences soil moisture content under the trees (Verdú and García-Fayos 1998). Such factors may then influence the density and distribution of tree seedlings. *E. subumbrans* shed their leaves during dry season, which resulted in open gaps under their crowns. This seemed to create suitable conditions for seedling recruitment, which agreed with the previous study by Navakitbumrung (2003) who concluded that the low shade and long leafless period of *Erythrina stricta* might be suitable for germination and recruitment of wind-dispersed species.

M. toosendan trees had a slightly lower mean crown width compared to *E. subumbrans*, whilst *S. axillaris* had largest mean canopy width (Table 1). However, *M. toosendan* and *S. axillaris* have denser multiple crowns than *E. subumbrans*. This characteristic is suitable for shading out weeds in the first 2 years of forest regeneration. But, the dense multiple crowns seemed to create unfavorable conditions for the naturally established trees, because they shade out seedlings too. *S. axillaris* trees were higher and had dense multiple crowns with many branches of pinnately-compound leaves and creating shadier conditions compared with *M. toosendan*. Thus, the number and species diversity of the seedlings in the *S. axillaris* plots were lower than *M. toosendan* plots, suggesting that different characteristic in crowns shape gave a different resulted for seedling communities beneath them.

P. cerasoides supported the highest population density and species richness of seedlings for both wind-dispersed and animal-dispersed seedling communities. One dominant tree seedling species in the *P. cerasoides*-plots was the large-seeded species *Castanopsis cerebrina* (Fagaceae) dispersed by medium-sized mammals. There were 62 seedlings (from 133 individuals of all seedlings in *P. cerasoides*-plots) growing densely beneath one *P. cerasoides*-plot (Data not shown). It was observed that one *C. cerebrina* tree, which was planted in 1998, was standing near this tree plot. Many *C. cerebrina* trees produce large amount of seeds after the rainy season. Therefore, it is likely that the *C. cerebrina* seedlings in this plot came from seeds dropped directly from this nearby mother tree. Lambers and Clark (2003) found that seed size is generally negatively correlated with seed dispersal distances but positively correlated with seedling survival. Moles and Westoby (2004) suggested that large-seeded species have higher seedling emergence rate through early seedling establishment than small-seeded species. In some tree plots clumped seedlings of *C. cerebrina* colonized the ground and shaded out many smaller seedlings (small-seeded species).

H. dulcis trees were the smallest in size and provided the smallest seedling sample plots in this study (Table 1). In all the planted plots since 1998, *H. dulcis* have been under the shade of other framework trees resulted in very small amount of seedlings beneath them.

The five selected framework species in this study are deciduous. However, their degrees of the deciduousness were different. The canopies of *M. toosendan* and *S. axillaris* were denser than *E. subumbrans* and *P. cerasoides* during the dry season in 2007 (Personal observation). The light-intensities (Lux/m^2, $n = 20$) were, however, measured during the rainy season, which were *E. subumbrans* (1295.5 ± 720.2), *P. cerasoides* (1188.9 ± 728.9), *M. toosendan* (1175.2 ± 718.2), *S. axillaris* (1014.7 ± 486.3), and *H. dulcis* (904.9 ± 535.4), respectively. The statistic differences were only detected between *E. subumbrans* and *H. dulcis* (two-tailed, *t*-test, $t = 2.290$, $df = 19$, $P \leq 0.034$), and *H. dulcis* and *M. toosendan* (two-tailed, *t*-test, $t = -2.5682$, $df = 19$, $P \leq 0.019$).

Growth rates of the seedlings depended on different conditions created by each framework tree. Different sunlight gap conditions depended on the shape of tree crowns. Lorena et al. (2005) concluded that canopy shading was the main mechanism enhancing seedling survival and affecting the growth rate of natural tree seedlings.

Physical damage of seedlings was found in many tree plots, such as *E. subumbrans* and *M. toosendan*. Most seedlings were damaged or died because of the falling tree branches. Litter accumulation in the tree plots might as well affect seedling communities. Many studies in natural forests showed that the presence of litter layer strongly influenced seedling recruitment (Dalling et al. 2002; Rebollo et al. 2001; Scariot 2000; Valio and Scarpa 2008). Based on the seedling survey, leafless or damaged seedlings were found beneath or surrounded by litter layer presented in some tree plots. However, many seedlings re-sprouted their shoots and flush their leaves again after the second monitoring in November 2006.

Seedling density and richness were positively correlated with light intensity (Fig. 2). Studies in the tropics also showed strong positive relationships with light availability (Agyeman et al. 1999; Kobe 1999; Montgomery and Chazdon 2002; Paz and Martínez-Ramos 2002; Svenning et al. 2008), with pioneer trees having a much higher growth response to light intensity than shade-tolerant species (Veenendaal et al. 1996). However, weak positive correlations between RHGR and light intensity were shown in this study. This may be the influence from competition interaction. For example, *E. subumbrans*-plots had highest light intensity due to the crown shape that allowed high levels of light and created favorable conditions for both tree seedling recruitment and herbaceous ground vegetation. This allowed the herbaceous ground vegetation to compete with tree seedlings and then affected tree seedling growth and distribution (Maguire and Forman 1983; Jensen and Meyer 2001; Rey Benayas et al. 2002).

Do high bird density, species richness and species diversity increase the natural tree seedling recruitment rate beneath framework tree species?

Crown-user bird species, e.g., many species of bulbuls (*Pycnonotus* spp.), seemed to promote seedling recruitment more than that of understorey birds, whilst the ground users had no effect on natural seedling recruitment.

The explanation of this could be fruiting phenology, which is the crucial factor influencing frugivore community (Bleher et al. 2003; Kimura 2003; Kissling et al. 2007; Noma and Yumoto 1997; Stoner and Henry 2007). The availability of fruit in the planted plots, especially for the understorey bird to feed on was low despite high diversity of bird obtained from *M. toosendan* and *S. axillaris*. Some frugivorous bird species e.g., bulbuls and white-eye have an ability to switch to an insectivorous diet when fruit production was low (Corlett 1998b; Zakaria et al. 2005).

Many frugivorous birds flew away immediately after perching on the non-fruit source trees, therefore the correlations between recruited animal-dispersed seedlings and seed-dispersing birds were low due to low probability of seed deposition under the non-fruit trees (Fig. 3). High frequency of bird visitation due to flower and fruit observed in *E. subumbrans* and *P. cerasoides* seemed to increase quantity of the seedlings in the sample plots. The fruit size of *P. cerasoides* was also important for seed dispersal. Smaller fruit with smaller seed might attract more bird species. The small-seeded tree species have a higher probability of being dispersed because they can be swallowed by birds with smaller gape widths (Datta and Rawatt 2008; Francisco et al. 2007; Neilan et al. 2006). However, this study only focus on the seedlings that growing after has been dispersed by birds or other seed dispersers. Seed traps should be a good choice to study the quantity of seed deposition in the plot (Cotrell 2004; Stevenson and Vargas 2008) by comparing the collected seed from the traps and the seedlings in plots to estimate the vegetation recovery. Combination of molecular tools, e.g., endocarp microsatellites DNA from tree seeds (Godoy and Jordano 2001) and ecological field data from the field work (Harms et al. 2000; Kollmann and Goetze 1997), can be used to find parentage relationships between the natural regenerating population in the planted sites and natural population existing in the forest.

Conclusions

Different framework tree species affected bird communities that play an important role on natural forest regeneration by dispersing seeds into the forest restoration plots by (1) flower and fruit availability of each framework tree species, which attract seed-dispersing birds by providing food resources and (2) attractiveness characteristics of the trees such as crown size, multiple branches for perching and nesting sites of birds, which enhances the seed deposition form seed-dispersing birds. Tree height, crown width and their denseness were important factors affecting seedling communities by creating suitable condition for natural-seedling recruitment. Seedling emergence, survival and growth rates depended on various conditions beneath each study trees. Some possible parameters which seemed to affect natural-seedling recruitment are light intensity, litter accumulation, physical damage of the seedling due to tree falls. However, these parameters were varied depending on each tree species

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