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Author(s)	Popradit, Ananya; Srisatit, Thares; Kiratiprayoon, Somboon; Yoshimura, Jin; Ishida, Atsushi; Shiyomi, Masae; Murayama, Takehiko; Chantaranothai, Pranom; Outtaranakorn, Somkid; Phromma, Issara
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Anthropogenic effects on a tropical forest according to the distance from human settlements

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Ananya Popradit[1], Thares Srisatit[2], Somboon Kiratiprayoon[7], Jin Yoshimura[4,5,6], Atsushi Ishida[3], Masae Shiyomi[8], Takehiko Murayama[9], Pranom Chantaranothai[10], Somkid Outtaranakorn[11] & Issara Phromma[12]

The protection of tropical forests is one of the most urgent issues in conservation biology because of the rapid deforestation that has occurred over the last 50 years. Even in protected forests, the anthropogenic effects from newly expanding villages such as harvesting of medicinal plants, pasturing cattle and forest fires can induce environmental modifications, especially on the forest floor. We evaluated the anthropogenic effects of the daily activities of neighboring residents on natural forests in 12 plots extending from the village boundary into a natural forest in Thailand. The basal area per unit land area did not present a significant trend; however, the species diversity of woody plants decreased linearly towards the village boundary, which caused a loss of individual density because of severe declines in small saplings compared with adult trees and large saplings in proximity to the village. An analysis of tree-size categories indicates a lack of small samplings near the village boundary. The current forest appears to be well protected based on the adult tree canopy, but regeneration of the present-day forests is unlikely because of the loss of seedlings.

Anthropogenic impacts and global climate change are one of the most critical issues on the conservation of forest ecosystems not only in developing countries[1] but also in developed countries[2]. The rapid population growth in developing countries has increased the demands in forest exploitation in the tropics[1]. Many people have migrated from urban areas to establish new villages in tropical forests, because of rapid population increase in cities for the last several decades[3,4]. Tropical forests have been heavily exploited by those immigrants. Urban immigrants, unlike indigenous people, have no traditional knowledge or

[1]Inter-Department of Environmental Science, Graduate School of Chulalongkorn University, Phayathai Rd. Phatumwan, Bangkok 10330, Thailand. [2]Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University, Phayathai Rd, Phatumwan, Bangkok 10330 Thailand. [3]Center for Ecological Research, Kyoto University, Otsu, Shiga 520-2113, Japan. [4]Department of Mathematical and Systems Engineering and Graduate School of Science and Technology, Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu 432-8561, Japan. [5]Marine Biosystems Research Center, Chiba University, Kamogawa 299-5502, Japan. [6]Department of Environmental and Forest Biology, State University of New York College of Environmental Science and Forestry, Syracuse, NY13210, USA. [7]Department of Environmental Science, Faculty of Science and Technology, Thammasat University, 99 Moo 18 Paholyothin Road, KlongLuang, Rangsit, Prathumthani 12121, Thailand. [8]Faculty of Science, Ibaraki University, Mito, Ibaraki 310-8512, Japan. [9]Department of Environmental Science and Technology, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, Nagatsuta, Midori-ku, Yokohama City, Kanagawa, 226-8502, Japan. [10]Department of Biology, Faculty of Science, KhonKaen University, 123 Moo 16, Mittraphap Road, Muang, KhonKaen 40002, Thailand. [11]Department of National Parks, Wildlife and Plant Conservation, 61 Pholyothin Road, Ladyao, Chatuchak, Bangkok 10900, Thailand. [12]Department of Environmental Science, Faculty of Science, KhonKaen University, 123 Moo 16, Mittraphap Road, Muang, KhonKaen 40002, Thailand. Correspondence and requests for materials should be addressed to A.P. (email: ananya-toon@hotmail.co.th) or A.I. (email: atto@ecology.kyoto-u.ac.jp)

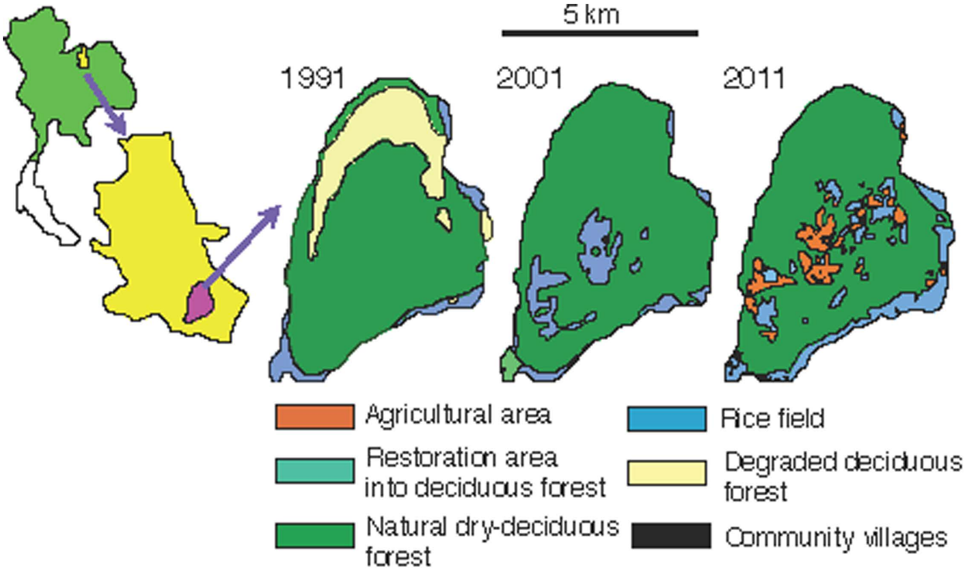

Figure 1. Temporal changes in land use in the Phu Koa (PK) area of Phu Kao–Phu Phan Kham National Park in Thailand. The changes in land use in 1991, 2001 and 2011 (from right to left) over the last 20 years in the protected area included in the study site. The area of degraded forest in 1991 had almost recovered to forests with high vegetation cover by 2001. From 2001 to 2011, the areas of rice fields decreased, but the village and agricultural areas began to expand. We make the figures based on the digital maps of land use in the Land Development Department in Thailand.

skill on the sustainable use of natural forests, causing severe damage to forest ecosystems[5,6]. The rapid expansion of these existing communities into protected areas is expected to cause severe anthropogenic degeneration and fragmentation of natural forests, further deteriorating the forest structure and biodiversity of important natural tropical forests[4,7,8]. Such anthropogenic impacts result in the degradation of ecological services received from forest ecosystems.

Protected areas in Thailand were first established approximately 50 years ago. Since then, the Thai government has tried to protect natural tropical forests, e.g., construction of network corridors[9]. Yet, the Thai government is not fully successful on the conservation efforts[10–12]. The present study site has been designated a protected area for the last 20 years (Fig. 1). There are three villages in the mixed deciduous forests (MDF) area in the Phu Kao–Phu Phan Kham National Park in Thailand. Despite its protected status, village areas have been expanded more rapidly in the last 20 years than in previous years (Fig. 1). These natural forests have high economic value from medicinal trees and as food banks. Illegal logging is strictly prohibited in the protected areas of Thailand. However, partial cutting of leaves, bark and roots of medicinal plants, and harvesting of edible fruits are still being practiced. Many studies to assay forest degradations use satellite images, because of the ease of broad surveys[13]. However, in such protected forests, anthropogenic effects are not easily detected from satellite images because of their dense canopy. Although these studies have not detected any anthropogenic impacts, continuous exploitation of medicinal and commercially valuable plants can severely affect forest ecosystems.

In Southeast Asia, MDF is a major tropical dry forest[14–16]. It experiences a distinct dry season for several months each year. Frequent forest fires happen during this dry months, killing small tree saplings. Harvesting medicinal plants and edible fruits, and pasturing cattle are also frequently conducted within the protected forests. To evaluate these anthropogenic impacts on the MDF in the national park, we analyzed the forest composition, species diversity, and natural regeneration in MDF according to the distance (200 to 2000 m) from the village boundaries.

To understand the present condition of the study forest, dominance (basal area per ha), the number of species per unit area, and some indices related to biodiversity were examined along the distance from the village boundary to the natural forests. To estimate forest regeneration and resulting future forests, the continuity from sapling to adult tree in each species was also examined. The conditions of medicinal woody plants and pioneer trees were separately analyzed, because they were suspected to be the first sign of forest damage in the current study forest. According to these variables, we can demonstrate how forest degradation worsens as the distance gets closer to the villages. Furthermore, based on species composition of adult and juvenile trees, we found out that the woody species have a high risk of disappearing in the future.

Results

Species structure and individual distribution of woody plants.

The study site exhibits a high biodiversity of woody plants (see the Methods section on the survey methods and measurements). The

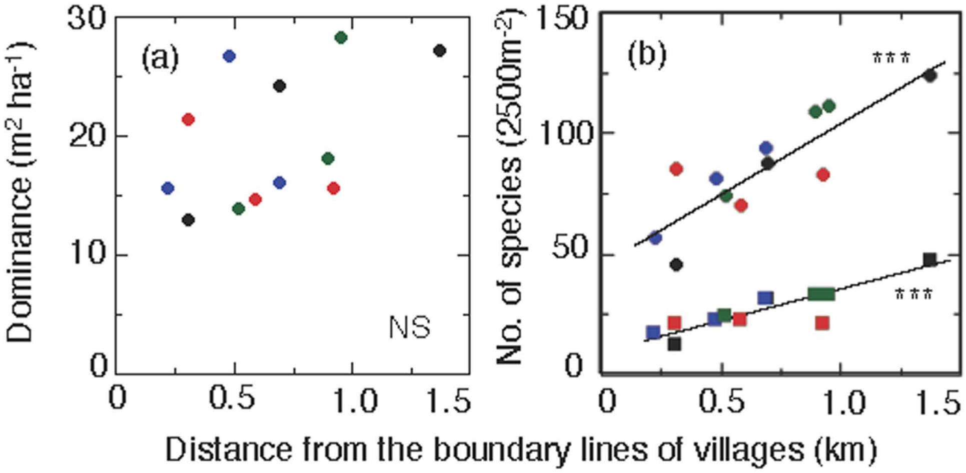

Figure 2. Relationship of dominance and the number of species according to the distance from village boundaries. (**a**) Dominance (=total basal area 1 ha^{-1}). (**b**) Numbers of species of all woody plants (circles) and medicinal plants (squares) plotted against the distance from the boundary lines of villages. The direction is indicated in plot colors for east (blue), north (black), south (red), and west (green). Statistical analyses showed that (**a**) is not significant ($r = 0.479$, NS), whereas (**b**) is significant for all woody plants ($r = 0.855$, $P < 0.001$) and for all medicinal plants ($r = 0.868$, $P < 0.001$). See Supplementary Fig. 2 and Supplementary Table 5 for more details on the plot positions.

total number of individual woody plants was 4211 in the entire research area (3 ha), and there were 148 species within 65 families (Table S1). Out of 148 tree species, 88 were medicinal species and 9 were pioneer species (Table S2). The mean density was 1,416 individuals ha^{-1}, and the mean total basal area was 20 m^2 ha^{-1}. We calculated the important values (IVs) in each species in each plot (2500 m^2 in land area). IV in a species is the sum of the relative frequency (*F*: percentage of the number of species to the total species), the relative individual density (*D*: percentage of the number of individuals in each species to the total number of individuals), and the relative basal area (*BA*: percentage of the basal area covered by a species to the total basal area) (see Equation (1) in Methods)[17]. Throughout the plots, 23 woody plant species were observed with high important values (IV > 11) and recognized as predominant tree species (Fig. S1 and Table S3). Based on the variation of Morisita's dispersion index (I_δ), all of the predominant tree species exhibited a clumped distribution ($I_\delta > 1$; Table S4), meaning that the distance between neighboring individuals was minimized for each species[18]. No obvious trend was observed in the spatial pattern of the predominant tree species with high IV values along with distance from the boundary lines (Figs S1 and S2).

The total basal area per a unit land area is an indicator of tree dominance in survey plots because it correlates with the maturity of forests. In this survey, a significant trend in total basal area per ha (Dominance) with distance from the village boundaries to the natural forests was not observed (Fig. 2a). However, the tree species composition was significantly different depending on the distance from the village boundaries. The numbers of total woody plant species and medicinal tree species significantly ($P < 0.001$) increased linearly with the distance from the village boundaries toward the forest (Fig. 2b). However, no significant trend was found between the number of pioneer tree species and the distance; the average number of pioneer tree species per 2500 m^2 in land area was 5.4 (Fig. S3).

To evaluate the contribution of these functional types (medicinal and pioneer trees) on the community structure of woody vegetation, their IV and its determinants (*F*, *D* and *BA*) in each plot were calculated (Fig. 3). The IV of medicinal trees increased significantly ($P < 0.01$) and that of pioneer trees decreased significantly ($P < 0.05$) with the distance from the village boundaries toward the forest. In the medicinal trees, an increase in all *F*, *D* and *BA* (i.e. relative number of species, relative number of individuals and relative basal area, respectively) contributed to the increase in IV. In the pioneer trees, a decrease in only *F* (i.e. relative number of species) contributed to the decrease in IV.

Species diversity and anthropogenic impact. To examine the variations of biodiversity in woody plants among the plots, the Shannon–Wiener Index (H'), Fisher's index (α), and Simpson's index (λ) were calculated for each plot (Fig. 4 and Supplementary Table 4). The values of H' increased significantly with distance from the boundary lines ($P < 0.01$ in overall; Fig. 4a). Here, all of the examined plots showed high H' values (>3.87) (see Table S5), indicating that high biodiversity still remains in the study area compared with the usual range of H' values in natural forests (between 1.5 and 3.5 and rarely surpassing 4.5)[19,20]. Fisher's α also increased significantly with distance from the boundary lines ($P < 0.01$ in overall; Fig. 4b). As expected, H' was positively ($p = 0.0001$) correlated to Fisher's α. Simpson's index

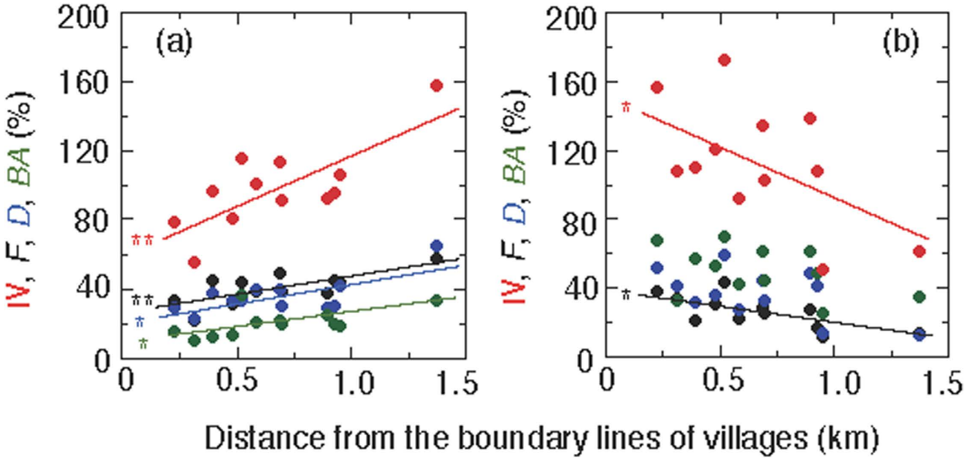

Figure 3. Relationship important value (IV) and its determinants (*F*: relative frequency, *D*: relative individual density, *BA*: relative basal area) to the distance from village boundaries. (**a**) medicinal tree species, (**b**) pioneer tree species. IV: red circles, *F*: black circles, *D*: blue circles, *BA*: green circles. See equation (1) for calculation and parameters (**$P < 0.01$, *$P < 0.05$).

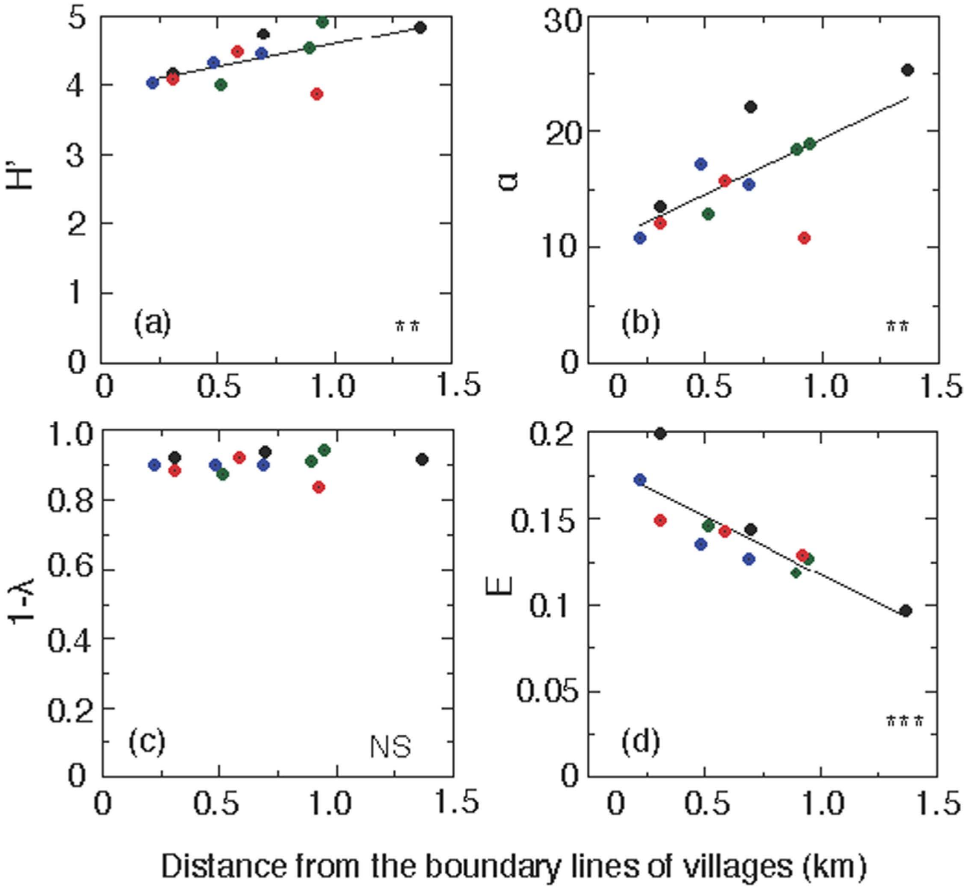

Figure 4. Three biodiversity indices and an evenness index plotted against the distance from village boundaries. (**a**) Shannon–Wiener H' ($\Sigma P_i \bullet \ln P_i$), (**b**) Fisher's α ($S/\ln[1 + N/\alpha]$), (**c**) 1-Simpson's λ ($1 - \Sigma P_i^2$), and (**d**) Hill's evenness ($(1/\lambda)/e^{H'}$) plotted against the distance from the boundary lines of the village. H', $1 - \lambda$, and α describe the overall species diversity, and E indicates the distribution pattern of all individual trees in each plot to the east (blue circles), north (black circles), south (red circles), and west (green circles) directions from the village into the forests. Statistical results are as follows: (**a**) ($r = 0.627$, $P < 0.01$), (**b**) ($r = 0.702$, $P < 0.01$), (**c**) ($r = 0.127$, not significant), and (**d**) ($r = 0.851$, $P < 0.001$).

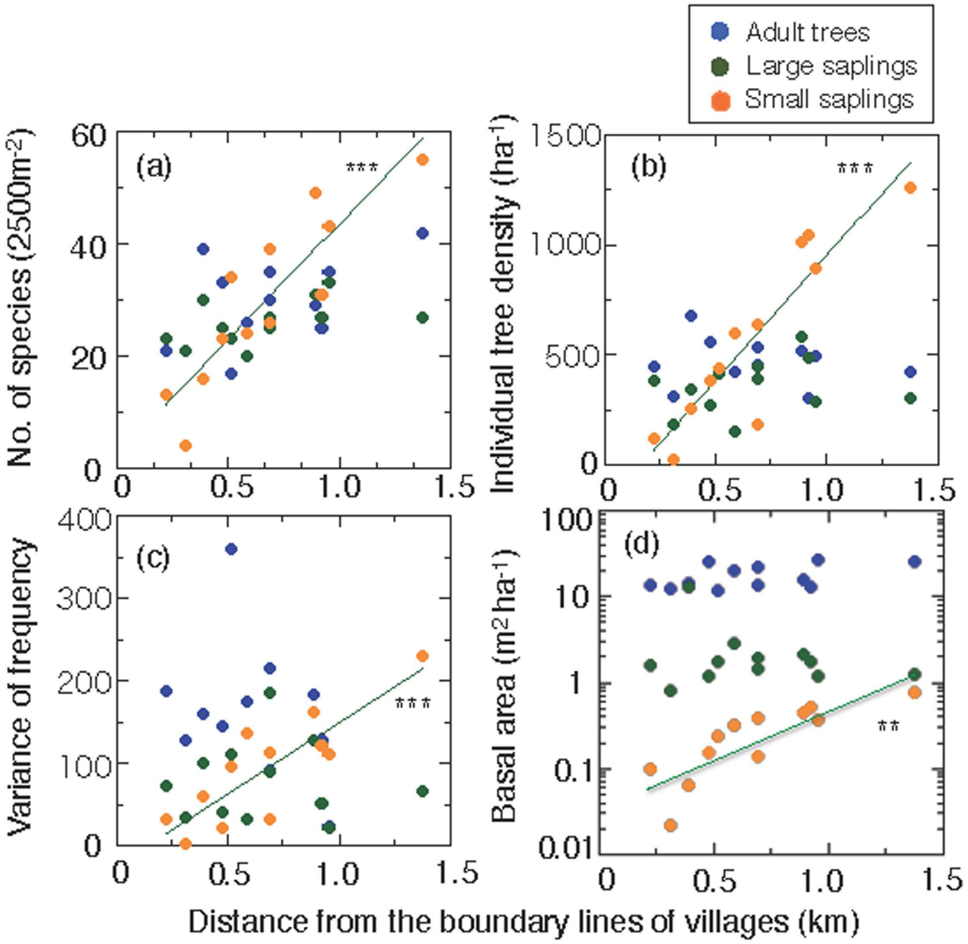

Figure 5. Number of tree species and other characteristics according to distance from village boundaries for three tree-size classes: adult trees, large saplings and small saplings. (**a**) Number of woody plant species, (**b**) density of individual woody plants, (**c**) variance of frequency, and (**d**) total basal area per unit land area, plotted against the distance from the boundary lines of village for adult trees (DBH $\geq$ 45 mm, blue circles), large saplings (DBH 20 mm $\leq$ DBH $<$ 45 mm, green circles), and small saplings (DBH $<$ 20 mm, orange circles). For all variables, significant correlations were only found for small saplings: ((**a**) $r = 0.886$, $P < 0.001$), ((**b**) $r = 0.915$, $P < 0.001$), ((**c**) $r = 0.845$, $P < 0.001$), and ((**d**) $r = 0.821$, $P < 0.01$). The variance of frequency indicates the distribution pattern of tree species within a plot; high values indicate that the distribution of all species in the plot differ from each other, whereas low values indicate that all species have a similar pattern of distribution.

(λ) is another measurement of biodiversity ranging between 0 (highest diversity) and 1 (no diversity). The values of $(1-\lambda)$ were similar or all plots (closed to 0); thus biodiversity was observed in all plots, and a trend along with distance from the villages was not observed (Fig. 4c). Significant differences were not observed in the values of $(1-\lambda)$ among all twelve plots (analysis of variance (ANOVA), $P = 0.69$). Note that the southern direction exhibits anomalies in all three biodiversity indices, and the intermediate plots exhibit a peak value.

To evaluate the distribution patterns of individual trees, we examined the evenness index (E), which decreased significantly with distance from the boundary lines ($P < 0.001$ in overall), indicating that the individual trees of all species tend to be regularly distributed in the plots close to the villages compared with remote plots.

Forest regeneration. Sapling trees on the forest floor are an important determinant of forest regeneration. In each plot, we surveyed individual trees and categorized them into three size classes: (1) adult trees (diameter of breast height (DBH) $\geq$ 45 mm), (2) large saplings (20 mm $\leq$ DBH $<$ 45 mm), and (3) small saplings (10 mm $\leq$ DBH $<$ 20 mm). For the adult trees and large saplings, the number of species, density of individual trees, variance of frequency, and log total basal area per unit land area were not correlated with distance from the villages (Fig. 5). This indicates that the prohibition law against tree logging has been enforced well in the protected area for the last 20 years. However, for the small saplings,

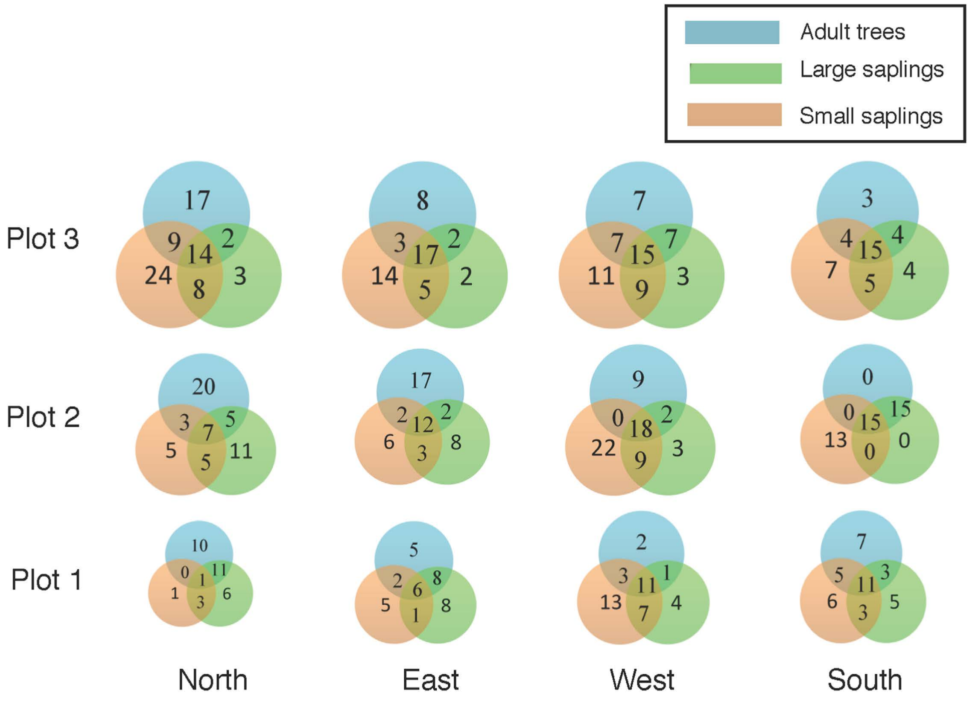

Figure 6. Euler diagram for the number of species in tree size categories (adult tree, large sapling, small sapling) with their overlaps. The area of each circle is dependent on the number of species. North, East, West, and South are the directions from the village boundary lines into the forest. Plot 1 is the nearest site to the villages, Plot 3 is the farthest site from the villages, and Plot 2 is an intermediate distance.

these values increased significantly with distance ($P < 0.001$ for number of species, density of individual trees, and variance of frequency; and $P < 0.01$ for log total basal area). In close proximity to the villages, the individual density of small saplings was very low ($0.24\,\mathrm{m}^{-2}$ and $1.2\,\mathrm{m}^{-2}$ in Plot N1 and E1, respectively; see Fig. S2 and Table S5 for plot locations), indicating a scant forest understory. In addition, the percentage of small saplings to the number of total individual trees was 6.7% (Plot N1) and 17.3% (Plot E1), indicating a shortage of juvenile trees in these plots.

The successful regeneration of a tree species should depend on whether there are enough number of individuals found in each size class from small saplings to adult trees. To estimate the future progression of forest regeneration, the number of tree species in each size class and overlapped size-classes for each plot are shown using an Euler diagram (Fig. 6). In the diagram, the overlap in numbers of species of different sizes provides a good estimate of regeneration success. If the number of overlapping species among all size classes is high, natural regeneration is expected to be successful (Plots N3, E3, W2, W3, S2 and S3, which are remote from the villages). However, if the number of overlapping species among all size classes is low, then future regeneration of adult trees might be disturbed, and result in the drastic changes to the composition of canopy-tree species (Plots N1 and E1, which are close to villages). Furthermore, if the numbers of overlapping species between large and small saplings are also low, forest regeneration might fail over time (Plots N1 and E1).

In some tree species, individuals were found in all size classes indicating successful regeneration in future. For example, in all directions, *Xylia xylocarpa*, *Bauhinia saccocalyx, Pterocarpus marcocarpus,* and *Cananga odorata* had enough individual trees in all size classes in all plots. In contrast, some tree species were found only in the adult-tree class, indicating that these species are likely to disappear in future, e.g., *Calycopteris floribunda* (IV = 0.82) in Plot N1, *Sauropus androgynus* (IV = 0.46) in Plot N2, *Dialium cochinchinense* (IV = 0.4) and *Excoecaria oppositifolia* (IV = 0.51) in Plot N3, and *Dalbergia* sp. (IV = 0.82) in Plot S1, which are all non-predominant species. Trees species that were only observed in the large sapling class in a plot might also be under the risk of extinction, including *Anthocephalus chinensis* (IV = 0.27) in Plot N3, *Gmelina philippensis* (IV = 0.19) in Plot W2, and *Dalbergia cochinchinensis* in Plot N3, W1, and W2. All these species except for *D. cochinchinense* are medicinal woody plants.

Discussion

The current study shows conflicting results. First, there are little or no apparent anthropogenic effects in terms of total basal area, Simpson's index (λ), and numbers and density of adult trees and large saplings (Figs 2a, 3c and 4). This finding may suggest that the study forest is fairly well maintained irrespective of distance from the villages. However, with respect to the future regeneration of the forest, a drastic effect was observed on the recruitment of trees in the studied forest (Figs 5 and 6). The species compositions within size classes exhibited a failure to regenerations for a number of species in close proximity to the villages (Fig. 6). These tree species are likely to be degraded by anthropogenic effects in the future because of a lack of saplings in close proximity to the villages.

Four major human-induced factors with significant effects on the biodiversity of tropical have been proposed: 1) deforestation and fragmentation, 2) over-exploitation, 3) invasive species, and 4) climate change[21,22]. Excessive land use by local residents will promote deforestation and forest fragmentation, including edge effects of forests[23]. Harvesting medicinal plants and edible fruits, trampling forest soil, and grazing by domestic animals (mostly cattle in Thailand) can reduce the seedling stock on the forest floor[24]. Forest fires usually occur during the dry season, killing tree saplings. All of these human activities may prevent seedling recruitment by altering the microhabitat of the forest floor and soil conditions, e.g., increasing dry conditions and destroying soil fauna, including mycorrhizal fungi. Furthermore, environmental changes at the forest floor, such as increasing solar exposure and decreasing CO_2 concentrations will cause a reduction in carbon gain and result in degradation of the biodiversity of understory plants and tree seedlings[25]. Although illegal logging of large trees are well prohibited, such anthropogenic disturbances to the forest floor and soil conditions are still critical factors that affect seedling recruitment and subsequent forest regeneration. Here IV and their determinants (F, D and BA) of medicinal trees decreased (Fig. 3a), and IV and F of pioneer trees increased (Fig. 3b) near the villages.

Our results indicate that adequate forest regeneration is relatively difficult in close proximity to villages. In addition, human access will be an important determinant of anthropogenic effects. Such conditions may be reflected in plots W1 and W2, where the access is limited by high elevation and steep slopes, thus, allowing the maintenance of a high numbers of species of all tree-size categories of individual trees (Fig. 6). Forest regeneration may be also affected by the interference in seedling recruitment via indirect effects of proximity to human residence. For example, wildlife may avoid human villages and their immediate proximity. As a result, seed dispersal via these animals may become extremely difficult. Such avoidance is observed in elephants[26,27] and a number of other many animal species[28,29].

The present survey was highly limited, investigated relatively small plot size, and only included twelve plots. Therefore, we might not have detected distance effects on dominance (total basal area per 1 ha) (Fig. 2a). By increasing the plot size, for example, we may observe a significant correlation with distance because a slight increase in dominance was found near the villages. The distance from the village boundaries was not evenly placed. Because of this imbalance in plot locations, the detectability of distance effects was greatly reduced. In the mountain this unevenness in plot locations is unavoidable because of geographical constraints and heterogeneity of the target natural forests (MDF) in the study area. Even with these severe limitations, effects are still observed on small saplings and tree species diversity, which suggests that the factors related to small saplings are important for the regeneration and sustainability of tropical forests. The present study illustrates the importance of evaluating the effects of human activities on natural forests in protected areas, where the forest cover does not exhibit any anthropogenic damages.

Methods

Study site and plot setting. The current vegetation survey was conduced in an MDF in the Phu Koa (PK) area of Phu Kao–Phu Phan Kham National Park, and the study site covered 318.4 km^2 and lies between 16°44′–17°2′N and 102°25′–102°43′E on the Khorat plateau, Thailand (Fig. 1). The average monthly precipitation during the dry season (November to April) was 40.5 mm from 1982 to 2013. The PK area is located on the upper northeastern plateau of the park, and the vegetation consists mainly of MDF, but dry dipterocarp forests and dry evergreen forests partially exist. MDFs have a high biodiversity of woody plants adapted to seasonal drought[14,15], and almost all of the trees are dry-deciduous, which have a period of leaf falling during the dry season[30–33]. Although the area of the park once was 19.7 km^2 (5.9% in forest area), only 3.1 km^2 (0.9% in forest area) of intact MDF remained in 2012[34].

The PK is shaped like a frying pan with a large plain in its center (Fig. S2). This area is suspected to overlie an extinct volcano that was active several million years ago. The Royal Forestry Department (RFD) and Department of National Park, Wildlife and Plant Conservation (DNP) in Thailand have set the boundary lines of the protected area within the forests. Here, we investigated the effects of village communities and activities of inhabitants on the species composition, species diversity and natural regeneration of woody plants in protected MDF forests.

Three villages are located in the center of the PK. Using a Global Positioning System (GPS; Garmin 60Csx, Garmin, Olathe, KS, USA) and a topographic map, we established the study plots in all four cardinal directions (almost north, west, south, and east) from the village boundary lines into the forests (Fig. S3). In each direction in the MDF, we established three plots (50 m × 50 m, called as L-quadrat) along a transect line, as follows: plots adjacent to village boundaries (Plot 1), plots far from village boundaries (Plot 3), and plots intermediate between the plots (Plot 2). In total, twelve plots were established (three plots in each direction). The range of elevation among the set plots was 235 m to 364 m a.s.l. The straight-line distance from the boundary lines in each plot was derived with ArcGIS 10.2.2 (Environmental Systems Research Institute Inc., Redlands, CA, USA). Detailed information on the position of each plot is shown in Supplementary Fig. 2 and Supplementary Table 5.

Data collection. Data collection was conducted from November 2013 to February 2014. We established 12 plots with a 50 m × 50 m quadrat (see Supplementary Fig. 2), with a total area of 3 ha. The survey area (3 ha) is sufficient to produce the species-area curve of this MDF[17]. Each large quadrat (50 m × 50 m, L-quadrat) was further divided into 25 sub-quadrats (S-quadrat) of 10 m × 10 m. All woody plants of 10 mm DBH (1.3 m above ground) in each plot were tagged and mapped to the nearest 10 m grid following a standard protocol[35]. In the MDF, frequent wildfires kill many seedlings and saplings that are less than 10 mm DBH during the dry season[36–38]. Therefore, we assumed that only trees and saplings with $\geq$10 mm DBH can survive a forest fire. We divided the examined individuals into three size categories: (1) adult trees (DBH $\geq$ 45 mm), (2) large-size saplings (20 mm $\leq$ DBH $<$ 45 mm) and (3) small-size saplings (10 mm $\leq$ DBH $<$ 20 mm).

Data analyses in forest structure and biodiversity. To evaluate the contribution of tree species to the forest structure and biomass of the MDF, we calculated IV (importance value) for each species[5,33,36]. The IV (importance value) for a species is the sum of the relative frequency (*F*; number of occurrences of the species as a percentage of the total number of occurrences of all species in each L-quadrat), relative density (*D*; number of individuals of a species as a percentage of the total number of individuals of all species in each L-quadrat) and relative dominance (*BA*; total basal area of all trees of one species as a percentage of the total basal area of all species in a plot)[17] as follows:

$$\mathrm{IV} = (F + D + BA) \tag{1}$$

where the maximum values of *F*, *D* and *BA* are 100, respectively. The values of IV were calculated for all woody plants and two functional types (medicinal and pioneer trees) in each plot (see Fig. 3 and Table S2).

The spatial pattern of individuals of the 23 predominant tree species is described using Morisita's I_δ index in dispersion[39] as follows:

$$I_\delta = q\frac{\sum x_i(x_i - 1)}{N\,(N - 1)} \tag{2}$$

where q is the total number of plots (L-quadrat), N is the total number of individuals in each species in all L-quadrats, and x is the number of individuals of one species in a single plot. Morisita's I_δ index is independent of sample size and diversity[40].

The community coefficient for the Bray–Curtis Index (BCI) was used to examine the similarity between plots[41]. Similarity (S_{ik}) between plots j and k can be expressed as follows:

$$s_{ik} = \frac{100\sum_i^p 2min\,(y_{ij},\ y_{ik})}{\sum_i^p \left(y_{ij} + y_{ik}\right)} \tag{3}$$

where y_{ij} and y_{ik} represent measures of species i in the sample plot j and k, and min (y_{ij}, y_{ik}) is the minimum of y_{ij} and y_{ik} and p is the number of species. In S_{ik}, Bray and Curtis further simplified this equation based on the species composition and calculated the percentage of similarity, %*S* (A, B), between plots A and B[42] as follows:

$$\%S\ (A, B) = \frac{2W}{A + B} \times 100 \tag{4}$$

where *W* is the sum of the minimum of IV between plot A and B for each species. The value of A+B represents the sum of *D*, *BA* and *F*; the value is 600 in this study. To compare the percentages of similarity in the forest community between plots, a matrix representing the %*S* and the percent dissimilarity (%DS = 100 − %*S*) between the paired plots is shown in Table S6.

To examine the species diversity of woody plants in each plot, we used the Shannon–Wiener Index ($H' = \Sigma P_i \times \ln P_i$)[41], where P_i is the value of n_i (number of individuals in species i)/N (total number of individuals in all species). H' is a measure of overall biodiversity and maximized when all species have the same number of individuals. This index assumes that individuals are randomly sampled from an infinite population. Simpson's index[43] is computed as $\lambda = \Sigma P_i^2$. Fisher's index α is defined by $S = \alpha\ \ln(1 + N/\alpha)$[44], where N is the total number of individuals in all species and S is the number of species in each L-quadrat. These parameters are measures used to clarify the diversity of tree species by distance from the boundary lines.

To measure the distribution pattern of all individual trees in each plot, the evenness index of the community (*E*) was calculated following the method of Hill (1973)[45]. The values of *E* represent a coherent system for biodiversity that includes the Shannon-Wiener index and Simpson index as follows:

$$E = \exp\left(\frac{1/\lambda}{H'}\right) \tag{5}$$

The value of *E* is a useful in determining the evenness of species structures among the plots[46].

References

1. FAO, *FAO Statistical Databases* (Food and Agriculture Organization, Rome, Italy, 2005).
2. Nowacki, G. J. & Abrams M. D. Is climate an important driver of post-European vegetation change in the Eastern United States? *Global Change Biol.* **21,** 314–334 (2015).
3. Olupot, W., Barigyira, R. & Chapman, C. A. The status of anthropogenic threat at the people-park interface of Bwindi Impenetrable National Park, Uganda. *Environ. Conserv.* **36,** 41–50 (2009).
4. Mackenzie, C. A., Chapman, C. A. & Sengupta, R. Spatial patterns of illegal resource extraction in Kibale National Park, Uganda. *Environ. Conserv.* **39,** 38–50 (2012).
5. Sassen, M. & Sheil, D. Human impacts on forest structure and species richness on the edges of a protected mountain forest in Uganda. *Forest Ecol. Manag.* **307,** 206–218 (2013).
6. Hunter, P. The human impact on biological diversity. *EMBO reports* **8,** 316–318 (2007).
7. Fashing, P. J., Forrestel, A., Scully, C. & Cords, M. Long-term tree population dynamics and their implications for the conservation of the Kakamega Forest, Kenya. *Biodivers. Conserv.* **13,** 753–771 (2004).
8. Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D. & Ramankutty, N. Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecol. Biogeogr.* **19,** 589–606 (2010).
9. Santisuk, T. *et al. Plants for our Future: Botanical Research and Conservation Needs in Thailand*. (Royal Forest Department, Bangkon, Thailand, 1991).
10. Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. & Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **403,** 853–858 (2000).
11. Stibig, H. J. *et al.* A land-cover map for South and Southeast Asia derived from SPOT-VEGETATION data. *J. Biogeogr.* **34,** 625–637 (2007).
12. Bajracharya, S. B., Gurung, G. B. & Basnet, K. Learning from community participation in conservation area management. *J Forest Livelihood* **6,** 54–66 (2007).
13. Trisurat, Y. Applying gap analysis and a comparison index to evaluate protected areas in Thailand. *Environ. Manage.* **39,** 235–245 (2007).
14. Ishida, A. *et al.* Contrasting seasonal leaf habits of canopy trees between tropical dry-deciduous and evergreen forests in Thailand. *Tree Physiol.* **26,** 643–656 (2006).
15. Ishida, A. *et al.* Seasonal variations of gas exchange and water relations in deciduous and evergreen trees in monsoonal dry forests of Thailand. *Tree Physiol.* **30,** 935–945 (2010).
16. Ishida, A. *et al.* Photoprotection of evergreen and drought-deciduous tree leaves to overcome the dry season in monsoonal tropical dry forests in Thailand. *Tree Physiol.* **34,** 15–28 (2014).
17. Curtis, J. T. & McIntosh, R. P. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* **32,** 476–496 (1951).
18. Vaughan, I. & Ormerod, S. The continuing challenges of testing species distribution models. *J. Appl. Ecol.* **42,** 720–730 (2005).
19. Magurran, A. E. *Ecological Diversity and its Measurement* (Princeton University Press, Princeton, NJ, USA, 1988).
20. Magurran, A. E. *Measuring Biological Diversity* (Blackwell, Oxford, UK, 2004).
21. Morris, R. J., Lewis, O. T. & Godfray, H. C. J. Experimental evidence for apparent competition in a tropical forest food web. *Nature* **428,** 310–313 (2004).
22. Sala, O. E. *et al.* Global biodiversity scenarios for the year 2100. *Science* **287,** 1770–1774 (2000).
23. Ewers, R. M. & Didham, R. K. Confounding factors in the detection of species responses to habitat fragmentation. *Biol. Rev.* **81,** 117–142 (2006).
24. Motta, R. Impact of wild ungulates on forest regeneration and tree composition of mountain forests in the Western Italian Alps. *Forest Ecol. Manag.* **88,** 93–98 (1996).
25. Ishida *et al.* Effective use of high CO_2 efflux at the soil surface in a tropical understory plant. *Sci. Rep.* **5,** 8991 (2015)
26. Blake, S., Deem, S. L., Mossimbo, E., Maisels, F. & Walsh, P. Forest elephants: Tree planters of the Congo. *Biotropica* **41,** 459–468 (2009).
27. Vanleeuwé, H. & Gautier-Hion, A. Forest elephant paths and movements at the Odzala National Park, Congo: The role of clearings and Marantaceae forests. *Afr. J. Ecol.* **36,** 174–182 (1998).
28. Worton, B. J. A review of models of home range for animal movement. *Ecol. Mod*. **38,** 277–298 (1987).
29. Nakicenovic, N. & Swart, R. *Emissions Scenarios* (Cambridge University Press, Cambridge, UK, 2000).
30. Bunyavejchewin, S. Analysis of the tropical dry deciduous forest of Thailand: I. Characteristics of the dominance-types. *Nat. Hist. Bull. Siam Soc*. **31,** 109–122 (1983).
31. Ashton, P. Toward a regional classification of the humid tropics of Asia. *Tropics* **1,** 1–12 (1991).
32. Blasco, F., Bellan, M. & Aizpuru, M. A vegetation map of tropical continental Asia at scale 1: 5 million. *J. Veg. Sci.* **7,** 623–634 (1996).
33. Marod, D., Kutintara, U., Yarwudhi, C., Tanaka, H. & Nakashisuka, T. Structural dynamics of a natural mixed deciduous forest in western Thailand. *J. Veg. Sci.* **10,** 777–786 (1999).
34. DNP, DNP *Statistic data* (Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand, 2012).
35. Manokaran, N. *et al. Methodology for the fifty hectare research plot at Pasoh Forest Reserve*. (Research Pamphlet, Forest Research Institute Malaysia, Kuala Lumpur, Malaysia, 1990).
36. Bunyavejchewin, S. *et al.* Spatial distribution patterns of the dominant canopy dipterocarp species in a seasonal dry evergreen forest in western Thailand. *Forest Ecol. Manag.* **175,** 87–101 (2003).
37. Marod, D., Kutintara, U., Tanaka, H. & Nakashizuka, T. The effects of drought and fire on seed and seedling dynamics in a tropical seasonal forest in Thailand. *Plant Ecol.* **161,** 41–57 (2002).
38. ICEM, *Thailand National Report on Protected Areas and Developmen. Review of Protected Areas and Development in the Lower Mekong River Region.* (International Center for Environmental Management, Indooroopilly, Queensand, Australia, 2003).
39. Morisita, M. Measuring of the dispersion of individuals and analysis of the distributional patterns. *Mem. Fac. Sci. Kyushu Univ. Ser. E* **2,** 5–235 (1959).
40. Wolda, H. Similarity indices, sample size and diversity. *Oecologia* **50,** 296–302 (1981).
41. Bray, J. R. & Curtis, J. T. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.* **27,** 325–349 (1957).
42. Shannon, C. E. A. Mathematical theory of communication. *ACM SIGMOBILE.* **5,** 3–55 (2001).
43. Simpson, E. H. Measurement of diversity. *Nature* **163,** 688 (1949).
44. Fisher, I. The making of Index Mumbers: A Study of their Varieties, *Tests, and Reliability*. (Houghton Mifflin Company, Boston and New York, USA, 1922).
45. Hill, M. The intensity of spatial pattern in plant communities. *J Ecol.* **54,** 225–235 (1973).
46. Carlo H.R. HEḶP, P. M. J. H. K. S. Indices of diversity and evenness. *Oceanis* **24,** 27 (1998).

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Author Contributions

A.P., T.S., P.C., S.K. and S.O. set and designed this study. A.P., T.M. and I.P. carried out the field measurements and analyzed the obtained data. M.S. supported statistical analysis. A.P., J.Y. and A.I. wrote the manuscript.

Additional Information

Supplementary information accompanies this paper at http://www.nature.com/srep

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Supplementary information

Title: Anthropogenic effects on a tropical forest according to the distance from human settlements

Authors: Ananya Popradit, Thares Srisatit, Somboon Kiratiprayoon, Jin Yoshimura, Atsushi Ishida, Masae Shiyomi, Takehiko Murayama, Pranom Chantaranothai, Somkid Outtaranakorn and Issara Phromma

Detailed site descriptions and results

Specific situation in forest protection in Thailand and South-east Asia

Currently, the forest damage due to human impacts and global climate change has been obvious in the world including developed and developing countries[1,2]. In Thailand, the annual rate of forest loss in 1995 was ranked in the top ten of tropical countries in the world[3]. To conserve natural forests, protected areas in Thailand were first established approximately 50 years ago. Thai government has identified a serious deterioration in the ecological service received from natural forests[4,5,6]. Therefore, Thai government has designed a new policy to prevent further deforestation and increase the area of forest cover and it has established network corridors of protected areas in addition to commencing reforestation[7]. However, human colonization of natural forests from urban areas continues because forests have high economic value in medicinal trees and as a food bank. These new inhabitants have almost no enough knowledge about the nature of these forests and lack a specific skill for sustainable resource use of the forests. Because of this, the degeneration of the important natural tropical forests have been continued in South-east Asia[2]. Therefore, clarifying the human impacts on natural forests is an urgent issue for the protection of the tropical forests in South-east Asia.

Study site and plot setting

The current vegetation survey was conducted out in the Phu Koa (PK) area of Phu Kao–Phu Phan Kham National Park (Fig. 1), which is one of o 127 national parks in Thailand. The national park covers 318.4 km^2 and lies between 16°44′–17°2′N and 102°25′–102°43′E in Nong Bua Lamphu Province, south of Udon Thani Province and north of Khon Kaen Province on the Khorat plateau, Thailand. The PK area is located in the park’s upper northeastern plateau.

The vegetation largely consists of mixed deciduous forests (MDF) along with dry dipterocarp forests and dry evergreen forests. Almost all of the trees of the MDF are dry-deciduous trees that experience an off-leaf period during the dry season[8-12]. Although the area of the park was once 19.7 km^2 (5.9% in forest area), only 3.07 km^2 (0.91% in forest area) of intact MDF remained in the national park in 2012[5]. The government of Thailand designated this national park as its 50th national park on September 20, 1985, which was partially to stop the severe degradation of this area caused by an increase in human activity over the preceding 20 years[13]. The Phu Koa Mountain Range consists of two parallel lines of mountains. The outer line is steeper and higher and ranges from 447 m to 580 m a.s.l., whereas the inner line is lower, 313 m to 380 m a.s.l (Fig. S2).

The PK is shaped like a frying pan and has a large plain in its center (Figs. 1 and S2). This area is suspected to overlie an extinct volcano that was active several million years ago. Based on the stratigraphic sequences and fossil correlation, two assemblages of trigoniodid bivalves are indicators of non-marine cretaceous bivalves that once inhabited the area. These two assemblages have been found in the PK and the Khorat Plateau[14].

The Royal Forestry Department (RFD) and Department of National Park wildlife and Plant Conservation (DNP) in Thailand had attempted to expel village inhabitants from this protected forest. However, several conflicts have occurred, and the RFD and DNP have been unable to expel the inhabitants. After these disputes, the RFD and DNP enacted the boundary lines for protected area within forest. Here, we investigated how the village communities and their activities affect the species composition, species diversity, and natural regeneration of woody plants in the protected area of the MDF.

Three villages (Dong Bak, Wang Mon, and Chai Mongkala) are located in the center of the PK. Using a GPS (Garmin 60Csx) and a topographic map, we established the study plots in all four cardinal directions from the village boundary lines towards the forest (Fig. S2, Table S1). In each direction, we established three plots along a transect line from the village boundary towards the forest. Three plots are located as follows: (1) adjacent to village boundaries, (2) far from village boundaries, and (3) intermediate between the plots. The locations of each plot were slightly adjusted, so that all plots were located only in the MDF. We attempted to space the three plots evenly along each transect (direction), but certain plots were moved intentionally along or away from the transect line until we found an area within the MDF. In total, twelve plots were established (three plots in each direction for the four cardinal directions). The range of elevation among the plots was 235 m to 364 m a.s.l. (Table S1). The straight line from the boundary lines in each plot was derived using a GIS (ArcGIS 10.2.2, Environmental Systems Research Institute).

Statistical treatments

To examine the effects of distant on the forest structure, a linear regression analysis was used (Figs. 2, 3, 4 and 5 in the main text), and statistical significance was determined with the Pearson product-moment correlation coefficient ($p < 0.05$). The statistical treatments were conducted with MINITAB (ver. 17, Kozo Keikaku Engineering Inc., Tokyo, Japan) and R (ver. 3.02, R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org).

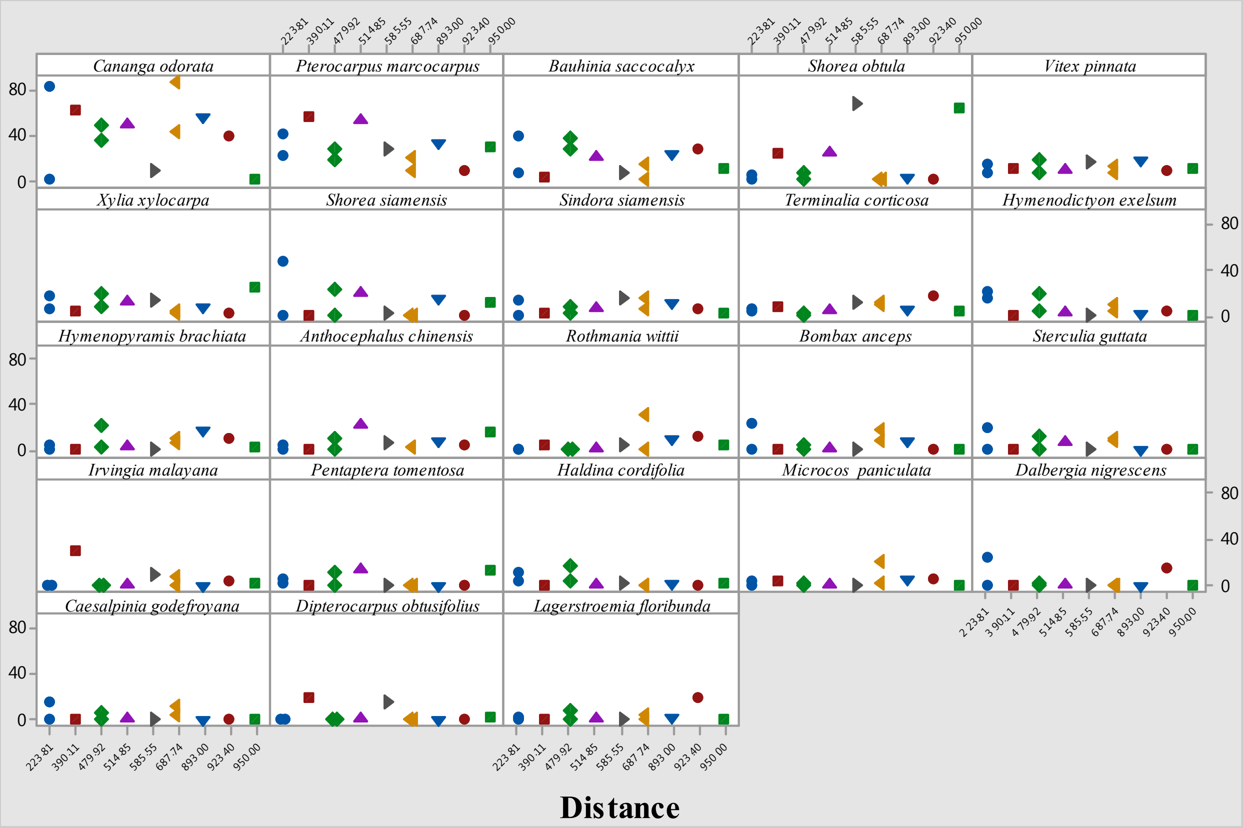

Figure S1 Importance Value (IV) of the 23 predominant tree species in each plot. The IVs in the predominant tree species (IV > 11) in each plot plotted against the distance from the villages boundary to the forest, where IV = D (density) + F (frequency) + BA (basal area). Here, predominant tree species are defined as the primary or secondary dominant species (highest and second highest IV, respectively) in each plot. From left to right and top to bottom, *Cananga odorata* (Annonaceae), *Pterocarpus marcocarpus* (Fabaceae), *Bauhinia saccocalyx* (Fabaceae), *Shorea obtula* (Dipterocarpaceae), *Vitex pinnata* (Verbenaceae), *Xylia xylocarpa* var. *kerrii* (Leguminosae-Mimosoideae), *Shorea siamensis* (Dipterocarpaceae), *Sindora siamensis* (Caesalpiniaceae), *Terminalia corticosa* (Combretaceae), *Hymenodictyon excelsum* (Rubiaceae), *Hymenopyram brachiata* (Lamiaceae), *Anthocephalus chinensis* (Rubiaceae), *Rothmania witti* (Rubiaceae), *Bombax anceps* (Bombacaceae), and *Sterculia guttata* (Sterculiaceae), *Irvingia malayana* (Irvingiaceae), *Pentapterato mentosa* (Combretaceae), *Haldina cordifolia* (Rubiaceae), *Microcos paniculata* (Tiliaceae), and *Dalbergia nigrescens* (papilinoideae), *Casalpiniago defroyana* (Leguminosae), *Dipterocarpus obtusifolius* (Dipterocarpaceae), and *Lagerstoemia floribunda* (Lythraceae).

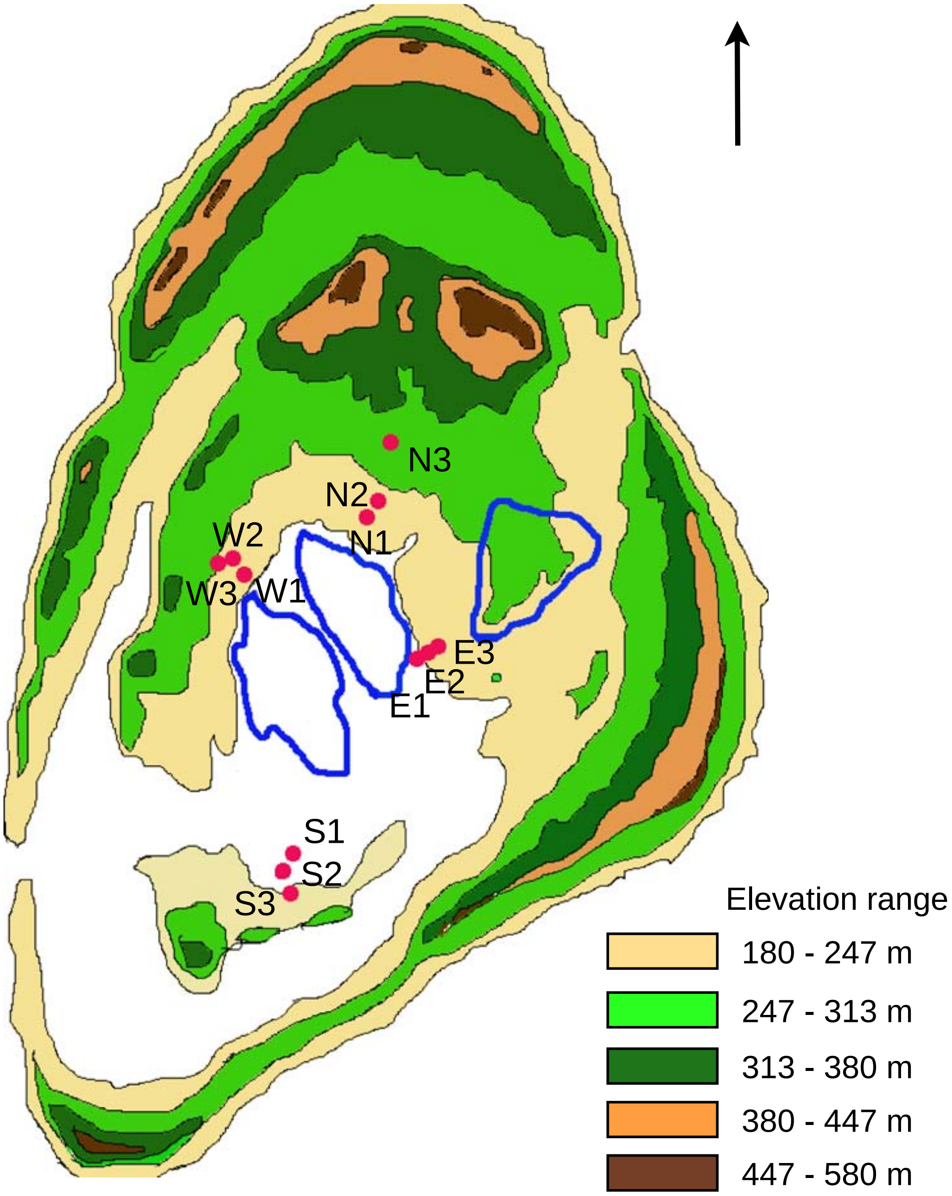

Figure S2 Contour map with the locations of the twelve survey plots. Twelve survey plots (points with red color) in the study site area. The blue line shows the boundary of three villages constructed within the protected area determined by the RFD and DNP in 2010. Now, the existence of villages is permitted by DNP. However, the expansion of village area and the excess-use of forest resources have been progressed. See Table S5 for topography information of each plot. We make the figure based on a digital map of the Land Development Department in Thailand. Arrow shows the north direction.

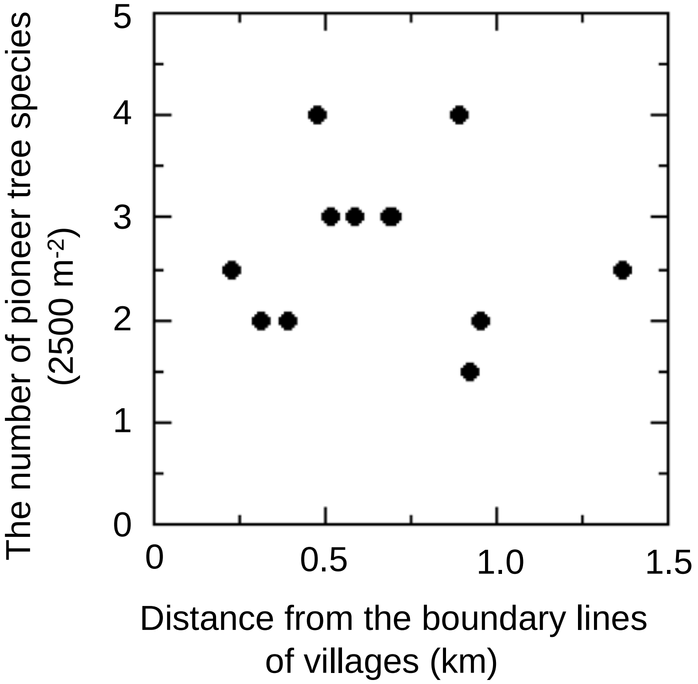

Figure S3 The numbers of pioneer tree species in the twelve survey plots. There is no significant trend between the numbers and the distance.

Table S1 Composition of woody species in the twelve survey plots. The values in parentheses are for medicinal woody plants. The high values of the variance of frequency indicate that the distribution of all species in the plots is quite different, whereas the low values indicate that all species have a similar pattern of distribution. Significant correlations with the distance (*P* < 0.05 in Pearson's linear regression) were only found for the number of species and individual density of all individuals. The effects of plant size-class are shown in Figure 3.

Plot	**No. Species (2500 m^{-2})**	**Density (individual ha^{-1})**	**Basal area (m^2 ha^{-1})**	**Variance of Frequency**
N1	32 (12)	520	13.0	131
N2	56 (31)	1032	24.3	172
N3	77 (47)	2044	27.2	290
E1	35 (17)	964	15.6	194
E2	50 (22)	1208	26.7	218
E3	51 (31)	1644	16.1	354
W1	42 (24)	1304	13.9	349
W2	62 (33)	2180	18.2	371
W3	60 (33)	1740	28.2	237
S1	39 (21)	1180	21.3	207
S2	48 (22)	1264	14.7	244
S3	41 (21)	1896	15.6	216
Tatal	**148**	**1416**	**19.6**	**-**

Table S2 Importance Values (IV) from woody plant species in each plot. The list of all woody plants observed in the study sites (MDF forest) and IVs of each tree species in each plot; the sum of the IV in each tree species is 300 (* indicates medicinal woody plant species, † indicates pioneer woody plant species, and • indicates emergent trees (the max. tree heights > 30m high)).

code	Scientific name	N1	N2	N3	E1	E2	E3	W1	W2	W3	S1	S2	S3
1*	*Polyalthia cerasoides (Roxb.) Benth. exBedd.*	0	1.05	6.6	0	0	0	0	0	2.04	0	0.99	1.08
2*	*Erythroxylum cuneatum (Miq.) Kurz*	0	0	0	0	0	0.69	0	0	0	0	0	0
3*†	*Careya sphaericaRoxb.*	0	1.29	1.59	0	1.02	2.55	8.91	2.13	0	0	3.78	0
4*	*Anthocephalus chinensis (Lark)A.Rich.exwalp.*	4.71	10.89	1.5	21.39	8.07	16.2	0	6.93	5.1	0	0	2.34
5	*Dalbergia sp.*	0	0	0	0	0	0	0	0	0	2.67	0	0
6*•	*Irvingia malayanaOliv. ex A. Benn.*	0	0	8.31	0	0	1.38	30.33	9.09	3.3	0	0	0
7	*Haldina cordifolia (Roxb.) Ridsdale*	12.03	17.46	0	1.26	2.16	3.18	0.96	1.95	0	3.63	4.86	1.14
8*	*Lanneaco romandelica*	0	2.49	0.57	11.37	2.79	5.34	10.35	7.32	0	4.14	0.9	6.15
9	*Quercus kingiana Craib*	3.15	0	0.57	0	0	0	0.9	2.34	0	0	0	0
10	*Unknown*	0	1.08	1.17	0	0	0	0	0	0	0	0	0
11	*Unknown*	0	0	2.04	0	1.08	1.38	0	0	0	0	1.29	6.93
12*	*Salacia chinensis L.*	0	0	0	0	2.01	0	0.9	0.57	1.98	1.02	0	0
13	*Harrisonia perforata (Blanco) Merr.*	8.82	0	0	0	0	0	1.62	0	0	0	0	3.93
14*	*Mahonia siamensis Takeda*	0	0	0	1.23	0	0	3.06	0	0	3.27	1.8	1.02
15*	*Streb lusasper Lour.*	0	0	0	0	0	0	0	0	4.89	0	0	0
16*	*Hymenopyramis brachiata Wall. ex Schauer*	0	1.56	6.45	3.21	17.1	2.07	0	1.17	10.29	4.47	21.3	10.41
17*	*Walsura trichostemon Miq.*	0	0	2.49	0	0	0	3.18	1.5	3.51	2.28	0	0
18*	*Antidesma ghaesembilla Gaertn*	0	1.05	3.12	0	0	0.93	0.9	0.57	0	0	0.99	0
19*	*Zollingeria dongnaiensis Pierre*	0	0	0.57	0	0	1.38	0	0.57	0	0	0	0
20*	*Senna siamea (Lam.) Irwin &Barneby*	0	1.02	0	0	0	0	0	0	0	0	0	0
21*	*Cassia garrettiana (Craib.) Inwin&Basneby*	2.55	2.07	0	2.88	1.23	2.37	0	0	1.17	1.02	0	0
22*	*Pavettato mentosa Roxb. ex Smith.*	0	0	0	0	0	0	0	0	0.66	0	0	0
23	*Unknown*	2.49	2.34	0	0	4.71	0	0	0	1.32	0	5.28	4.26
24*	*Smilax spp.*	0	0	0.57	0	0	0	0	0	0	0	0	0
25*	*Microco spaniculata L.*	0	0	21.03	0	5.34	0	4.41	0.57	5.25	3.48	1.77	2.85
26	*Nephelium hypoleucum Kurz*	0	0	0.57	0	0.99	0.69	0	0	0.9	0	0.9	0
27*	*Cassia fistula L.*	0	0	0.57	0	0	0	0.9	0	0	0	0	0
28	*Anomianthus dulcis (Dunal) J.Sinclair*	0	0	0	0	0	0	0	0	4.2	0	0	0
29*	*Smilax bracteataC.Presl subsp. verruculosa*	0	0	0.72	0	0	0	0	0	0.69	0	0	0
30	*Stereospermum fimbriatum (Wall. ex G.Don)*	3.99	2.43	7.53	2.7	0.99	0	0	0	0	0	4.2	1.95
31*	*Bombax anceps Pierre.*	0	1.2	8.43	1.23	8.31	0	0	0	1.32	24.36	5.16	16.95
32*	*Canthiumberberi difolium Geddes*	0	0	1.2	0	0	0	0	1.74	0	0	0	0
33*	*Millettiabran disiana Kurz*	0	0	0.69	0	0	0	0	0	0	0	4.95	4.92
34*	*Diospyros decandra Lour.*	0	0	0	0	0	0	0	0	3.69	1.11	0	0
35*	*Butea monosperma*	0	0	0	0	0	0	0	0	0	2.52	0	0
36	*Dalbergia nigrescensKurz.*	25.14	0	0	0	0	0	0	0	15.57	0	2.01	0
37*	*Ochnaintegerrima (Lour.) Merr.*	0	0	0	2.58	0	6.45	2.97	2.55	1.32	0	0	0
38*	*Diospyros castanea Fletch.*	0	0	0.57	0	1.05	0	0	1.14	1.71	0	0	0
39	*Dalbergia oliveri Gamble ex Prain.*	0	0	1.47	0	1.05	3.24	2.76	1.47	3.96	6.33	4.53	0.81
40*	*Gmelina arboreaRoxb.*	0	1.08	0	0	0	0	0	0	0	0	0	0
41*	*Suregada multiflora (A.Juss.) Baill.*	0	0	5.31	0	0	0	0	0.66	8.64	1.11	0	1.89
42†	*Xylia xylocarpa (Roxb.) Jaub. Var.*	16.86	19.71	5.01	11.85	8.1	24.81	4.35	12.87	2.19	5.22	8.7	1.71
43	*Unknown*	0	0	0.57	0	0	0	0	0	0	0	0.93	0
44	*Anneslea fragrans Wall.*	0	0	0	0	0	0	0	0	0	0	0.96	0
45*	*Schleicheraolosa*	1.95	4.47	0.57	0	3.39	0.69	0.93	4.56	2.82	0	3.3	4.53
46*	*Hopea odorata Roxb.*	0	0	0.57	0	0	0	0	0	0	0	0	0
47†	*Cananga odorata*	0	34.8	41.82	48	55.68	0	60.66	8.46	38.46	81.75	48.15	86.73
48	*Lagerstraemia calyculata. Kurz*	10.32	0	0	0	0	0	0	0	0	0	0	0
49•	*Terminalia corticosa Pierre ex Laness.*	6.15	0	9.93	4.71	5.28	4.98	8.22	11.94	16.47	4.53	2.94	11.64
50	*Lagerstroemia floribunda Jac*	0	0	0	0	3.15	0	0	0	18.78	2.19	8.52	4.83
51*	*Excoecaria oppositifoliaGriff.*	0	0	1.53	0	0	0	0	0	0	0	0	0
52*	*Ehretia laevis Roxb.*	0	0	0	0	0	0	0.93	0	0	0	0	0
53*	*Ellipanthusto mentosus* Kurz var. tomentosus	0	0	1.47	0	0	0	3.99	9	0	0	0	0
54*	*Cratoxylum formosum (Jack) Dyer subsp.*	3.9	0	1.68	0	0	9	4.59	4.41	0	0	5.22	1.56
55	*Cratoxylum cochinchinense (Lour.) Blume*	0	2.55	1.68	0	0	0	0	0.57	0	0	0	0
56*	*Calycopteris floribunda Lamk.)*	2.46	0	0	0	0	0	0	0	0	0	0	0
57	*Vitex pinnata*	5.88	6.42	5.79	7.71	16.62	9.21	10.2	15.6	7.71	14.28	17.13	11.46
58	*Strychnosnux-blanda A.W. Hill*	0	0	0	0	0	0.75	0	0	0	0	0	0
59†	*Shorea obtula*	4.2	5.76	0	23.94	2.55	63.27	23.07	66.96	0	0	0	0
60*	*Miliusave lutina (Dunal) Hook.f. & Thomson*	0	1.08	0	0	0	0	0	0	0	0	2.34	0
61	*Erythrina variegata Linn.*	0	0	0	0	0	0	0	0	0	0	0	9.09
62*	*Xantolis cambodiana (Pierre ex Dubarb) P.Royen*	0	0	0.57	0	0	0	0	0	1.02	0	1.23	0
63*	*Sterculia monosperma Vent*	0	0	0	0	0	0	0	1.77	0	0	0	0
64*	*Bauhinia scandens L. var. horsfieldii (Miq.)*	0	0	0	0	1.17	0	0	0	0	0	0	0
65	*Unknown*	0	0	1.92	0.78	0	4.26	1.02	0	0.66	1.14	0	0
66†•	*Pterocarpus marcocarpus*	40.26	17.61	9	52.8	33.48	29.1	56.34	26.61	8.79	21.06	26.94	19.05
67*	*Grewiae riocarpaJuss.*	0	1.05	0.57	0	0	1.38	0	3.36	0.66	0	4.41	0.78
68	*Sterculia guttataRoxb.*	0	0	7.71	5.79	0.99	0	0	0.57	0.75	19.71	12.48	10.86

Table S2 (Continue)

code	Scientific name	N1	N2	N3	E1	E2	E3	W1	W2	W3	S1	S2	S3
69	*Broussonetia papyrifera*	0	0	0.57	0	0	0	0	0	0	0	0	0
70	*Unknown*	4.47	1.08	1.77	0	0	0	0	0	0.78	5.67	3.06	6.87
71	*Unknown*	0	0	0	1.44	1.23	0	0	0	0	0	0	0
72*	*Croton subiyratusKurz*	0	0	4.53	0	0	0	0	0	0	0	0	0
73*	*Croton oblongifoliusRoxb.*	0	0	0.6	0	0	0	0	0	0	0	0	1.05
74*	*Sauropus androgynus (L.) Merrill.*	0	1.38	0	0	0	0	0	0	0	0	0	0
75*	*Melientha suavis Pierre*	0	1.02	0	1.2	0	1.77	0	0	0	0	0	0
76*	*Thyrsostachys siamensis Gamble*	0	3.21	0	0	0	0	0	0	0	0	0	0
77*	*Caesalpinia pulcherrima (L.) Sw.*	0	0	0.6	0	0	0	0	0	2.25	0	0	1.56
78*	*Albizia lebbeckBenth.*	0	1.23	0	2.37	2.4	0.69	0	0.78	5.37	3.75	0	0
79†	*Dipterocarpus tuberculatusRoxb.*	0	0	4.14	0	3.15	0	0	1.98	0	0	0	0
80*	*Dalbergia cochinchinensis Pierre*	0	0	3	0	0	0	1.89	0.57	0	0	0	0
81	*Erythophleum succirubrum Gagnep.*	0	0	0	0	1.05	0	0	0	0	0	0	0
82*	*Mimusop selengi L.*	0	0	0.57	0	0	0	0	0	0	0	0	0
83*	*Schrebera Swieteniodes Roxb.*	0	1.05	0	0	0	0	0	0	0	0	0	0
84*†	*Spondias bipinnata*	0	0	0	0	1.17	0	0	0	0	2.04	3.48	0
85	*Canarium sabulatum Guillaumin*	0	0	0	0	0	1.47	0.9	0	0	0	0	0
86*	*Phyllanthus emblica Linn.*	0	0	1.77	0	0	2.58	0	4.14	0	0	0	0
87*	*Purging croton, Croton tiglium Linn.*	3.06	1.44	3.54	0	0	0	0.9	0.57	3.36	0	0	0
88*	*Gardenia erythrocladaKurz.*	0	1.32	0	0	0	5.01	0	0	0.75	2.85	0	0
89•	*Sindora siamensisTeijsm.exMiq.*	0	2.16	15.72	5.49	11.49	1.83	2.85	15.09	6.33	14.1	7.62	6.12
90	*Afzelia xylocarpa (Kurz) Craib*	0	6.84	0	1.38	6.81	0	0	0	3.63	3.24	0.9	1.74
91	*Calophyl luminophyllum L.*	0	0	0	0	0	0	0	0	2.85	0	0	0
92	*Mangifera caloneura Kurz*	0	0	0	2.79	3.12	0	0	0	0	0	0	0
93*	*Buchanania latifoliaRoxb.*	0	0	0	0	0	9.03	2.01	2.31	0	0	0	0
94*	*Artocarpus lakoochaRoxb.*	0	0	0.99	0	0	0	0	0	0	0	0	0
95	*Docynia indica (Andr.) Decne.*	0	2.73	0	0	0	1.14	0	0	13.23	1.02	0.93	0
96	*Fagraea fragrans*	5.49	1.02	0	0	0	1.74	0	0	0.84	0	0	0
97*	*Tamilnadia uliginosa (Retz.) Tirveng. &Sastre*	0	1.5	0	0	0	3.27	0	0	0	0	0	0
98	*Morinda coreia*	4.02	3.75	12.3	10.62	2.1	11.19	4.59	4.38	2.22	0	2.46	0
99	*Persea kurziiKosterm.*	0	0	3.21	0	0	0	0	0	1.56	0	0	0
100*	*Pentapterato mentosa Roxb.*	6.36	11.16	0	13.65	0	14.1	0.93	1.17	0	1.59	0	0
101*	*Gluta usitata (Will.) Ding Hou*	0	1.08	0.9	2.64	0	0	0	4.41	0	0	0	0
102†	*Shorea siamensis*	46.71	23.16	0	19.95	15.09	11.97	0	2.82	0	0	1.05	0
103*	*Heterophragma sulfureum Kurz*	0	0	0	2.52	1.74	1.08	0	0	0	0	2.22	0
104*	*Bridelia retusa (L.) A. Juss.*	0	4.02	0	1.77	0	2.58	0	0.57	0	1.59	0	1.68
105*	*Ziziphus oenoplia (L.) Mill. var. oenoplia*	0	3.99	1.77	0	0	0	0	0.78	0.69	0	0.9	2.43
106	*Melia azedarach L.*	0	1.11	1.5	1.23	0.99	5.1	2.67	0	0	1.68	0	0.78
107*	*Hymenodictyon exelsum Wall.*	20.52	4.62	4.83	2.97	2.34	0.69	0.9	0.78	3.81	15.18	19.65	9.33
108*	*Terminalia sp.*	1.92	0	0.6	0	0	0	0	0	0	0	0	0
109*	*Diospyros castanea Fletchev*	0	7.38	0.9	2.64	2.22	0	0	0	1.17	1.02	0	0
110*	*Vitex quinata(Lour.)F.N.Williams*	0	2.73	2.88	0	0	0	0	0	1.14	0	2.37	11.64
111	*Azadirachta excelsa (Jack) Jacobs*	0	0	0	0	0	0	0	1.71	0	0	0	0
112	*Crudia chrysantha, K. Schum*	2.01	0	0	0	0	0	0	0	0	0	0	0
113	*Milletia sp.2*	1.92	11.1	0	0	10.02	0	0	12.09	7.68	10.68	3.54	0
114	*Tetrameles nudiflora R. Br.*	0	0	0	0	0	0	0	0	0	0	2.19	0
115*	*Terminalia bellirica (Gaertn.) Roxb.*	0	0	0	0	0	0	0	0	0	0	0	0.78
116	*Albizia chinensis (Osbeck) Merr.*	2.1	1.14	0	0	3.69	0	0	2.13	6.96	0	0.9	0.87
117	*Desmos cochinchinensis Lour.*	0	0	1.23	0	0	0	0.9	1.14	0.66	0	0	0
118*	*Crypteronia paniculata Blume.*	1.98	0	0	0	0	0	0.9	0	0	0	0	0
119*	*Pentace burmanicaKurz.*	0	0	1.38	0	0	0	0	0	0	0	0	0
120	*Bauhinia saccocalyx Pierre.*	37.92	37.02	0	19.5	24.36	10.32	1.92	5.94	26.7	5.64	26.91	13.38
121*	*Capparisse piaria Linn.*	0	0	0	0	0	0.69	0	0	0	0	0	0
122*	*Catunaregam tomentosa (Blume ex DC.)Triveng*	4.23	3.12	0	3.09	2.07	3.51	1.98	0.57	0	0	2.55	0
123*	*Caesalpinia godefroyanaO.Kze. C.*	0	0	4.23	0	1.23	0	0	0	0.69	16.23	6.33	11.88
124	*Dialium cochinchinense Pierre*	0	0	1.2	0	0	0	0	0	0	0	0	0
125	*Flacourtiaindica (Burm.f.) Merr.*	0	0	0.99	0	0	0	0	0	0.66	0	0	0
126*	*Terminalia Corticosa Pierre ex laness*	0	5.43	0.57	0	0	3.72	0	0.57	0	0	0	0
127*	*Antidesma ghaesembillaGaertn.*	0	0	0	0	0	0	0	0.57	0	0	0	0
128*	*Rothmania wittii Bremek*	0	0	31.71	1.32	10.92	3.96	3.57	4.02	11.04	1.14	0	0
129*	*Adenanthera pavonina L.*	0	4.53	0.6	0	0	0	0	0	4.08	0	0	0
130*	*Lepisanthes rubiginosa (poxb) Leenh.*	0	0	0	0	0	0	0	0	5.61	1.32	0	0
131	*Eugenia cuminiDruce*	0	0	0.9	0	0	0	0	0	0	0	0	0
132	*Ternstroemia gymnanthera (W. & A.) Bedd.*	0	1.08	0	0	0	0	0	0	0	0	0	0
133*	*Terminalia catappa L.*	0	0	0	0	0.99	0	0	0	0	0	0	0
134*	*Pterolobium integrumCraib*	2.28	0	0.99	0	0	2.34	6.63	2.37	4.14	0	0	0
135*	*Memecylon myrsinoidesBlume*	0	0	6.9	0	0	0	0	0	0	0	4.92	1.02
136*	*Memecylon edule Roxb.*	0	0	0	0	1.38	0	1.17	0	0	0	0	0

Table S2 (Continue)

code	Scientific name	N1	N2	N3	E1	E2	E3	W1	W2	W3	S1	S2	S3
137*†	***Dipterocarpus obtusifolius Teijsm.exMiq.***	**0**	**0**	**0**	**0**	**0**	**2.7**	**18.75**	**16.35**	**1.14**	**0**	**0**	**0**
138*	***Unknown***	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1.02**	**0**	**0**	**0**	**0**
139	***Unknown***	**0**	**0**	**0.99**	**0**	**0**	**0**	**0**	**0.57**	**0**	**0**	**0**	**0**
140	***Dalbergia cultrate Grah.ex Berth.***	**0**	**7.14**	**0.96**	**0**	**1.02**	**0**	**0**	**0**	**0.93**	**0**	**0**	**0**
141*	***Sphenodesme involucrata (Presl) Robinason***	**0**	**0**	**1.65**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
142*	***Diospyros ehretioides Wall. ex G. Don***	**0**	**0**	**0**	**0**	**1.23**	**0.69**	**0**	**0.57**	**0**	**0**	**0**	**0**
143	***Anthocephalus chinensis (Lamk.) A. Rich. exWalp.***	**0**	**0**	**0.81**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
144	***Wrightiadubia Spreng.***	**0**	**0**	**0.6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
145*	***Unknown***	**0**	**0**	**0.57**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
146	***Cochlospermum regium(Mart. &Schrank) Pilg.***	**0**	**0**	**0**	**0**	**0**	**1.53**	**0**	**0.6**	**0**	**0**	**0**	**0**
147*	***Celastruspa niculata Wild.***	**0**	**0**	**3.57**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
148	***Gmelinaphilippensis Cham.***	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.57**	**0**	**0**	**0**	**0**

Table S3 Species list of the predominant woody plants and their importance value (IV) in each plot. IV = *D* (relative density) + *F* (relative frequency) + *BA* (relative basal area). In total, 23 woody plants from all plots were considers predominant species with high IVs (IV > 11).

Scientific name	N1	N2	N3	E1	E2	E3	W1	W2	W3	S1	S2	S3
Cananga odorata		34.8	41.8	48.0	55.7		60.7		38.5	81.7	48.2	86.7
Pterocarpus marcocarpus	40.3	17.6		52.8	33.5	29.1	56.3	26.6		21.1	26.9	19.1
Bauhinia saccocalyx	37.9	37.0		19.5	24.4				26.7		26.9	13.4
Shorea obtula				23.9		63.3	23.1	67.0				
Shorea siamensis	46.7	23.2		19.9	15.1							
Vitex pinnata					16.6			15.6		14.3	17.1	11.5
Xylia xylocarpa	16.9	19.7				24.8						
Hymenodictyon exelsum	20.6									15.2	19.7	
Sindora siamensis			15.7					15.1		14.1		
Bombax anceps										24.4		17.0
Dalbergia nigrescens	25.2								15.6			
Hymenopyramisbrachiata					17.1						21.3	
Terminalia corticosa									16.5			11.6
Anthocephalus chinensis				21.4		16.2						
Dipterocarpus obtusifolius							18.8	16.3				
Sterculiaguttata										19.7	12.5	
Rothmaniawittiibremek			31.7									
Irvingiamalayana							30.3					
Caesalpiniagodefroyana										16.2		11.9
Microcospaniculata			21.0									
Lagerstroemia floribunda									18.8			
Haldina cordifolia		17.5										
Pentapteratomentosa						14.1						

Table S4 The distribution pattern of individuals of 23 predominant woody plants species (IV>11). A value of 1 in Morisita's index (I_δ) indicates a random distribution, values >1 indicate a clumped distribution, and values <1 indicate a uniform or regular distribution.

Scientific name	**Family**	I_δ
Cananga odorata	Annonaceae	1.8
Pterocarpus marcocarpus	Fabaceae	1.3
Shorea obtula	Dipterocarpaceae	4.1
Vitex pinnata	Verbenaceae	1.6
Bauhinia saccocalyx Pierre.	Fabaceae	1.5
Sindora siamensis	Caesalpiniaceae	1.7
Lagerstroemia floribunda	Lythraceae	3.8
Terminalia corticosa	Combretaceae	1.8
Dalbergia nigrescens	Papilinoideae	4.0
Hymenopyramis brachiata	Lamiaceae	2.2
Bombax anceps	Bombacaceae	3.1
Sterculia guttata	Sterculiaceae	2.8
Haldina cordifolia	Rubiaceae	1.6
Anthocephalus chinensis	Rubiaceae	2.2
Dipterocarpus obtusifolius	Dipterocarpaceae	6.0
Irvingia malayana	Rvingiaceae	6.0
Pentaptera tomentosa	Combretaceae	3.3
Caesalpinia godefroyana	Leguminosae	2.9
Hymenodictyon excelsum	Rubiaceae	1.7
Shorea siamensis	Dipterocarpaceae	3.0
Xylia xylocarpa	Leuminosae-Mimosoideae	1.9
Rothmania wittii	Rubiaceae	5.3
Microcos paniculata	Tiliaceae	5.5

Table S5 Values of the Shannon–Wiener Index (*H’*), Fisher’s α, 1-Simpson’s *λ*, and Hill’s Evenness (*E*) indexes in each survey plot. *H’*, α, and (*1-λ*) are indexes of the biodiversity of woody plants, and *E* is an index of the evenness of the distribution pattern of all individual trees. See the main text for the equations.

Plot	Distance	*H’*	*α*	*1-λ*	*E*
N1	310.00	4.15	13.56	0.92	0.20
N2	692.00	4.73	22.02	0.94	0.14
N3	1369.59	4.83	25.18	0.92	0.10
E1	223.81	4.03	10.80	0.90	0.17
E2	479.92	4.31	17.08	0.90	0.90
E3	687.74	4.44	15.34	0.90	0.14
W1	514.85	3.99	12.83	0.87	0.13
W2	893.00	4.53	18.42	0.91	0.15
W3	950.00	4.93	18.87	0.94	0.13
S1	390.11	4.07	12.04	0.89	0.15
S2	585.55	4.47	15.75	0.92	0.14
S3	923.40	3.87	10.77	0.84	0.13

Table S6 Topography of the survey plots. Abbreviations in plots: N, E, W and S indicate north, east, west, and south from the village boundary to the forest, respectively.

Plots in cardinal direction		**Topography**	
North	UTM coordinate zone 48Q	Distance from the village boundary lines (m)	Elevation (m ASL)
N1	230111 1876584	310	256
N2	230277 1876780	692	290
N3	230503 1877600	1370	364
East			
E1	231455 1874233	224	279
E2	231615 1874313	480	290
E3	231190 1874112	688	268
West			
W1	228450 1875531	515	272
W2	228202 1875830	893	286
W3	228051 1875554	950	270
South			
S1	229227 1870986	390	248
S2	229119 1870750	586	235
S3	229244 1870324	924	268

Table S7 Percentage similarity and percentage dissimilarity in species composition among plots. To examine the similarity or dissimilarity between plots, Bray and Curtis Index (BCI) values were used to determine a standardized species score to combine the measurements of IV (D + BA + F) in woody plant species. The upper right section and the lower left section show the similarity and dissimilarity between two plots, respectively. For the similarity values, the minimum value was 17.1 between Plot N1 and N3, indicating that the species compositions in these plots presented the greatest differences of all plot pairs, and the maximum value was 68.9 between Plot S1 and S3, indicating a similar species composition. The similarity in forest structure between plots appears to be independent of both direction and distance.

	N1	**N2**	**N3**	**E1**	**E2**	**E3**	**W1**	**W2**	**W3**	**S1**	**S2**	**S3**
N1		51.3	17.1	44.7	39.6	38.6	27.7	30.7	30.5	23.0	40.7	25.4
N2	48.7		31.0	57.1	54.8	43.9	30.6	35.1	43.0	36.4	46.8	36.9
N3	82.9	69.1		35.6	43.7	21.4	38.0	32.5	44.6	41.6	44.1	43.7
E1	55.3	43.0	64.5		61.6	55.6	57.4	43.2	37.2	42.9	48.5	43.2
E2	60.4	45.2	56.3	38.4		37.1	46.6	43.4	54.6	56.0	64.4	54.0
E3	61.4	56.1	78.6	44.4	63.0		39.4	60.2	22.2	24.2	29.6	22.1
W1	72.3	69.4	62.0	42.6	53.6	60.6		51.9	33.7	43.0	40.4	40.7
W2	69.3	64.9	67.5	56.8	56.6	39.9	48.1		31.2	33.7	35.5	29.0
W3	69.5	57.1	55.4	62.8	45.4	77.8	66.3	68.8		40.7	48.4	43.3
S1	77.0	63.6	58.4	57.1	44.0	75.8	57.1	66.3	59.4		57.9	68.9
S2	59.3	53.2	56.0	51.5	35.6	70.4	59.6	64.6	51.7	42.1		61.2
S3	74.6	63.1	56.4	56.8	46.0	77.9	59.3	71.0	56.7	31.1	38.8	

References

1 Puhe, J. & Ulrich B. *Global Climate Change and Human Impacts on Forest Ecosystems*: *Postglacial Development, Present Situation, and Future Trends in central Europe*. (eds. Puhe, J. & Ulrich B.) Ecological Studies **143**, 892 P (Springer-Verlag Berlin Heidelberg, 2001).

2 Guhardja, E., Fatawi M., Sutisna, M., Mori, T. & Ohta, S. (eds.) *Rainforest Ecosystems of East Kalimantan*: *El Niño, Drought, Fire and Human Impacts*. (eds. Guhardja, E. *et al.*) *Ecological Studies* **140**, 330 P (Springer-Verlag Tokyo, 2000).

3 Bajracharya, S. B., Gurung, G. B. & Basnet, K. Learning from community participation in conservation area management. *J. Forest Livelihood* **6**, 54-66 (2007).

4 Santisuk, T. *et al. Plants for our Future: Botanical Research and Conservation Needs in Thailand.* (Royal Forest Department, Bangkon, Thailand, 1991).

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

6 Stibig, H. J. *et al.* A land-cover map for South and Southeast Asia derived from SPOT-VEGETATION data. *J. Biogeogr.* **34**, 625-637 (2007).

7 Trisurat, Y. Applying gap analysis and a comparison index to evaluate protected areas in Thailand. *Environ. Manage.* **39**, 235-245 (2007).

8 Bunyavejchewin, S. Analysis of the tropical dry deciduous forest of Thailand: I. Characteristics of the dominance-types. *Nat. Hist. Bull. Siam Soc* **31**, 109-122 (1983).

9 Ashton, P. Toward a regional classification of the humid tropics of Asia. *Tropics* **1**, 1-12 (1991).

10 Blasco, F., Bellan, M. & Aizpuru, M. A vegetation map of tropical continental Asia at scale 1: 5 million. *J. Veg. Sci.* **7**, 623-634 (1996).

11 Marod, D., Kutintara, U., Yarwudhi, C., Tanaka, H. & Nakashisuka, T. Structural dynamics of a natural mixed deciduous forest in western Thailand. *J. Veg. Sci.* **10**, 777-786 (1999).

12 Ishida, A. *et al.* Seasonal variations of gas exchange and water relations in deciduous and evergreen trees in monsoonal dry forests of Thailand. *Tree Physiol.* **30**, 935-945 (2010).

13 Department of National Parks, W. a. P. C. Statistic data. (2012).

14 Sha, J., Pan, Y., Wang, Y., Zhang, X. & Rao, X. Non-marine and marine stratigraphic correlation of Early Cretaceous deposits in NE China, SE Korea and SW Japan, non-marine molluscan biochronology, and palaeogeographic implications. *J. Stratigraphy* **36**, 357-381 (2012).