Reconciling Indigenous and Scientific Ecosystem and Soil Fertility Indicators in Swidden Systems of Northern Thailand

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Reconciling indigenous and scientific ecosystem and soil fertility indicators in swidden systems of Northern Thailand

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General introduction

1.1. Overview

Swidden cultivation systems with fallow periods of five to ten years were once common in mountainous and remote areas of Northern Thailand. Many of these systems are relatively close to resembling natural succession and are characterised by their low environmental impact in terms of synthetic and mineral inputs. Instead, they rely on extensive land resources and fire to clear fallows or new areas for cultivation. These systems require low input from farmers to recover soil fertility in preparation for the next cropping cycle. Governments and authorities in the region often consider swidden agriculture as a backward, low-production system responsible for deforestation due to its high land demand. Over recent decades, increased population pressure, improved linkage to markets, and the prohibition of forest encroachment have put farmers under increasing pressure to shorten fallow periods. The main crop in traditional swidden systems also changed from upland rice, typically found in the traditional swidden systems, to more profitable continuously cultivated maize or other cash crop production systems. As a result, the problems of weed and pest infestation, nutrient loss, and productivity decline under shortened fallows has led to a boost of herbicide, pesticide and fertilizer application. In order to sustainably intensify the original low input swidden system, criteria and indicators are needed to determine optimum fallow duration. It should be sufficient for the restoration of the ecosystem, while guaranteeing adequate provision of food and income for farmers.

1.2. The swidden cultivation system

Swiddening is a rotational agricultural system that originally combined one or a few years of crop cultivation with extended fallow periods (5-20 years) and fields cleared by slash and burn (Mertz et al., 2009). These systems are characterized by low external inputs. During fallow periods, regeneration of natural vegetation modifies soil and microclimatic conditions and restores soil fertility. When a new cropping cycle is initialised, the built- up vegetation biomass is incorporated into the soil as ashes or mulch (Van Reuler and Janssen, 1993). Apart from restoring soil fertility, a closing canopy of natural vegetation reduces weed pressure (Kameda and Nawata, 2017). Shifting cultivation was widespread in ancient cultures around the world, although its extent is difficult to quantify due to its diverse and dynamic land cover (Schmidt-Vogt et al., 2009). As the system is land-intensive and increases in demographic pressure widespread, swidden farming in many regions has shifted towards shortened fallow periods or transformed into other agricultural systems, threatening soil regeneration and sustainability of the overall system. Fox et al. (2009) studied political and economic trends of swidden systems in Mainland Southeast Asia and found six main factors that have driven the demise or shift from swiddening to more intensified systems: (1) classification of swiddeners as ethnic minorities; (2) governments classifying fallows as protected forests that must not be cleared; (3) expansion of national parks into swidden fields and fallows; (4) enforced resettlement of swiddening communities; (5) privatization and commoditization of land that often used to belong to a community; and (6) expansion of markets and infrastructure (e.g. road networks) and the promotion of industrial agriculture. The challenge of sustainably intensifying swidden systems lies in finding the balance between shortened fallow periods and the maintenance of crucial ecosystem functions such as soil properties, hydrological functions, biodiversity, and soil carbon stocks, among others.

1.3. Changing role and perception of swidden agriculture in Northern Thailand

The mountainous north of Thailand is home to numerous ethnic groups and their respective cultural and agricultural practices. The main staple crop for most groups is rice, grown as paddy or upland rice. Paddies are cultivated continuously, but limited in areas due to soil conditions, water availability, and topography (Lennartz et al., 2009; Wade et al., 1999). Upland rice is typical for extensive agriculture as it requires less water and labour for field preparation, however, it depletes soil fertility when grown for more than two or three consecutive periods and is more susceptible to weed pressure (Schmidt-Vogt, 1998). Traditionally, upland rice is not cultivated during more than three consecutive periods without a longer fallow period of 10 to 15 years (Schmidt-Vogt, 2000). On one hand, burning and expansion into natural forests are mostly perceived as environmentally unfriendly (Ding et al., 2012; Van Do et al., 2010). On the other hand, it has been stated that farm system level nutrient balances are not *per se* negative where nutrients from upland fields (mostly by erosion) flow into paddies (Dung et al., 2008; Schmitter et al., 2010). A general trend towards intensification – mechanization, increasing amounts of mineral and synthetic inputs and shortened fallow periods – can be observed (Schmidt-Vogt et al., 2009) due to the government`s forest protection policies, among other factors. Still, agricultural practices among ethnic groups differ strongly. Most groups, like the

Lahu community of Bor Krai in our case study, have reduced fallow periods to 5 or 6 years, or even less, in accordance with the trends described by Schmidt-Vogt et al. (2009). They have switched from swidden cultivation for subsistence to cash cropping, and heavily rely on pesticide and fertilizer use. On the other hand, particularly small groups in remote areas adhere to the traditional way of farming (i.e. fallow duration of 10 years or longer, no herbicides, pesticides and mineral fertiliser use). These communities, e.g. the Karen of Nong Khao in our study, are nowadays often seen as role models for environmentally-friendly production (Forsyth and Walker, 2008), but are experiencing increasing internal and external pressure to intensify their systems (Wangpakapattanawong, 2002). In this context, various models of reduced fallow periods and even complete abandonment of swidden farming in favor of continuous cropping have been observed (Schmidt-Vogt et al., 2009). Indicators are needed to determine to which degree fallow periods can be reduced without jeopardizing the systems' resilience and ecological sustainability. Such objective criteria might take external pressure off of the farmers.

1.4. Secondary forest succession in swidden systems

Natural regeneration is the cheapest and, in many ecosystems, the most effective way to restore disturbed sites, to maintain tree species diversity of the secondary forest and avoid soil degradation by minimizing exposure to erosive and drying elements (Kleinman et al., 1995). Various agricultural systems mimic plant succession (Ewel et al., 1981; Schneider et al., 2017) to make use of natural system dynamics (e.g. Analogue Forestry, permaculture) (Ribeiro Filho et al., 2013). While the focus of the systems studied here is on annual monocrops as typical pioneer elements, the entire rotation represents a type of managed succession. The short annual cropping cycle of one to two years is integrated in a comparably long fallow period. During cropping phases, annuals and re-sprouting rootstocks of woody plants coexist.

Agricultural practices include significant system disturbances like slashing, burning and planting, which lead to changes in water and nutrient balances and plant community structure. As a consequence, recovery rates (via re-sprouting, seed bank, fallow biomass) and species composition of secondary forests, depend on cropping cycle, fallow duration, weeding practices, stump treatment, burning, and fertilizer application. Managed systems that rely on a larger proportion of re-sprouting late-successional tree species establish a higher biomass in a shorter time than such starting from seeds. This shortens the grass- or herb-dominated pioneer stage and leads to earlier canopy closure and changes in microclimate, favouring shade-tolerant species and a greater diversity of woody species (Niether et al., 2018). Apart from temporal and management aspects, spatial characteristics of the system, e.g. size of disturbed area or connectivity between undisturbed locations, determine fallow regeneration.

1.5. Soil fertility dynamics in swidden systems

Soil physical, biological and chemical properties influence crop growth. On the other hand, soil properties evolve during different phases of swidden systems due to management and vegetation effects. A study from southern Brazil found that burning during the conversion phase increased soil temperatures up to >500 ^{o}C at the soil surface and <100 ^{o}C at a soil depth of 5 cm, depending on soil moisture (Thomaz et al., 2014). In another study, 33% of the entire runoff volume and

55.6% of total soil loss were measured during cultivation in the first year of the swidden cycle, when the soil was left exposed (Thomaz, 2013). Further effects of exposed soil are compaction and increased SOM decomposition, as well as decreases in soil moisture, microbial biomass, and organic matter. On the other hand, pH, base saturation (Mg, Ca, Na, K) and CEC have been reported to improve due to ash deposition after burning. However, the amount of macronutrients are subsequently decreased due to crop uptake, surface runoff, leeching, and erosion during cultivation and beginning of the fallow period (Ribeiro Filho et al., 2013).

Soil fertility recovery towards initial conditions depends on land use intensification, number of cropping cycles and the length of the fallow period (Teegalapalli et al., 2018). In a study conducted in northern Vietnam, 37 and 6 years of fallow were estimated to be necessary for restoring N and P balances, respectively (Dung et al., 2008). However, a study on impact of fallow length on soil structure from western Thailand found that there were no significant differences in bulk density between fallow plots (0 to 10 year fallow) and forest (Grange and Kansuntisukmongkol, 2004). Wood et al. (2017) found in a study in the Peruvian Amazon that a long fallow duration (>12 year) could help to increase SOM, available P, exchangeable Na, silt and nitrate. But they also found that the number of cropping cycles and farmers' cropping practices had a stronger impact on soil fertility than fallow duration. As a current trend, smallholder farmers in Central Amazonia prefer to intensify cultivation on more fertile soils (Junqueira et al., 2016). In addition to farmers' practice and fallow duration, topographic conditions and plant species composition also had an impact on soil properties (Ribeiro Filho et al., 2013; Lawrence et al., 2005; Lenka et al., 2013).

1.6. Indigenous knowledge and ecological indicators

Indigenous knowledge is widely accepted as an important source for decision making in agriculture and natural resource management (Berkes et al., 2000). Although decision rules may not be fully based on mechanistic explanations of processes, they often contain observations made and tested by generations of farmers. They build on biological indicators that integrate knowledge of various disciplines and impacts of a variety of processes.

Many farmers that practice shifting cultivation base their decision on when and where to reinitiate a cropping cycle on biological indicators. For example, farmer interviews in East Borneo, Indonesia, showed that farmers used certain groups of plant species and their structure to classify forest succession stage and soil fertility (Siahaya et al., 2016). In Cordillera, the Philippines, farmers believed that *Ficus spp.* trees maintain sufficient groundwater supply (Camacho et al., 2016). In Thailand, farmers believed that the presence of *Macaranga denticulata* (Bl.) Muell. Arg. help to maintain productivity of upland rice (Yimyam et al., 2003). Ideally, such indicators are integrated measures of chemical and biological soil fertility, hydrology, microclimate, and plant society that characterise the overall status of the system. Like bioindicators used in environmental impact assessment, traditional indicators are integrated measures of ecosystem status and they are easy to observe, at least for those trained in the system. Typical indicators can be soil characteristics, such as topsoil colour and soil “hardness” (Schuler et al., 2006), or the appearance / abundance of certain plant species that stand for a determined phase of natural succession (Schmidt-Vogt, 2001). Farmers’ indicators that describe maturity of a fallow for slashing (as a proxy of restored soil fertility) can usually not be directly associated to one chemical or physical soil variable alone. The concept of soil fertility includes intact ecosystem functions like aggregate stability, soil organic matter contents, water holding capacity, or biological diversity and goes beyond mere soil productivity for cropping.

On the other hand, increasing mobility, migration, and urbanisation imply that the necessary traditional knowledge for ecosystem assessment is continuously eroding in many rural areas (Schmidt-Vogt et al., 2009). Documentation, critical assessment, and alignment of traditional knowledge and scientific methods has the potential for more informed decision-making in ecosystem management.

1.7. Justification of the study

Particularly in traditional systems, current socio-economic, political and cultural changes call for shortened fallows or extended cropping cycles. In order to make such far-reaching management decisions, indicators for monitoring recovery of ecosystems need to be defined. In our research we focused on tree structural and diversity-related indicators in forests as climax stages at both study sites and on key tree species as traditional farmer indicators to characterise the regeneration status of soil fertility in fallow ecosystems at Nong Khao. Furthermore, structural diversity of the tree community, embedded into a mosaic of crops, early and late-successional communities, is an important foundation for biodiversity of the entire ecosystem. Whereas environmental factors like soil organic matter, light absorption by canopy or microclimate change during succession, biomass and plant species-related variables integrate biophysical growth conditions. As a result, they are good indicators of change in terms of ecosystem resilience and recovery. Another important indicator for farmers' decisions on plot selection is relative abundance, defined as the number of trees per species over number of all trees. Due to the heterogeneity of soil properties, even of the same fallow age, there are differences in plant community components in that area as well. Therefore, the tree species found in that area may not only be affected by the changing fallow ages, but also affected by different topographic factors and soil properties.

1.8. Research objectives

The first main objective of this study was to analyze secondary succession patterns of tree species composition at two contrasting sites in Northern Thailand over time. The focus was on stand structure and species diversity in short-term fallow rotations under imminent shortening of fallow periods. Appropriate fallow duration was assessed from an ecological standpoint of plant ecosystem recovery with reference to the end of the current rotation cycle. Extension of the fallow period was not studied as it is not a viable option for farmers. As appropriate fallow duration depends on multiple criteria, biological indicators were to be selected that stand for both stand structure and diversity. To justify further reduction of fallow duration, the majority of indicator variables needed to pass a peak within the currently practiced fallow duration. Secondly, it was of interest whether observed indicators and trends were generic across the contrasting sites and systems selected for our study.

As a second main objective, we tried to identify parallels and discrepancies between indigenous and scientific indicators of fallow maturity as a proxy for restored soil fertility in order to develop a set of indicators that are reproducible, easy to observe, comprehensive, and meaningful for farmers. The indigenous knowledge indicators were based on the abundances of tree species, which the farmers related to specific soil properties linked to crop cultivation and yield potential.

1.9. Hypotheses

The hypotheses that guided this research were:

1. Dominant species composition shifts during succession, even in the short-fallow rotations of 6 to 10 years practiced by Northern Thai ethnic groups. Species composition and diversity can thus serve as indicators to characterize the fallow stage.
2. Non-linear temporal changes in tree cover, density, height, and aboveground biomass can be used to assess structural recovery dynamics in short-time fallows. Changes in tree species diversity as the fallow ages, observable on the field, can indicate system recovery.
3. Structural and species diversity are related indicator groups and can be used to evaluate sites with contrasting natural forest vegetation. Therefore, the method has the potential for generic use to assess sustainability of fallow periods from the perspective of plant structural and species diversity.
4. Parameters used by farmers to characterise soil fertility are meaningful in so far as soils under early and mature fallows differ in these parameters.
5. Tree species used by farmers to identify mature fallows with fertile soil are appropriate indicators to reflect soil fertility status, as they preferentially grow on more fertile soils.
6. Prediction of soil fertility parameters based on farmer indicators can be improved by adding species from systematic botanical surveys, increasing the number of explanatory variables

Study sites

The study was carried out at two contrasting sites in Northern Thailand, which are described in the following. Field and statistical methods are also explained in this section.

The study was conducted in Nong Khao and Bor Krai villages in the Mae Hong Son province, northern Thailand (Figure 1). Both sites are located in mountainous environments with steep slopes and are inhabited by ethnic minorities. Nong Khao is a remote Karen village with difficult market access and traditional subsistence upland rice-based agriculture (Tongkoom, 2009). Bor Krai is a Lahu village in Pang Ma Pha district, Mae Hong Son province, close to the national road (see Figure 1), that has seen considerable agricultural intensification in terms of synthetic inputs, maize cultivation, marketing of pigs and reduced fallow periods (Schuler et al., 2006).

2.1. Locations, topography, geology and soils

Nong Khao is situated on sedimentary rock, 987 meters above sea level (N 19° 13´ 45.7˝, E 98° 06´ 43.7˝), whereas Bor Krai is located on limestone, 726 meters above sea level (N 19° 33´ 7.2˝, E 98° 12´ 28.8˝). On the slopes of Nong Khao, the soils are characterised by high clay contents and low CEC (Tongkoom 2009), P_{av} and pH. Clay content increases sharply in the lower horizons, classifying the soils as Acrisols (with Ca^{2+} and Mg^{2+} concentrations < 24 cmol/kg and base saturation < 50%). Where argic horizons are not present, Nitisols prevail. The silt / clay ratio is below 0.4, and the soil colours cover a wide range from 2.5YR to 10YR. Soils in the Bor Krai area were mostly Luvisols, and had a higher CEC and base saturation (Schuler et al., 2006).

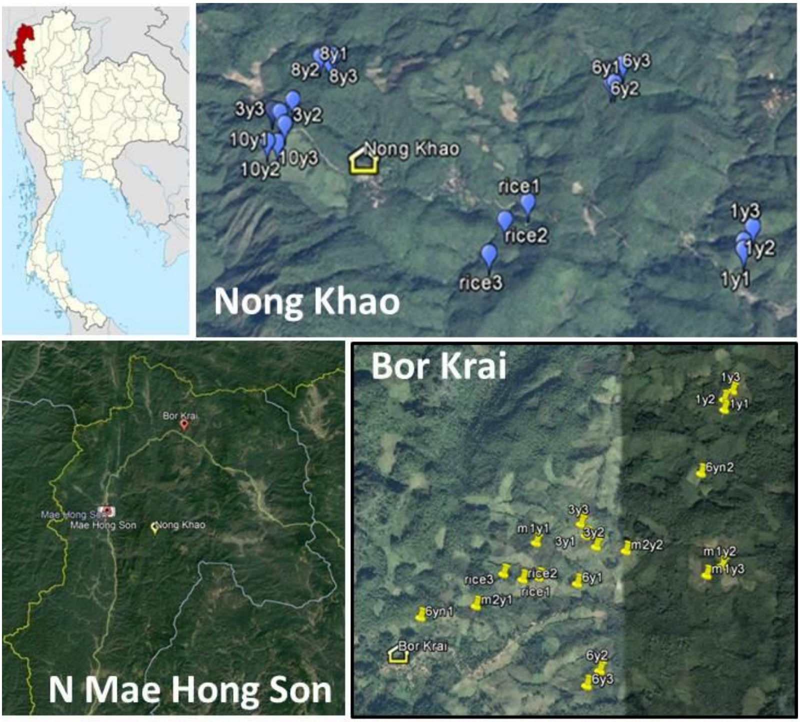

Fig. 1   Figure 1: Geographic locations of Mae Hong Son province (top left), sites Nong Khao and Bor Krai (bottom left) and field plots in Nong Khao (top right) and Bor Krai (bottom right). Field codes: m = maize, rice = upland rice, 1y, 3y, 6y, 8y, 10y = fallow age in years. Last number = replicate. Source: Google Earth Pro. Image Date: 12/11/2015.

Inventories were carried out on farmers' fields under typical management. Plots in Nong Khao were cleared using community labour and in clusters, thus plots of the same fallow age were adjacent (Figure 1). In Bor Krai, plots were managed individually and less clustered by age.

2.2. Climate

According to the Köppen-Geiger classification (Peel et al., 2007), Mae Hong Son has a tropical savanna or tropical wet and dry climate (Aw). Average weather data (2000-2010) measured by the Thai Meteorological Department at Mae Hong Son station (267 meters above sea level, N 19° 18´, E 97° 50´) (Figure 2) show precipitation of 1,365 ± 229 mm per year and average temperature of 26.4 ± 2.8 °C. Monthly data from the same source show a rainy season from middle of May until middle of October and seasonal temperature minima and maxima in January and April, respectively.

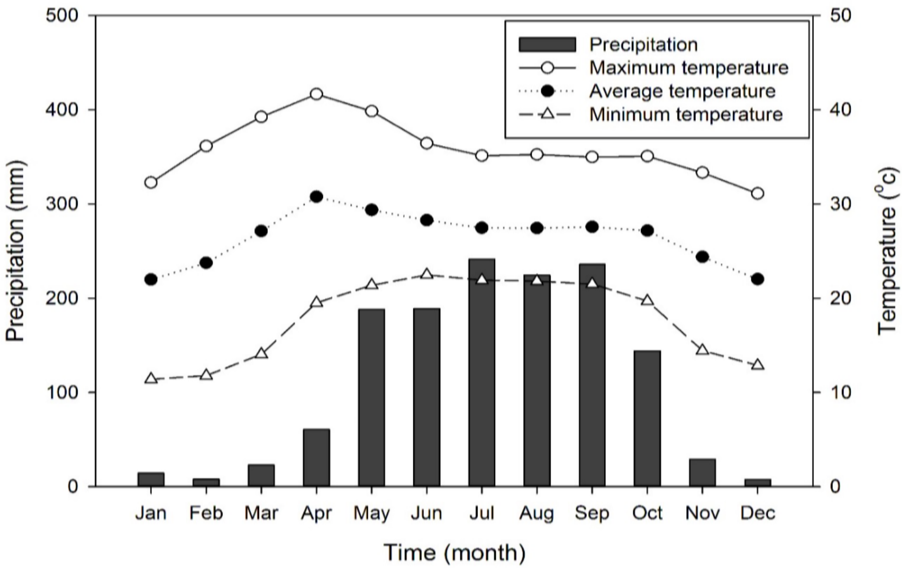

Figure 2: Average monthly precipitation and mean daily maximum (○), average (●) and minimum (Δ) temperature of Mae Hong Son province (Average; 2000-2010).

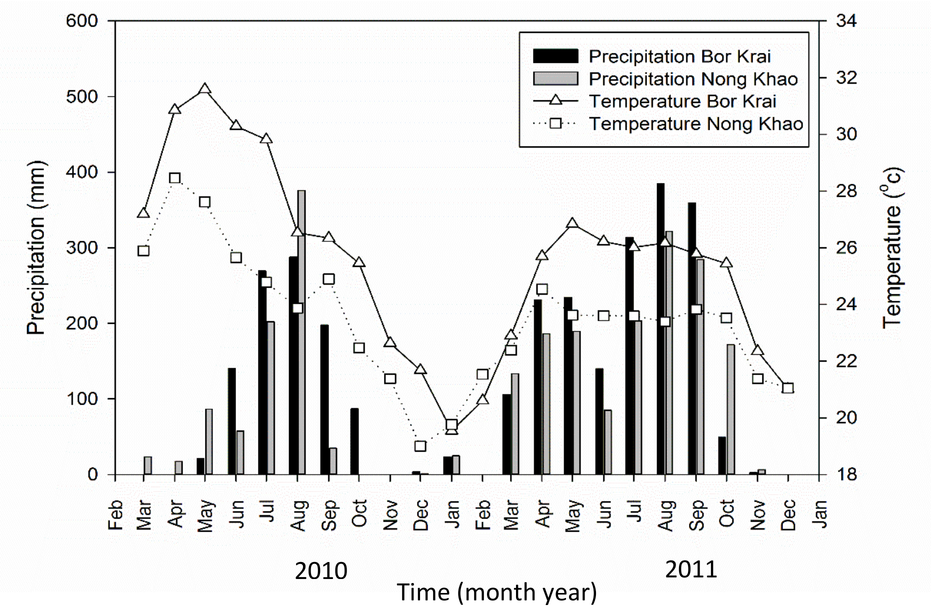

Figure 3: Monthly precipitation and average air temperature in Bor Krai and Nong Khao village during the study period from 2010 to 2011.

Weather data in both villages (Fine Offset Electronics WH 1080 in Nong Khao; Mae Hong Son Rice Research Center for Bor Krai) (Figure 3) showed that in 2010, a dry year with late onset of the rainy season, precipitation in Nong Khao (1184 mm) was higher than in Bor Krai (1023 mm). In 2011, a relatively wet year, precipitation in Nong Khao (1783 mm) and Bor Krai (1842 mm) was similar. Monthly average air temperature in Nong Khao (24.4 °C and 22.7 °C) was lower than in Bor Krai (26.7 °C and 24.4 °C) in both years.

2.3. Natural vegetation

The mostly evergreen natural forest in lower Nong Khao is dominated by Fagaceae (*Castanopsis* spp*., Quercus* spp*.,* and *Lithocarpus* spp.), whereas near ridges evergreen forest with pine (*Pinus merkusii* and *Pinus kesiya*) prevails. Natural mixed deciduous and deciduous forest in Bor Krai is dominated by Dipterocarpaceae mixed with teak *(Tectona grandis*), *Dalbergia* spp*., Lagerstroemia* spp*.* and bamboo. Timber has been extracted at both sites over the past few decades.

2.4. Socio-cultural and agricultural information

In our interviews with farmers in Nong Khao, it was mentioned that the village had been established more than 200 years ago. At that time, there were 7 households. In 2010, there were 43 households, and 336 people (165 of females and 171 males). In the beginning, the village believed in spirits. About 50 years ago, most of them became Christians and some Buddhists. Although religion changed, agricultural practices largely remained the same, until recently. The village is located 35 kilometers from the city Mae Hong Son, but travel time by car is 2-3 hours in the dry season and even longer during the rainy season. Only two cars were available in Nong Khao, so that access to the local market was very limited. Consequently, the agricultural production system was a traditional subsistence-based upland rice cultivation system. The total agricultural area of the village, including fallowed plots and forest, was 527 ha, less than 10% of the total village area (Figure 1). On the slopes, upland rice is planted for one year without fertilizer or herbicide. More than 30 species of vegetables are intercropped with upland rice for daily household consumption. After harvest, plots are fallowed for about 10 years. On plains along streams (2% of the agricultural area), paddy rice is planted on terraces. Every year, the upland rice crop of the entire community is planted in one common area. The size of the common field is about 52.7 hectare per year. Families cultivate their plots individually. Each household has a plot of about 1-1.6 ha. Farmers jointly decide the location of the upland rice fields as well as when a new cropping cycle after fallow will be initiated. Fencing and clearing fire breaks are also done by the community. Collective decision making implies a common or even consensual perception of soil fertility criteria and indicators. As soil fertility is not homogeneous in the large common field, individual farmers use indicators based on traditional knowledge to judge soil fertility status. Under 'good' soil conditions, rice and vegetable productivity will both be high, whereas under 'bad' conditions rice production will be acceptable, but vegetable production, especially tuber crops, may not be sufficient to cover a whole year's consumption.

Based on the interviews conducted in Bor Krai, the village was established about 50 years ago by five families who moved from a nearby village, Jar Bo. The Lahu people of Bor Krai are famous for their hunting skills and as a result have always been concerned with keeping the nearby forests intact. Nowadays, hunting in the forest is prohibited, so they shifted towards holding livestock. Their agriculture is also upland rice-based, but it clearly differs to Nong Khao in regard to intensification. The crop rotation starts with upland rice on the slopes in the first year, followed by maize, grown for pig fodder, in the second year. Some farmers grow annual crops continuously. Herbicides are used for plot preparation before planting upland rice. After two years of cultivation, plots are fallowed for 5-6 years. Decisions in regard to the plots are made on a household basis. In a study by Schuler et al. (2006) on local knowledge of soil classification, it was found that farmers mostly used colors to indicate soil fertility. From our interviews we also found that farmers make decisions on the suitable crop type by soil color. Common rules mentioned were, for example in Bor Krai, “black soil is good for planting upland rice” and “red soil is good for planting maize”.

Materials and methods

3.1. Experiments conducted

Two field surveys were conducted within the scope of this study: The first compared structural and species diversity related to tree characteristics linked to fallow age at Nong Khao and Bor Krai. The minimum fallow age that allowed to maintain various ecosystem functions could then be determined.

The second field and farmer survey were conducted at the Nong Khao site to relate plant species from the first survey to fertility-related soil variables.

3.2. Field measurements

3.2.1. Plot layout and sampling strategy

Tree and soil properties were surveyed in crop fields before burning and in fallows of 1, 3, 6, 8- and 10-years duration in Nong Khao, whereas in Bor Krai, fallow durations were 1, 3 and 6 years. In 2010, three plots at different slope positions (upper, middle and lower) were established for each fallow stage, and repeated on three different hills, i.e., 45 plots in Nong Khao and 27 plots in Bor Krai. In 2011, 36 and 18 fallow plots, respectively, were monitored, while the oldest fallow treatment monitored 2010 was under cultivation again after 10 years fallow. This approach combined monitoring and a false time series. Rectangular measurement plots, with the dimensions of 6 x 50 m^2, for studying tree community were located within fallow plots perpendicular to slope direction. Plot size was based on Tongkoom (2009), derived from species-area curves. Within the plots, eight variables representing stand structure and tree species diversity were assessed based on previous studies (Jepsen, 2006; Schmidt-Vogt, 1998;

Sovu et al., 2009; Van Do et al., 2010; Wangpakapattanawong et al., 2010). For the soil survey, the soil samples were collected at beginning, middle and end of the rectangular measurement plots. The study of relationship between soil properties and tree indicators species used tree species data surrounding soil sampling points of plot size of 5 x 6 m^2 within the tree community rectangular plots (Figure 4).

Figure 4: Example of plot lay-out and soil sampling points of 10-year fallow in Nong Khao. Field codes: 10y = 10-year fallow age. Second number = hill ID. Last number = sampling point ID of *each hill. Yellow rectangular plots for tree community survey size were 6 x 50 m. Orange rectangular plots for surveys of* indicator trees of soil properties size were 5 x 6 *m*. *Source: Google Earth Pro. Image Date: 12/11/2015.*

3.2.2. Plant structural response variables

Measured plant structural variables included diameter at breast height (DBH) as well as canopy height and diameter. Diameters at breast height were measured yearly for all stems of trees taller than 1.5 m using a vernier caliper gauge. For large diameters, girth was determined using a measuring tape and calculating the diameter. Tree height for every stem was measured using a steel tape. For stems >8 m (length of the steel tape), we measured at the estimated half of the total height and then multiplied by two. Where an individual tree consisted of various stems, canopy diameter was measured as the aggregated canopy (Figure 5).

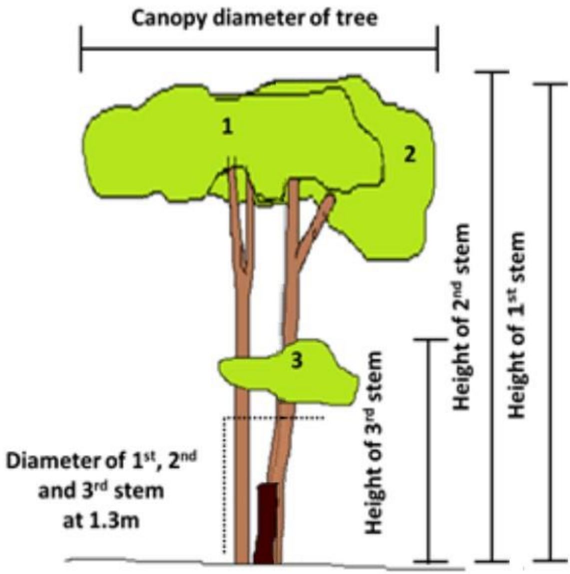

Figure 5: Measurements taken for tree data collection.

To estimate aboveground biomass, allometric equations developed for Northern Thailand by Ogawa et al. (1965) were used. They are based on DBH x tree height (H) and dry weight of stems and branches of individual trees:

$$w_{TC} = 0.043(DBH^2H)^{0.95} \qquad \textit{Equ. 1}$$

where w_{TC} is dry weight of total aboveground woody organs (stem + branches) in kg. *DBH* was measured in cm, and *H* in meters. This equation was proven suitable for estimating aboveground biomass in swidden cultivation fallows in Myanmar by Chan et al. (2013).

3.2.3. Tree diversity-related response variables

The 72 tree survey plots were established between March and April 2010. Every tree taller than 1.5 m was tagged with a number, and the position in the plot was recorded. Numbers of individual trees – and stems for those cases where trees were re-sprouting from stumps after clearing – of every species were counted in all plots and the density of stems per area was calculated.

All trees taller than 1.5 m from one survey plot were identified in the field to a species level by a botanist, J. F. Maxwell of the Herbarium of Biology department, Chiang Mai University. Additionally, local names according to the villagers were recorded. All other plots were accordingly classified. Trees not on the compiled list were taken to the Herbarium of Chiang Mai University for identification.

3.2.4. Soil properties

In the center of each 6 x 5 m tree measurement plot and in the rice plots, soil samples from the top 30 cm were collected from pits at three different soil depths (topsoil, first subsoil, and second subsoil) according to genetic horizons (Figure 6). Six treatments (rice, 1, 3, 6, 8, 10-year fallow) per 3 different soil depths per 9 points per 3 hills sampled over three depths gave 486 soil samples in total. These were analysed for bulk density (BD) by sampling undisturbed cores in steel cylinders of know volume and drying the soil at 105°C to constant weight. Soil pH was measured in 1M KCl. SOM was analysed by the Walkley-Black method (Cottenie, 1980). Plant available Phosphorus (P_{av}) was determined by Bray II (Pagel et al., 1982).

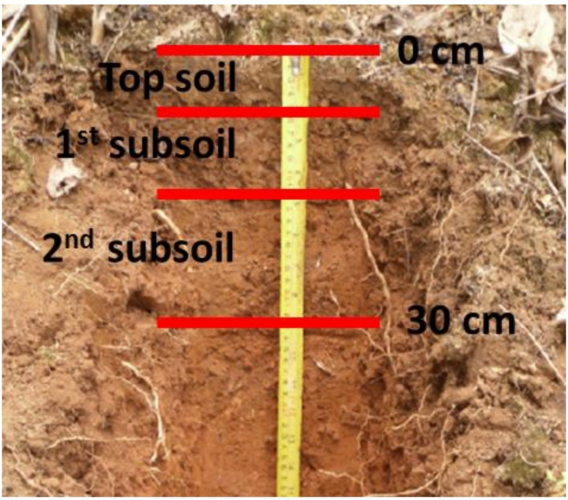

Figure 6: Genetic horizons distinguished within the top 30 cm of a soil profile (example).

3.3. Interviews (Indigenous knowledge)

Information on village history, agricultural system, crop types and yields, plot locations and farmers' decision criteria for plot selection after fallow was collected during the interviews at Nong Khao village. Three focus group discussions with overall 19 key informants selected by recommendation of the village headman. The 19 farmers – including headman, shaman and a traditional healer – were respected in the village for their knowledge on swidden farming and traditional plant use. The group was composed of 12 men and 7 women, both Christians and Buddhists, all above 25 years. Participants represented 15 out of the overall 43 households in Nong Khao. In addition, in depth interviews were conducted in 30 individual households. Traditional indicator trees of soil or ecosystem conditions related to crop productivity were listed by local name. Joint plant and soil surveys were conducted with five of the farmers.

3.4. Data analysis

3.4.1. Indices describing community structure

For each 300 m^2 plot, species richness was determined as the total number of species. Tree density was computed as the number of individuals per hectare. Species diversity was calculated according to the Shannon-Wiener diversity index (Shannon, 1948):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \qquad \text{Equ. 2}$$

where p_i is number of individuals per species divided by the total number of trees, and S is the total number of species.

Equitability (evenness of species distribution) of tree species communities was expressed using Pielou's evenness index (Pielou, 1966):

$$J' = H'/H'_{max} = H'/\ln S \qquad \textit{Equ. 3}$$

where H'_{max} is the potential maximum value of the Shannon-Wiener diversity index that would be reached if all species were equally abundant.

Pielou's evenness index (*J'*) relates population sizes of different species in an ecosystem. With respect to fallow vegetation, evenness is an indicator for dominance of certain pioneer and later-successional tree species. *J'* is constrained to a value between 0 and 1. A lower *J'* represents less evenness of individuals over species and the presence of a dominant species.

Stand structure was characterized by stem density, DBH, and height. The relative ecological importance of each tree species was expressed by the Importance Value Index (IVI), calculated according to Curtis and McIntosh (1950) by the following equations:

$$IVISpA = (relative\ frequency + relative\ dominance + relative\ density) / 3 \qquad \textit{Equ. 4}$$

$$Relative\ frequencySpA = \left(\frac{frequency\ of\ species\ A}{sum\ of\ frequencies\ all\ species}\right) \times 100 \qquad \textit{Equ. 5}$$

$$FrequencySpA = \frac{number\ of\ plots\ in\ which\ species\ A\ occurs}{total\ number\ of\ plots\ sampled} \qquad \textit{Equ. 6}$$

$$Relative\ dominanceSpA = \left(\frac{total\ basal\ area\ of\ species\ A}{total\ basal\ area\ of\ all\ species}\right) \times 100 \qquad \textit{Equ. 7}$$

$$Relative\ density SpA = \left(\frac{number\ of\ individuals\ \ of\ species\ A}{total\ number\ of\ individuals}\right) \times 100 \qquad \textit{Equ. 8}$$

The theoretical range of relative frequency, relative dominance, and relative density is 0-100%. Therefore, the dimensionless value for *IVI* also ranges between 0-100.

Canopy cover was calculated using QGIS (version 2.4.0-Chugiak). The position of each individual tree was mapped in the survey plots. Canopies were drawn by a buffer function. The size of the buffer was half of the canopy diameter. After adding the canopy buffer layer, an area function was used to calculate the canopy cover inside the plot.

The similarity of species abundance between plots was calculated using PRIMER (version 6), which is based on a modified version of the Bray-Curtis coefficient (Clarke and Warwick, 2001).

The similarity between the jth and kth plots, S_{jk} , is expressed as:

$$S_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p}\left|y_{ij} - y_{ik}\right|}{\sum_{i=1}^{p}\left|y_{ij} + y_{ik}\right|}\right\} \qquad \textit{Equ. 9}$$

where y_{ij} is the count for the ith species in jth sample plot ($i = 1,2, \dots, p$) and y_{ik} is the count for the ith species in kth sample plot. Plots were then grouped by cluster analysis with average linkage procedures.

3.4.2. Statistical analysis

In our first study, which related tree structure and diversity parameters to fallow age, temporal maxima of the abovementioned field variables throughout all fallow stages were calculated to determine transition points, or absolute maxima. Two approaches were taken to derive temporal maxima: a) Calculating optima using quadratic regressions and b) comparing means between years. To identify optima for tree diversity, community structure, and aboveground biomass, analysis of the LS-means and the quadratic regression was conducted using the Statistical Analysis Software program (version 9.4, SAS Institute 2015), i.e. the SAS MIXED procedure. In all models, whether regression or categorical effects models, we allowed for spatial and temporal correlation among observations made on the same hill, by fitting an anisotropic power model (Piepho et al., 2004). Different transformations (square root, inverse, log base 10) to meet distributional assumptions for mixed models were considered for every response variable with the exception of canopy cover, which was transformed to a logit scale. Before fitting mixed models, correlations between spatial variables (altitude, aspect, slope, spatial coordinates, and plot position on hills) per plot were estimated by Spearman's correlation. To avoid multicollinearity and collinearity among variables, one of each variable in pairs with correlation $r > 0.7$ was eliminated. To determine the LS-means in the mixed model, fallow age classes were fitted as fixed main effects to test the temporal dynamics of structure- and diversity-related variables. Further explanatory variables were added if they passed an F-test with $p < 0.05$ using a backward elimination procedure. Position on hill (upper, middle and lower) and time of data collection (1st and 2nd year) were classes and used as random effects. The statistical significance level was 0.05 and best-fit data transformations were selected based on studentized residual plots. Pairwise comparisons of LS-means were used to separate response variable means by fallow age. Means not sharing a letter indicated significant differences ($p < 0.05$) between years of fallow age (Piepho and Edmondson, 2018). Optima were then identified by changes between years. The second method to find the optimum was to calculate maxima or minima of quadratic polynomial trends per quadratic regression according to fallow age. This was achieved using the SAS MIXED procedure, with the same random effects as for the LS-means model, but without classifying fallow age as a categorical factor. In this case, fallow age was a quantitative variable and a quadratic regression model was fitted. The full model contained fallow age (first degree) and the square of the fallow age (second degree) as fixed effects for analyzing the quadratic polynomial trend. Finally, the age (x) of the maximum yield for the quadratic polynomial y=a+bx+cx^2 was calculated as x_max= -b/2c. In case of an inverse transformation of y, this corresponds to the minimum of 1/y. We assumed that tree species, community structure, and aboveground biomass were influenced by explanatory topographic variables such as aspect, altitude, position on the hill, slope and geographic location, and not only by fallow age. A stepwise multiple linear regression was used to identify meaningful explanatory variables. These were then ranked by explanatory power calculating standardized beta coefficients. The variable with the highest beta value was the most influential variable.

To relate soil fertility to tree species (4.2.), a preselection of soil samples for further statistical analysis was undertaken by principal coordinates analysis: georeferenced soil data (bulk density, organic matter, P_{av} and pH) from different depths and fallow ages were analysed using Primer (software version 6.1.16) (Clarke and Warwick, 2006). Data was organized by soil properties, sampling depth, and fallow age. So that the soil data could be compared despite differing units, variables were normalised to a range from 0 to 1. A lower triangular resemblance matrix was created and used to calculate the Euclidean distances dissimilarity index between soil samples. Soil sample groups were then classified by overlaying the vector of each soil property in a principal coordinates analysis (PCO) (Clarke and Warwick, 2001).

Based on this, we fitted multiple linear regressions using a) abundances of farmers' indicator species and b) abundances of species found during our detailed botanical surveys as independent variables to predict soil properties.

Individual species were then ranked by best fit, determined by the lowest AIC, in a multiple regression model. In both indicator models, abundances, fallow age, and topographic variables were considered as potential predictors in the model. Variable selection was done using a stepwise forward algorithm in the GLMSELECT procedure to avoid selection of unrealistic variables (Heinze et al., 2018). Then, the selected variables were assessed by a best fit model in the MIXED procedure. This accounted for spatial distribution among observations on the same hill by fitting an anisotropic power model (Piepho et al., 2004). Within the stepwise multiple linear regressions, predictors were ranked by explanatory power of our measured variables. This was achieved using standardized coefficients (with the variable of highest absolute value being the most influential one). The Kenward-Roger method (Kenward and Roger, 1997) was employed to determine the degrees of freedom of the denominator for both the LS means and quadratic regressions as well as for the multiple regression models.

Results and discussion

4.1. Ecosystem recovery indicators as decision criteria on potential reduction of fallow periods in swidden systems at different sites[1]

4.1.1. Results

Dynamics of stand structure and biomass during fallow periods

Tree density, biomass, habitus (DBH and height), and canopy cover are analysed in this subsection. Density and canopy cover are considered indicators for plant competition, whereas DBH and biomass indicate carbon stocks.

Development of stem density with fallow age

In Bor Krai, stem density increased in the 1-year, 2-year and 3-year fallows, before reaching its maximum and stabilizing after year 6 (Figure 7a and b). Correspondingly D-max, the maximum derived from the regression, was reached around year 4. This was based on log-transformed density data of individual stems per area. In Nong Khao, significant differences appeared only between year 9 and 10, and maximum density was reached in year 4, as in Bor Krai (Figure 7a and b). From the outset, stem density in Nong Khao was higher than in Bor Krai.

Increase of average DBH with fallow age

Diameter at breast height and its log-transformed analogue served as comparative indicators of tree volume and carbon stocks. Both sites showed increasing DBH over time (Figure 7c). The maximum in Bor Krai was reached by

[1] Published in Ecological Indicators 95:554-567 (2019).

year 4 based on log DBH (Figure 7d). There was no maximum DBH in Nong Khao within the observation period. DBH in Bor Krai was higher than in Nong Khao after the first year.

Increase of average height with fallow age

Absolute differences between sites were minimal, tree height in both showed a tendency towards linear increase (Figure 7e and f). Inverse tree height continuously decreased in Bor Krai, reaching its (preliminary) minimum between 5 and 6 years, which was the end of the current fallow period. In Nong Khao, inverse values continuously decreased until year 8, before increasing by year 10. Despite uncertainties usually related to height measurements, standard errors were low and models highly significant.

Changes of canopy cover with fallow age

Canopy cover data, although not collected for all years, was analyzed based on the logit-transformed values of canopy cover over open area (Figure 7g and h). For Bor Krai this parameter increased steadily until year 6 so that there was no changing point. In contrast, canopy cover in Nong Khao increased until year 8, and then slightly decreased (although not significantly) towards year 10. Spatially explicit measurements of stem positions and canopy diameters allowed the analysis of the spatial canopy distribution and gap formation in the stands (see Figure 9). From the outset, canopy cover in Bor Krai was lower than in Nong Khao.

Changing aboveground biomass with fallow age

Tree aboveground biomass was derived from DBH and height measurements using the allometric equations of Ogawa et al. (1965). The aboveground biomass values from different fallow stages were compared using log-transformed data (Figure 8a and b).

As was the case with height and DBH, a continuous increase was observed in the log-transformed aboveground biomass. In Bor Krai it stabilized at year 4, whereas it stabilized at year 10 in Nong Khao. The maximum in Bor Krai was calculated for year 5, while no change was found in Nong Khao in the observed fallow age classes. Aboveground biomass in Bor Krai was originally lower than in Nong Khao, but after 2 fallow years both sites did not differ significantly ($\alpha = 0.05$).

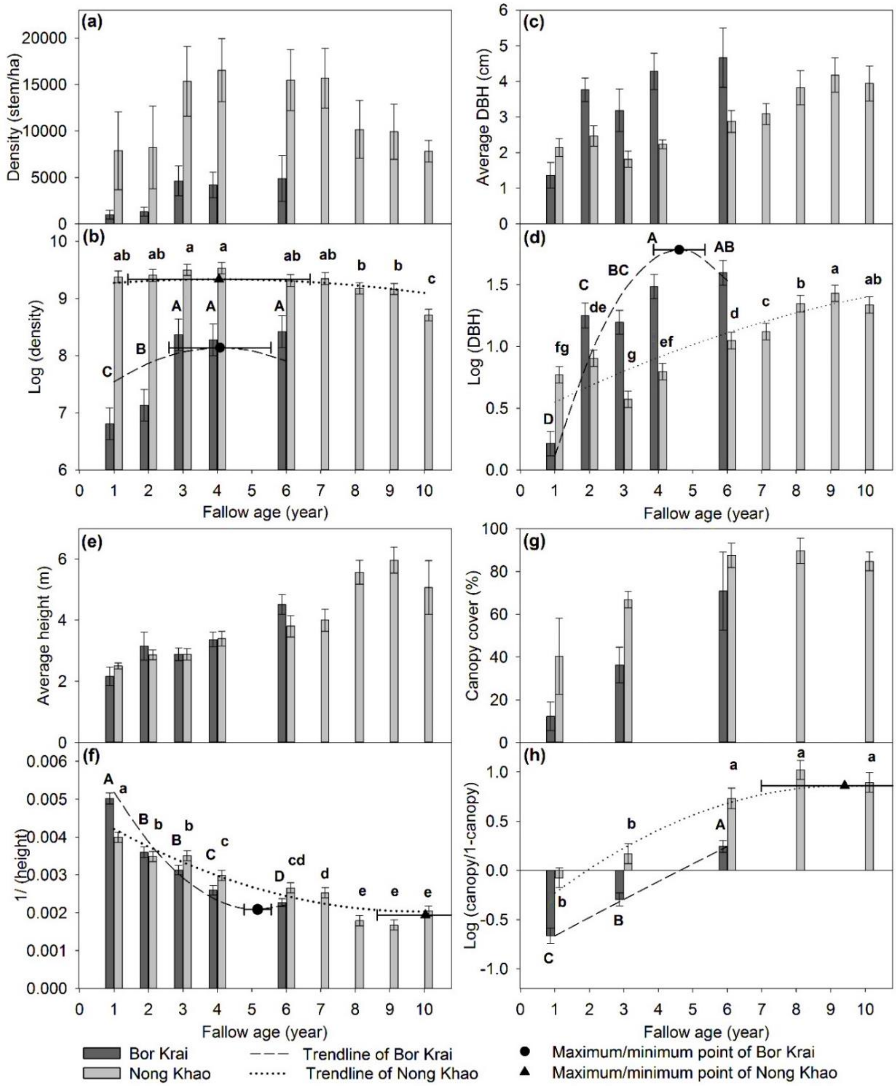

Figure 7: Dynamics of tree stand structural variables on plots over different fallow stages (n=9 plots per year) in Bor Krai and Nong Khao. Per variable, upper figures show averages and standard deviations. Lower figures show transformed data

used to fit multiple regressions with a quadratic term for the variable itself, and including fixed effects shown in Table 3. Error bars of lower figures represent standard errors. Means not sharing a letter indicate significant differences (p < 0.05) between years of fallow age. Maxima or minima are shown where present. (a) Stem density. (b) Multiple regression and LS- Means for log-transformed stem density. (c) Diameter at breast height (DBH). (d) Multiple regression and LS-Means for log-transformed DBH. (e) Tree height. (f) Multiple regression and LS-Means for inverse-transformed tree height. (g) Canopy cover. (h) Multiple regression and LS- Means for log-transformed canopy cover over uncovered area.

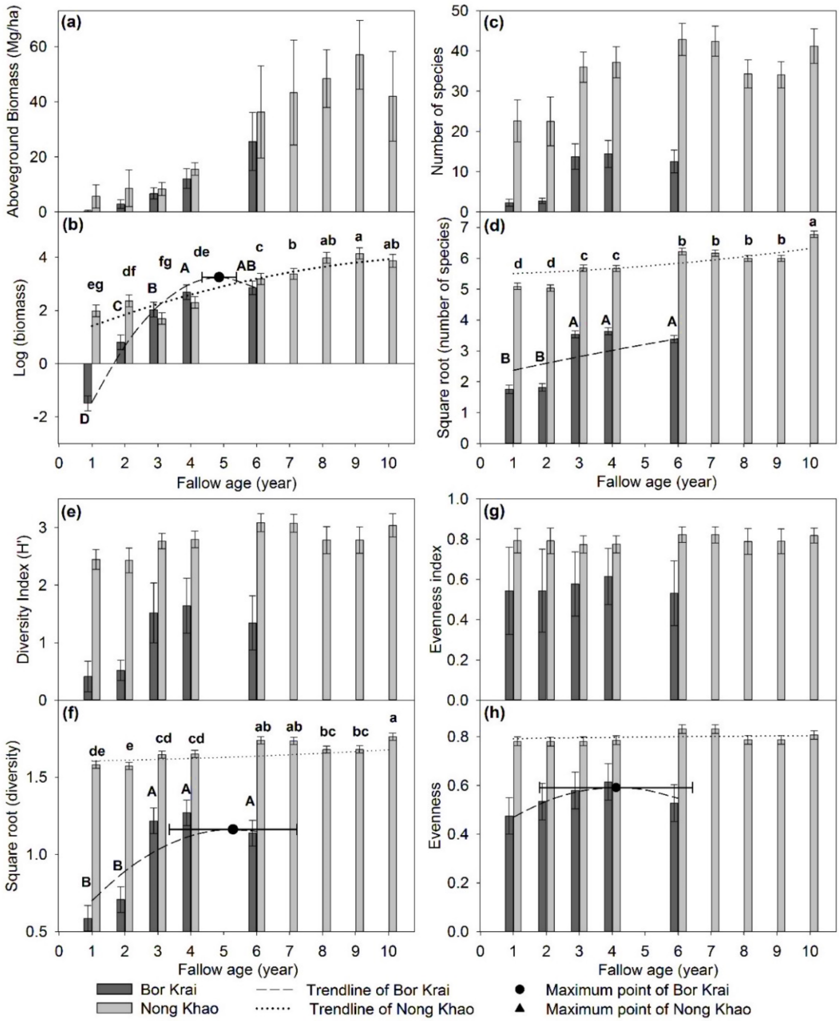

Figure 8: Dynamics of tree aboveground biomass (AGB) and tree species diversity over different fallow stages (n=9 plots per year) in Bor Krai and Nong Khao. For each variable, the upper figure shows averages and standard deviations. The lower figure shows transformed data used to fit multiple regressions with a quadratic term for the variables itself, and including fixed effects shown in Table

3. Error bars of the lower figures represent standard errors. Means not sharing a letter indicate significant differences ($p < 0.05$) between years of fallow age. Maxima or minima are shown where existent. (a) Aboveground biomass. (b) Multiple regression and LS-means for log-transformed aboveground biomass (c) Species numbers (d) Multiple regression and LS-means for square root-transformed species numbers. (e) Shannon-Wiener diversity index (H'). (f) Multiple regression and LS-means for square root-transformed H'. (g) Pielou's evenness index (J'). (h) Multiple regression and LS-means for evenness index.

Dynamics of tree species diversity with fallow age

Species number and the derived Diversity and Evenness Indices were analyzed to characterize changes in species diversity according to fallow age.

Changes in species numbers with fallow age

Tree species of all individuals > 1.5 m height were classified on all plots of all sampled fallow stages at both sites (Figure 8c). Square root-transformed species numbers (Figure 8d), increased in Bor Krai after year 2 and then remained stable, whereas in Nong Khao they remained stable during years 1 and 2, increased towards year 3, and then between years 5 and 10. Thus, apart from the generally higher species number in Nong Khao, no peak or optima were reached during the observed fallow stages in either site.

Change of diversity index over time

The Shannon-Wiener diversity index (H') was calculated as an integrated measure of species number and population size (Figure 8e and f). In line with the species numbers, diversity increased from year 2 to 3 and then remained stable in Bor

Krai. A turning point was reached in year 5. Diversity index was overall higher in Nong Khao and followed the trends observed for species numbers.

Change of evenness index over time

Averages for Pielou's Evenness Index are shown Figure 8g. In the case of Bor Krai, the untransformed evenness index gave the best fit. Values increased from the first to the fourth year and then dropped, but significant differences between years were not found. By contrast, a changing point was found according to the regression in year 4 (Figure 8h). Nong Khao showed generally higher levels than Bor Krai and no changes in evenness between years.

Species importance and dominance and similarity between plots

Based on the survey of different fallow ages conducted over two years, we identified a total of 45 tree species, representing 38 genera and 23 families in the 27 sample plots in Bor Krai. In the 45 sample plots in Nong Khao, 118 tree species, representing 92 genera and 41 families were identified (Table 1).

The total number of species across all plots per fallow age showed the same trend as the average number of tree species according to fallow age (Figure 8c): In Bor Krai, the 4-year fallow stand contained the highest number of species, genera, and families, followed respectively by the 3rd, 6th, 2nd, and 1st year. In Nong Khao, the total tree species number in the 10th year fallow was highest, followed respectively by years 6 and 7. Total species numbers of all replicates per fallow stage at both sites were always about two to three times higher than average species numbers per plot sample, indicating high variability between plots. In Bor

Krai there was a clear increase in the number of tree species during the first three years, but this was not as apparent in Nong Khao.

Table 1: Total number of tree species, genera and families on all studied plots per fallow age class in Bor Krai (n = 27) and Nong Khao (n = 45).

Fallow age (years)	Bor Krai			Nong Khao		
	No. of species	No. of genera	No. of families	No. of species	No. of genera	No. of families
1	7	5	5	73	63	31
2	10	8	7	71	61	30
3	38	33	21	75	63	32
4	39	34	22	75	62	32
6	32	28	18	89	74	36
7				88	73	36
8				75	64	35
9				74	64	34
10				92	75	37
Total	45	38	23	118	92	41

Species dominance was calculated by the Importance Value Index (IVI), which is based on density, distribution, stem basal area and canopy cover. In Bor Krai, both the *IVI* and canopy cover gave the same ranking of species, with *Lagerstroemia villosa* as the predominant species in all survey years, followed by *Xylia xylocarpa* var. *kerrii* in years 1 and 6. In both areas, the dominance of these two species, indicated by the *IVI*, was clearest in year 1, followed by year 6, while canopy cover increased with fallow age, in case of *L. villosa* (Table 2), up to 84%. *L. villosa* appears to follow a typical pioneer species strategy, high seed dispersal and rapid growth. The *IVI* and canopy cover coincided to a lower degree in Nong Khao, and dominance was less pronounced and shifted between fallow stages. From year 3 onward, *Macaranga denticulata* and *Eurya acuminata* became dominant and attained a significant high canopy cover in year 8, but decreased in absolute terms towards year 10, in parallel with DBH and biomass. *Aporosa villosa* was among the dominant species during most years according to the IVI, but less so in regard to canopy cover.

Table 2: Importance value index and % canopy cover of dominant species in Bor Krai and Nong Khao villages during different fallow stages. Numbers in brackets represent top ranking positions from 1 to 3.

	Importance Value Index					% Canopy cover				
Fallow age (year)	1	3	6	8	10	1	3	6	8	10
Dominant species in Nong Khao										
Gluta obovata	12.2 (1)	0.3	0.7	1.1	0.5	9.6 (1)	0.1	1.0	0.7	0.7
Aporosa villosa	7.8 (2)	8.6 (2)	7.1 (2)	3.3	6.7 (3)	3.7	10.4	19.1 (1)	7.3	15.0 (3)
Litsea glutinosa	6.1 (3)	1.1	0.5	1.9	0.1	4.0 (3)	0.8	0.8	4.4	0.0
Croton argyratus	3.9	0.0	0.9	0.2	0.0	4.1 (2)	0.0	3.5	0.7	0.0
Lithocarpus polystachyus	1.9	1.7	3.2	2.2	7.0 (2)	0.7	1.9	8.5	4.4	16.7 (2)
Macaranga denticulata	1.0	9.0 (1)	0.1	13.4 (2)	9.2 (1)	0.3	12.3 (1)	0.1	51.9 (1)	33.2 (1)
Eurya acuminata	0.2	7.9 (3)	0.8	13.7 (1)	1.5	0.0	10.9 (3)	1.8	40.5 (2)	3.2
Maesa ramentacea	0.5	6.4	2.2	3.1	3.9	0.2	11.6 (2)	6.5	7.4	12.1
Wendlandia tinctoria	0.5	4.8	8.6 (1)	3.2	2.4	0.2	5.5	18.4 (2)	8.2	5.4
Styrax benzoides	0.3	3.8	4.8 (3)	4.0 (3)	2.0	0.1	5.5	13.1 (3)	10.1 (3)	4.1
Dominant species in Bor Krai										
Lagerstroemia villosa	65.0 (1)	36.3 (1)	43.0 (1)			16.7 (1)	24.5 (1)	84.2 (1)		
Xylia xylocarpa var. *kerrii*	11.9 (2)	4.1	7.9 (2)			1.5 (2)	2.2	9.3 (2)		
Holarrhena pubescens	6.8 (3)	3.7	2.6			0.4 (3)	1.1	2.3		
Anogeissus acuminata	1.5	1.4	5.1 (3)			0.1	1.2	8.2 (3)		
Tectona grandis	0.0	5.3 (3)	2.2			0.0	2.5 (3)	2.0		
Miliusa velutina	1.7	9.6 (2)	2.1			0.1	4.6 (2)	1.5		

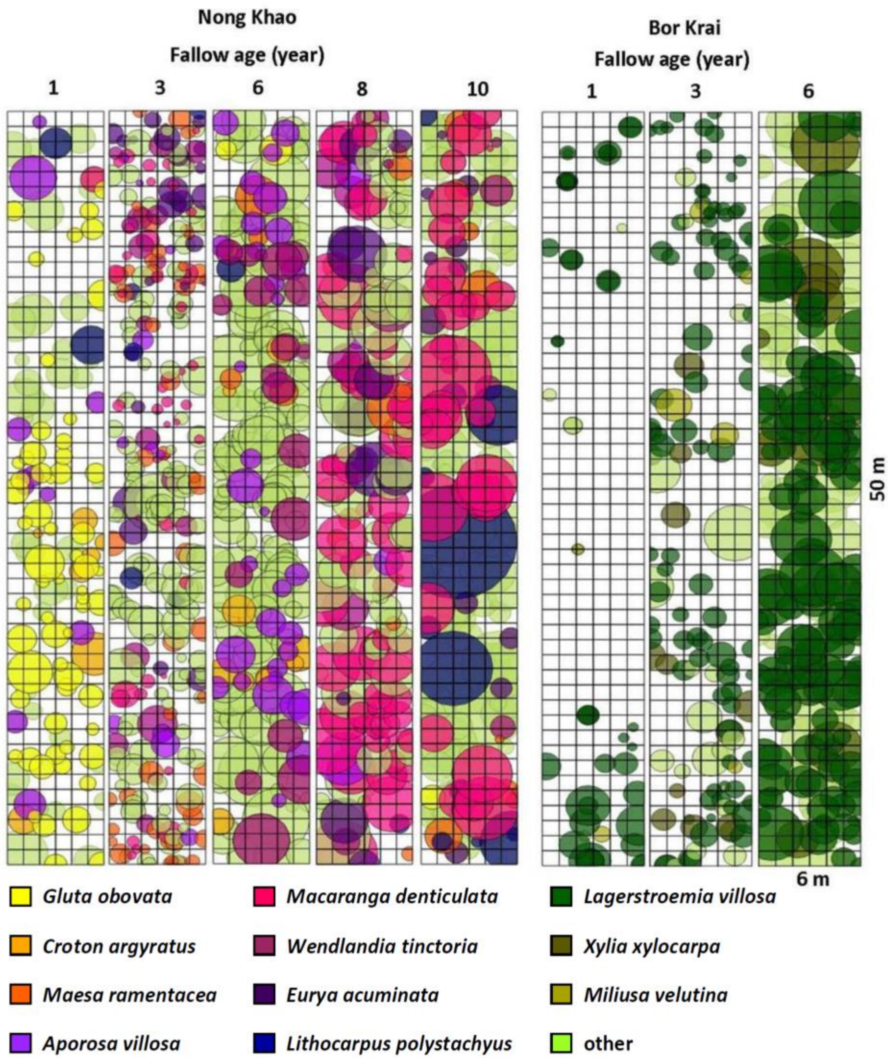

Figure 9: Georeferenced canopy cover of trees in different chronosequence sample plots (size 6 x 50 m) after 1, 3, 6, 8- and 10-years fallow in Bor Krai and Nong Khao. Canopy cover layers were arranged by the highest percent cover per species and plot.

Visualization of canopy diameter derived from geo-referenced tree positions from an exemplary one sample plot false time-series at both villages (Figure 9) shows that canopy cover increased from 1- to 6-year fallow, but not much beyond (see also Figure 7g). The top 2 species listed in Table 2 are also clearly visible. During the early age of fallow only the dominant species, such as *Gluta obovata*, *Croton argyratus* and *Maesa ramentacea,* were distributed acoross the plot. However, clear gap dynamics can be seen, even in the 10-year fallow in Nong Khao, canopy cover never exceeded 80-95%.

Variability in species composition between plots of the same age has been mentioned in context with Table 2. In order to compare the tree species composition between plots we used the average-based Bray-Curtis similarity index derived from cluster analysis. Figure 10 shows that tree communities at the two study sites were clearly distinct, whereby data from continuously monitored plots showed higher similarity index values compared to those from the chrono-sequence plots. 3- and 4-year fallows in Nong Khao were more similar to 8-, 9- and 10-year fallows, compared to 6- and 7-year fallows.

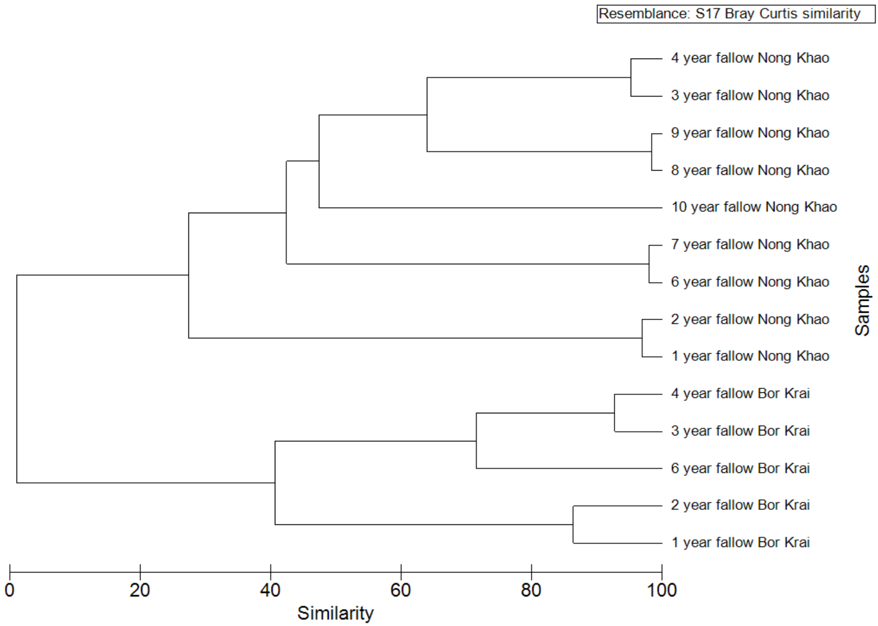

Figure 10: Plots of different fallow ages at two sites grouped by cluster analysis according to similarity (%) in tree species composition.

Grouping, particularly in Nong Khao, may have been influenced by the spatial clustering of collectively managed plots (see Figure 10). In Bor Krai, 3- and 4-year fallows were more similar to 6-year fallows than to 1- and 2-year fallows. Fallow age played an important role in regard to similarity index values, along with distance between plots. 1 and 2-years fallows contained significantly lower species numbers compared to plots of other fallow ages (Figure 8d).

Influence of topographic and spatial variables on species diversity and tree community structure

A remaining and crucial question is the degree to which fallow age served as an explanatory variable rather than topographic factors. To explain the recovery of tree species' number and community structure, fallow age, topographic variables (aspect, altitude, position on hill, slope, geographic location), and vegetation variables (number of species, density, aboveground biomass, average DBH and height) were tested using a stepwise multiple linear regression analysis.

Table 3: Stepwise multiple regression analysis for diversity and structure-related indicators at Nong Khao and Bor Krai. Standardized Beta Coefficients (B) show the relative explanatory power of the variables

				Standardized Coefficients	
Dependent Variable	Transformation	Study site	Explanatory Variable	*B*	Std. Error
Density	Log(density)	Bor Krai	(Constant)	7.824	0.241
			Fallow age	0.305	0.133
		Nong Khao	(Constant)	9.226	0.067
			No. of species	0.362	0.03
			Evenness index	0.13	0.041
			Fallow age	0.044	0.044
DBH	Log(DBH)	Bor Krai	(Constant)	1.133	0.107
			Fallow age	0.43	0.106
			Density	-0.086	0.024
		Nong Khao	(Constant)	1.024	0.045
			Fallow age	0.284	0.038
Height	1/(height)	Bor Krai	(Constant)	3.36E-03	1.22E-04
			Fallow age	-8.60E-04	1.66E-04
			Slope	2.53E-04	1.36E-04
			Aspect	4.90E-05	1.61E-04
			Density	2.00E-05	9.10E-05

Dependent Variable	Transformation	Study site	Explanatory Variable	Standardized Coefficients *B*	Standardized Coefficients Std. Error
Height	1/(height)	Nong Khao	(Constant)	2.78E-03	9.00E-05
			Fallow age	-7.50E-04	8.10E-05
Canopy cover	Logit canopy cover	Bor Krai	(Constant)	-0.309	0.029
			Density	0.327	0.04
			Fallow age	0.313	0.032
			Slope	-0.157	0.034
		Nong Khao	(Constant)	0.642	0.063
			Fallow age	0.377	0.049
			Density	0.189	0.046
			Position on hill	-0.077	0.06
Above ground biomass	Log(biomass)	Bor Krai	(Constant)	1.331	0.279
			Fallow age	1.345	0.275
			Density	0.348	0.085
			Slope	-0.203	0.301
		Nong Khao	(Constant)	3.008	0.133
			Fallow age	0.857	0.108
			Density	0.231	0.063
			Slope	-0.186	0.121
			No. of species	0.145	0.074
			Position on hill	-0.051	0.093
Number of species	Square root (no. of species)	Bor Krai	(Constant)	2.813	0.155
			Fallow age	0.346	0.116
			Density	0.345	0.127
			Evenness index	0.146	0.084
		Nong Khao	(Constant)	5.917	0.093
			Density	0.429	0.047
			Fallow age	0.274	0.073
Diversity index (Shannon-Wiener index: H')	Square root (diversity)	Bor Krai	(Constant)	0.962	0.067
			Fallow age	0.174	0.051
		Nong Khao	(Constant)	1.679	0.014
			Fallow age	2.34E-02	9.70E-03
			Density	2.29E-02	6.03E-03
Evenness index (Pielou's index: *J'*)		Bor Krai	(Constant)	0.534	0.043
			Fallow age	0.04	0.032
		Nong Khao	(Constant)	0.7974	0.0082
			Density	-0.0115	0.0026
			Fallow age	0.0041	0.0041

Fallow age was the main determinant for stand structure and species number in Nong Khao, whereas topography played only a minor role. In Bor Krai, topography played a role for biomass, canopy cover and height, but was less prominent compared to fallow age. Tree density and species number were highly correlated (overall Spearman correlation $r=0.85$, $p<0.001$) in Nong Khao, whereas in Bor Krai density did not influence species number. Importance of fallow age was generally higher in Nong Khao than in Bor Krai.

4.1.2. Discussion

To decide if fallow periods in traditional agricultural systems of the Karen and Lahu in Northern Thailand can be shortened without compromising the ecological functions of secondary forest succession, indicator variables were chosen that represent stand structure and tree species diversity as important ecosystem characteristics. These were monitored and surveyed over the currently practiced fallow durations at the two study sites. Our assumption was that relevant indicator variables need to pass a peak within the currently practiced fallow duration to justify a further reduction in the length of fallows.

Species turnover and diversity as indicators for assessment of fallow periods

Our first hypothesis assumed that fallow stages are characterised by shifts in the composition of (site-specific) dominant species. Thus, a potential reduction in fallow duration could be assessed based on in the assumption that a specific successional stage at the end of the fallow period should be reached.

Two species inventories, of a mature secondary forest in Bor Krai (Seanchanthong 2005) and of a 30-year old forest in Nong Khao (Tongkoom 2009), both on plots of comparable dimensions to this study, served as benchmarks for climax vegetation. During the initial fallow stages, both of study sites had a high proportion of benchmark forest species in common (Figure 11a and b). This was due to their locations within a largely forested environment, with high regeneration from stumps and rootstocks leading to high survival and regrowth rates (Kennard, 2002; Vieira and Proctor, 2007; Wangpakapattanawong et al., 2010). Seedlings < 1.5 m in height were not captured by our inventory method and add to the number of forest species. In this respect, both study sites had the genetic potential to develop into natural forest and were – for agricultural systems – still relatively similar to the surrounding natural forest (Ding et al., 2012).

In Nong Khao, the number of tree species and the diversity index were high from the beginning of the fallow period. Dominance in terms of *IVI* and canopy cover shifted over time, so that different successional stages could be distinguished (Table 2): *Gluta obovata*, *Aporosa villosa* and *Litsea glutinosa* dominated during the first fallow year, *Wendlandia tinctoria* and *Styrax benzoides* during the 6-year fallow. Fast-growing pioneer trees propagated by seed included *Croton argyratus* (ballistically dispersed) in the first-year fallow, *Macaranga denticulata* (animal dispersed), dominant in 3-, 8- and 10-year fallows, and *Eurya acuminata* (animal dispersed), dominant in 3- and 8-year fallows. (Fukushima et al., 2008) also observed the dominance of *E. acuminata* and other species that produce small berries, which are dispersed over large distances by birds. This is a comparative advantage over species with large fruits and slow re-sprouting behavior, like many Fagaceae (Teegalapalli and Datta, 2016). While dominance shifted over time, diversity, and evenness indices in Nong Khao remained at a constantly high level and peaks were not detected. Species number at the end of the fallow period was higher than in the nearby forest, due to the presence of fallow and forest species (Seanchanthong, 2005).

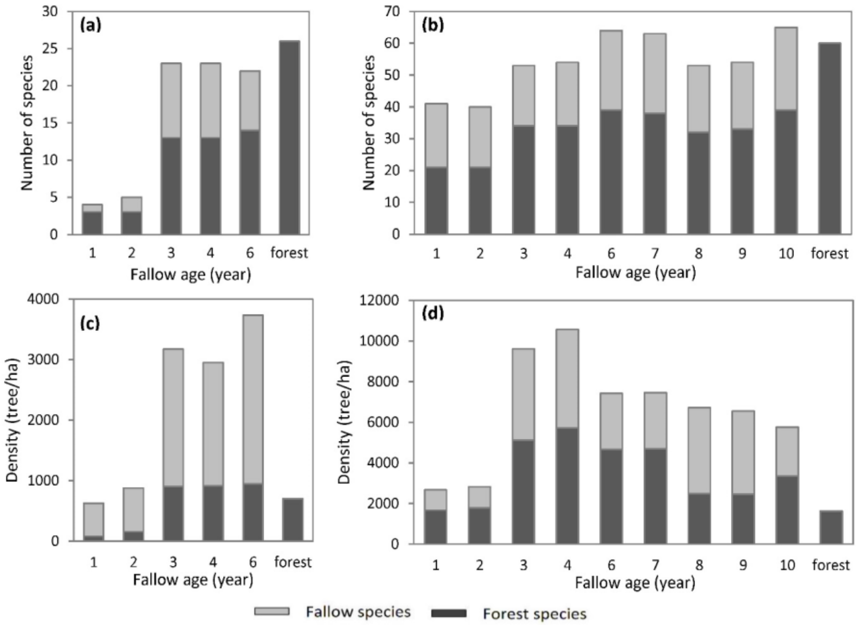

Figure 11: Numbers of fallow and forest species over fallow age at Bor Krai (a) and Nong Khao (b) sites and tree density at Bor Krai (c) and Nong Khao (d) compared with forest data from the studies by Seanchanthong (2005) in Bor Krai and Tongkoom (2009) in Nong Khao. Note the different scales on the y-axes.

In Bor Krai, the most dominant species during all fallow years was *Lagerstroemia villosa*, favoured because of its resistance to fire, and then its fast regrowth afterwards. Its tiny, winged seeds are also widely dispersed by the wind. Its canopy is not too dense, particularly in the dry season, so that other deciduous tree species such as *Xylia xylocarpa* var. *kerrii* and *Miliusa velutina* could also be found nearby. These species regenerated from rootstocks or stumps, but grew slower than *Lagerstroemia villosa*. Dominance did not shift to other species and proportional canopy cover of *L. villosa* still increased over time (see *IVI* in Table 2). Species numbers did not pass a peak (Figure 8d), but fallow species still constituted around one third of all species at the end of the fallow period (Figure 11c). The diversity index in Bor Krai was low at the beginning of the fallow, and reached but did not pass a peak within the fallow period (Figure 8f). At the end of the fallow period, the overall species number was still lower than in the nearby forest, and also three times lower than in the six-year fallow in Nong Khao (disproportional to the difference between the benchmark inventories) – another potential indicator of site degradation. The most dominant species observed during the various fallow periods were not found in the forest plots, indicating that the system, despite its high proportion of forest species, was still far from the climax stage.

Sites clearly differed in terms of species number and diversity index throughout the entire fallow period. Correspondingly, the tree species diversity of the climax stage in Nong Khao doubled that of Bor Krai (Figure 11a and b). Apart from natural differences in climax vegetation, this may be due to more advanced degradation, in regard to a loss of diversity, from intensified agriculture in Bor Krai. It seems probable that, apart from the fallow duration, the number of consecutive cultivation cycles is an important factor for degradation of tree species diversity. Up to three years of cropping (including herbicide use) in Bor Krai may have more seriously affected the soil seed bank as well as reduced the resilience of residual vegetative forest species regeneration more severely than one year of upland rice cultivation in Nong Khao.

In terms of our hypothesis, successional stages could be distinguished by the shift in dominant species over time in Nong Khao. Based on in-depth interviews, we know that the dominance of *Macaranga denticulata* is the main indicator of fallow maturity for villagers before initiating a new cropping cycle (see 4.2.).

As a result, we reject our first hypothesis in the case of Bor Krai, where one species dominated the community in terms of individual numbers and IVI.

Changes in stand structure and biomass

Our second hypothesis stated that typical peak or saturation curves (with slope = 0 at some point in time) for structural variables indicate changes in climax stages, which then could be used to identify appropriate fallow duration.

In Nong Khao, stem density passed a turning point and subsequently decreased in both LS-means and quadratic regressions (Figure 7a and b), which was our criterion for potentially shortening the fallow period. The increase during early succession can be attributed to invasion and colonization of pioneer species and re-sprouting of trees (Uhl et al., 1981). With progressive canopy closure, tree density decreased, due to light competition (Kennard, 2002) and the limitation of pioneer species recruitment (Van Breugel et al., 2007). The death of individual stems of a plant, counted separately, also influenced density (Ding et al., 2012; Sovu et al., 2009; Van Do et al., 2010; Vieira and Proctor, 2007). The regression peak for average tree height was reached in year 10, which was supported by LS-means values (Figure 7f). Both methods showed that the peak was outside the fallow period for the aboveground biomass (AGB) (Figure 8a).

In Bor Krai, the regression maxima of all structural variables except canopy cover were within the six years fallow period, but all curves displayed a plateau shape, so that none passed a peak. Density increased throughout the fallow period, and exceeded density at the benchmark site. Average tree height in Bor Krai reached a preliminary maximum, but no turning point within 6 years. After 6 years of fallow, AGB for Bor Krai and Nong Khao was around the same level, 20 Mg/ha. It seems that agricultural intensification and loss of species diversity in Bor Krai had no effect on AGB, as suggested by (de Aguiar et al., 2013; Van Do et al., 2010). On the other hand, time-averaged C stocks of swidden systems have been found to be dependent on fallow duration (Hepp et al., 2018).

With respect to the second hypothesis, structural response variables and derived biomass can be used as indicators for recovery times, if general curve shapes for the variables are known and a turning point is reached within the observed fallow period. In our case, knowing the endpoint of the climax community allowed drawing conclusions on species diversity and tree density. This was not the case for biomass, but general curve shapes are known and can be linked to different intensification levels. For example, Kenzo et al. (2010) found that fast fallow regrowth after a short first-time cropping period, and then sigmoid regrowth curves after repeated longer cultivation times as described by Van Do et al. (2010). For some response variables, results from the quadratic regressions and LS-means differed, which made interpretation difficult. Based on the results of the tests of hypotheses 1 and 2, we found our indicator based approach suitable to use when deciding if fallow duration reduction was appropriate. However, stand structure and biodiversity are not the only decisive criteria, and a comprehensive assessment would include soil fertility and soil productivity

(Cairns and Garrity, 1999; Cairns and Brookfield, 2011) as well as socio-economic factors. When taking these factors into account, extending rather than reducing fallow periods in Bor Krai could reduce weeding and pesticide costs and stabilize soil fertility assuming that sufficient land was available.

Methodology and generalization of the approach

In this study, we used a combined chronosequence and monitoring approach, in which plots of comparable topography, but different fallow ages, were selected for measurements in the first study year, and then monitored the following year. For a successional research question, temporally independent samples are not needed, so that a monitoring approach is not critical. When interpreting the data, we had to account for plot properties or spatial clustering overriding effects of fallow duration (Jepsen, 2006). We quantified the explanatory power of spatial location, hill position, altitude, slope and aspect on species composition through multiple regression analysis. For both sites, fallow age as a determinant for all investigated variables outweighed the spatial variables, slope, aspect and hillslope position (Table 3). Canopy cover and AGB were slightly influenced by spatial factors, in Bor Krai by slope, and in Nong Khao by slope position. Some variables were closely correlated, often with tree density, so that fallow age only explained part of the variability.

The LS-means and maxima of the quadratic regressions agreed closely, indicating a good fit for the regression model. Where this was not the case, the LS-means could be helpful in distinguishing the peaks from plateaus, where the quadratic term of the linear regressions was not significant (not shown). Based on our analysis, it was determined that, a) both analyses showed no change over time (evenness index in Nong Khao); b) regression maxima coincided with the fallow period of highest values identified by LS-means. This was the case for most variables, assuming that non-existing maxima are in agreement with LS-means plateau curves. According to the AGB, a regression maximum could help to narrow down points in time for decisions on fallowing, as the LS-means results gave a wide range of years. In response to our research question on shortening fallow periods, some conclusions can be drawn. Table 4 summarizes results of both methods. Under the premise that both methods should show a transgression of a maximum, shorter fallow periods are not justified for both sites without compromising ecological functions. Declining tree density in Nong Khao is not considered an indicator for reduction of fallow duration, as the natural trend should resemble thinning (Kennard, 2002; Van Do et al., 2010).

Table 4: Summary of regression and LS-means results.

		Bor Krai		**Nong Khao**	
Group	**Response variable**	**Max. of regression (y)**	**LS-means**	**Max. of regression (y)**	**LS-means**
Structural	Density	4.1	Plateau	4.1	Lin. decrease
	DBH	4.6	Plateau	n.a.	Plateau
	Height	5.2	Plateau	10.0	Plateau
	Cover	n.a.	Plateau	9.4	Plateau
	AGB	4.9	Plateau	n.a.	Plateau
Diversity-related	Sp. number	n.a.	Plateau	n.a.	Plateau
	Diversity	5.3	Plateau	n.a.	Plateau
	Evenness	4.1	n.s.	n.a.	n.s.

The contrasting study sites had been selected to assess in how far our approach was generic for different types of climax vegetation and land use systems. We assume generic curve shapes per response variable represent biological processes, e.g. plateau shape for DBH, plateau or Gompertz curves for biomass, peak or continuous decrease for density. In our case, curve shapes per response variable were the same at both sites, such as the mainly plateau curves and constant trends for Pielou's evenness index. We assumed that in longer fallows, response variable values would pass a peak due to light competition. A decreasing, but not significant downward trend of the regression curves as well as LS-means results could be observed for several response variables (Figure 7 and Figure 8). While the general mechanisms apply, site-specific adjustments to regression factors and polynomial function need to be applied to represent characteristics of climax vegetation, management and degradation stage of the system. Following the partial acceptance of the previous hypotheses, we accept the third hypothesis for the approach *per se*, while concrete recommendations on fallow duration must be based on site-specific data.

4.2. Tree species as traditional indicators of soil fertility in Nong Khao[2]

4.2.1. Results

Farmers' indicator species for soil fertility restoration

Farmers explained that the decision to end a fallow period and initiate a new cropping cycle was based primarily on soil fertility, assessed by observation of indicator trees. Tree abundance and soil fertility were functions of fallow age. Amounts of leaf litter and decomposition of old tree stumps were mentioned in this context. By experience and common agreement cropping could start after about 10 years of fallow. Younger plots (8 to 9 years fallow) could be chosen if a 10-year fallow had been disturbed (e.g. by fire) or if the soil under an older fallow plot was not considered sufficiently fertile for cultivation. Further criteria for cropping were weed suppression and topography with valley bottoms being preferred to ridges.

Farmers assessed absolute and relative tree abundances semi-quantitatively and related them broadly to soil conditions. During the meetings, farmers agreed on ten tree species and one genus as indicators of soil quality (Table 5). Four of these species were indicators of 'good' soil, i.e. soil that produces 'good' rice *and* vegetable yields (an average rice yield in Nong Khao was 2.6±1 Mg ha^{-1}); five species indicated hard (compacted) soil. *Eurya acuminata* DC., if dominant, indicated that the soil was not appropriate for planting rice.

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[2] Published in Ecological Indicators 127:107719 (2021).

Table 5: Tree species, their indication regarding soil fertility and cropping according to farmers, and appearance by successional stage

Family	Species	Indication	Succession stage
Euphorbiaceae	*Croton roxburghii*	good soil*	Climax
	Macaranga denticulata	good soil	Pioneer
Hypericaceae	*Cratoxylum formosum* subsp. *pruniflorum*	hard soil	Climax
Leguminosae	*Dalbergia cultrata*	good soil	Climax
Moraceae	*Ficus* spp, mostly *Ficus hirta*	good soil	Climax
Myesinaceae	*Maesa ramentacea*	hard soil	Climax
Myrtaceae	*Tristaniopsis burmanica* var. *rufescens*	hard soil	Climax
Rubiaceae	*Canthium parvifolium*	hard soil	Pioneer
	Prismatomeris tetrandra	hard soil	Pioneer
Theaceae	*Eurya acuminata*	not good for rice	Climax
	Schima wallichii	good soil	Climax

* Farmer definition for “good soil” is good for vegetable *and* upland rice cultivation

Changing soil physical and chemical properties with fallow age

To assess soil compaction and relate it to farmers tree indicator for "hard soil", we used BD; while for soil fertility we used the proxies organic matter, Pav and pH and related them to the farmers' indicator species used for 'good soil'.

Comparison of topsoil properties between fallow stages by LS-means and quadratic regression showed significant changes over time for all soil parameters (Figure 12).

Mean BD at the beginning of the fallow period was lower than after 6 years fallow, i.e. succession initially went along with topsoil compaction (Figure 12a). Medians of 1- and 8-years fallow (Figure 12a, boxplots) were opposed to their LS-means and variability (SE), i.e. higher in years one (0.112) and 8 (0.061) compared to other years (0.026 to 0.036). This reflected differences in elevation of plots of different fallow stages (Figure 13). Consequently LS-means and regression of BD over fallow age included altitude as a fixed effect. Likewise, SOM (Figure 12b) included altitude and exposition as fixed effects. Trends of both SOM LS-means and regression as well as medians consistently showed maximum in years 3 to 4. Due to the higher variability (SE) in years 1 (1.37) compared to other years (0.3 to 0.67), SOM values were not significantly different from other stages. The median SOM in fallow year 1 was about 6% lower than for the other fallow stages up to year 8 (8 to 10 %). For P_{av} (Figure 12c) and pH (Figure 12d) there were no topographic fixed effects and LS-means trends were reflected by the medians. LS-means and regression analysis showed turning points with minima around years 8 and 7, respectively. Highest values occurred in year 1 for both P_{av} and pH.

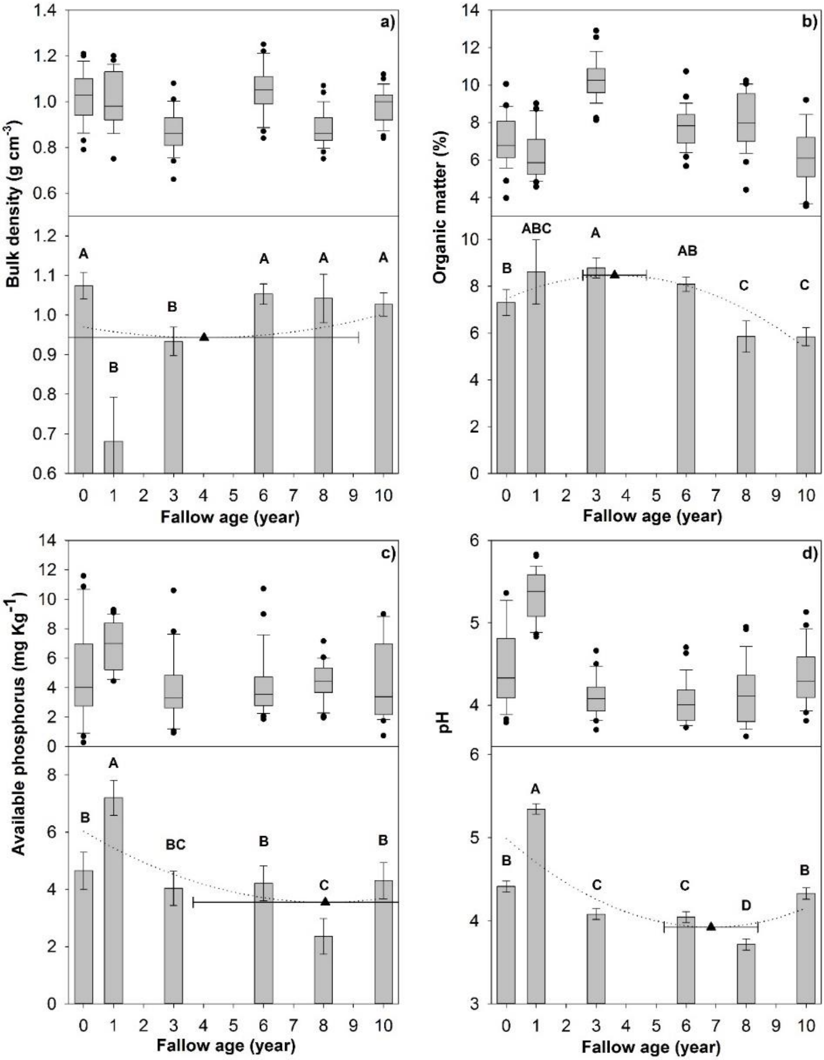


Figure 12: Topsoil properties of plots of upland rice field (0 year fallow) and different fallow age (n = 27 samples per year). a) Bulk density, b) Organic matter, c) plant available Phosphorus and d) pH. Box plots display the distribution of data. Columns show LS-means with standard errors and graphs show multiple

regressions with a quadratic term including fixed effects. Means not sharing a letter indicate significant differences ($p < 0.05$) between years of fallow age. Maxima or minima with standard errors are shown as horizontal lines on the regression curves.

Figure 13 shows the elevation effect that led to high standard errors of LS-means and divergence from the medians for BD. The median altitude of year one plots (934 m a.s.l.) was clearly below plots of other fallow stages (1068 to 1127 m a.s.l.) and the average altitude of the entire area (1068±63 m a.s.l.).

Consequently, the SE of the LS means for bulk density and organic matter were high compared to other fallow stages. Furthermore, medians of the 1-year fallow differed from the respective means and LS means from regressions (Figure 12a and b, boxplots). Exposition was as another fixed effect of SOM model. Due to some plots of 6- and 10-year fallow that were located on this exposition (Figure 14), SE of LS-means of both fallows were similar and smaller than on other plots. On the other hand, many sampling plots of 1-year fallow were located on the same direction with 6-year fallow, but their SE were very different. Therefore, exposition effects in the SOM model were comparably low and partly overruled by the altitude effect.

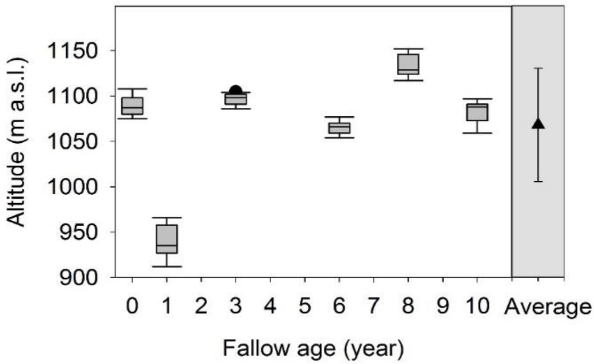


Figure 13: Altitude of plots of different fallow age (n = 27 samples per year). Averages for all years are shown on the right.

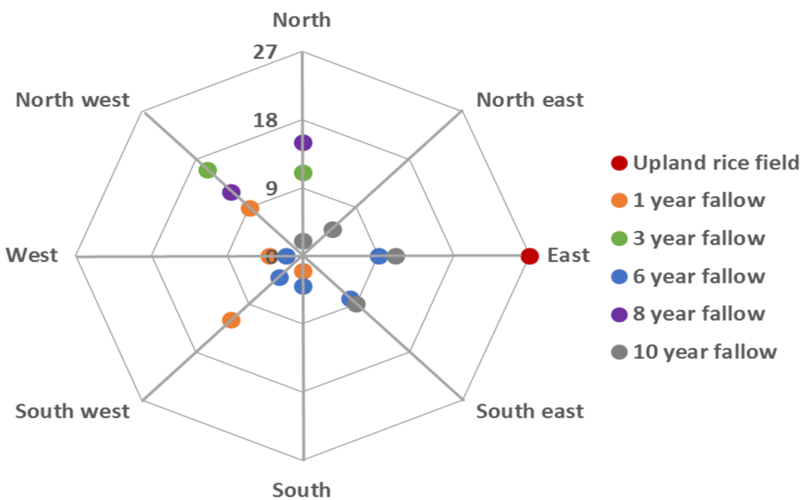


Figure 14: Exposition of plots of different fallow age (n = 27 samples per year). Averages for all years are shown on gray triangle.

A Principal Coordinate Analysis (PCO) showed that differences in soil properties between different fallow age were more pronounced in the topsoils, while subsoil data, except year 1 subsoil pH and BD, showed no significant trends between fallow stages and concentrated around the centre of the PCO plot (Figure 15). Topsoil samples differed from both subsoil layers in terms of higher SOM and lower DB. Subsoil data showed no significant trends between fallow stages and were not further analysed statistically.

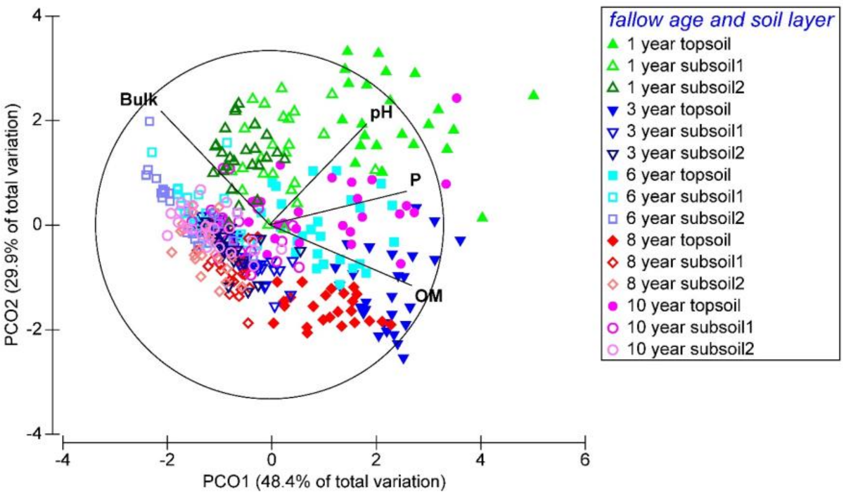


Figure 15: Principal coordinates analysis (PCO) showing soil samples from 3 depths under different fallow age (1, 3, 6, 8 and 10 years) based on the resemblance matrix of Euclidean distances. The vector overlay shows the Spearman correlations of soil variables (Bulk = bulk density, OM = organic matter, P = plant available Phosphorus and pH) with the PCO axes. Soil from 0 to 30 cm was classified by genetic horizons into topsoil, subsoil 1 and subsoil 2.

Abundances of fallow species in relation to soil properties

Farmers' indicator species as predictors of soil properties

The relationship of indicator species abundances found during our vegetation surveys and measured soil properties was estimated using multiple regression analysis (farmers' indicator model). During our vegetation survey all ten species and one genus were found. Seven species were selected in the regression model, out of which four were significantly related to either SOM, P_{av}, and pH (Table 6).

Table 6: Multiple regression analyses predicting soil properties from surveyed abundance of farmers' indicator species and further species found during vegetation surveys. Akaike Information Criterion *estimates relative model fit (lower values indicating better fit); standardized coefficients show the relative explanatory power of the variables; asterisks stand for significance (f-test) at 0.05 level.*

Dependent variable: Bulk density		**Dependent variable:** Organic matter	
Model: Farmers' indicator species	**AIC:** -277.7	**Model:** Farmers' indicator species	**AIC:** 452.2
Explanatory variable	**Stand. coeff.**	**Explanatory variable**	**Stand. coeff.**
Intercept	0.878 ± 0.020 *	Intercept	5.543 ± 0.240 *
Exposition	0.115 ± 0.039 *	Fallow age	2.680 ± 0.561 *
Prismatomeris tetrandra	0.013 ± 0.008	Altitude	1.830 ± 0.520 *
Tristaniopsis burmanica var. *rufescens*	-0.013 ± 0.008	*Dalbergia cultrata*	0.258 ± 0.113 *
		Ficus hispida	0.213 ± 0.111

Dependent variable: Bulk density		**Dependent variable:** Organic matter	
Model: All surveyed species	**AIC:** -325.9	**Model:** All surveyed species	**AIC:** 391.1
Explanatory variable	**Stand. coeff.**	**Explanatory variable**	**Stand. coeff.**
Intercept	0.891 ± 0.010 *	Intercept	5.970 ± 0.134 *
Exposition	0.087 ± 0.023 *	Fallow age	2.228 ± 0.319 *
Litsea monopetala	0.034 ± 0.008 *	Altitude	2.092 ± 0.299 *
Markhamia stipulata	-0.023 ± 0.006 *	*Craibiodendron stellatum*	0.519 ± 0.104 *
Croton roxburghii	-0.021 ± 0.008 *	*Terminalia bellirica*	0.466 ± 0.120 *
Litsea cubeba	-0.021 ± 0.006 *	*Horsfieldia amygdalina*	0.391 ± 0.081 *
Goniothalamus laoticus	0.020 ± 0.007 *	*Dalbergia cultrata*	0.325 ± 0.076 *
Phoebe lanceolata	0.020 ± 0.006 *	*Colona floribunda*	0.301 ± 0.098 *
Grewia abutilifolia	-0.019 ± 0.006 *	*Phoebe lanceolata*	-0.256 ± 0.090 *
Horsfieldia amygdalina	-0.018 ± 0.005 *	*Dalbergia oliveri*	-0.255 ± 0.121 *
Machilus gamblei	-0.017 ± 0.006 *	*Tristaniopsis burmanica* var. *rufescens*	-0.253 ± 0.094 *
Flacourtia indica	-0.016 ± 0.006 *	*Eugenia siamensis*	-0.239 ± 0.090 *
Pavetta tomentosa	-0.015 ± 0.005 *	*Ilex umbellulata*	-0.231 ± 0.111 *
Spondias pinnata	-0.014 ± 0.006 *	*Ficus hirta*	0.231 ± 0.075 *
Tristaniopsis burmanica var. *rufescens*	-0.013 ± 0.006 *	*Pterospermum semisagittatum*	-0.218 ± 0.080 *
Lithocarpus polystachyus	-0.013 ± 0.006 *	*Buchanania glabra*	0.209 ± 0.077 *
Sterculia balanghas	-0.012 ± 0.006 *	*Aporosa octandra*	-0.196 ± 0.096 *
Pterospermum semisagittatum	-0.012 ± 0.006 *	*Dillenia parviflora* var. *kerrii*	0.193 ± 0.082 *
Antidesma sootepense	0.012 ± 0.006 *	*Scleropyrum pentandrum*	0.192 ± 0.082 *
Morinda tomentosa	-0.012 ± 0.006 *	*Symplocos macrophylla* subsp. *sulcata*	0.192 ± 0.084 *
Aporosa villosa	0.010 ± 0.006	*Litsea glutinosa* var. *glutinosa*	0.181 ± 0.079 *
Protium serratum	0.010 ± 0.006	*Diospyros malabarica* var. *siamensis*	-0.181 ± 0.076 *
Quercus kerrii	0.009 ± 0.006	*Antidesma acidum*	-0.176 ± 0.085 *
		Oroxylum indicum	-0.158 ± 0.083
		Anneslea fragrans	-0.149 ± 0.079

Dependent variable: P_{av}
Model: Farmers' indicator species **AIC:** 536.5

Explanatory variable	**Stand. coeff.**
Intercept	6.192 ± 0.919 *
Exposition	-1.089 ± 1.011 *
Slope	0.594 ± 0.295 *
Macaranga denticulata	0.577 ± 0.232 *
Cratoxylum formosum subsp. *pruniflorum*	0.480 ± 0.155 *
Fallow age	-0.473 ± 0.907 *

Dependent variable: pH
Model: Farmers' indicator species **AIC:** 45.2

Explanatory variable	**Stand. coeff.**
Intercept	4.385 ± 0.090 *
Altitude	-0.355 ± 0.172 *
Eurya acuminata	-0.082 ± 0.031 *
Fallow age	-0.002 ± 0.193 *

Dependent variable: P_{av}
Model: All surveyed species **AIC:** 447.3

Explanatory variable	**Stand. coeff.**
Intercept	4.421 ± 0.205 *
Lagerstroemia cochinchinensis var. *ovalifolia*	1.005 ± 0.141 *
Altitude	-0.976 ± 0.179 *
Polylthia simiarum	0.728 ± 0.140 *
Aporosa octandra	-0.666 ± 0.099 *
Ficus hispida	0.645 ± 0.114 *
Markhamia stipulata	-0.607 ± 0.122 *
Erythrina subumbrans	0.600 ± 0.146 *
Craibiodendron stellatum	-0.598 ± 0.101 *
Exposition	0.577 ± 0.458 *
Pterospermum semisagittatum	-0.557 ± 0.099 *
Castanopsis tribuloides	-0.452 ± 0.149 *
Slope	0.440 ± 0.115 *
Sterculia balanghas	0.427 ± 0.098 *
Canarium subulatum	0.400 ± 0.104 *
Rhus chinensis	-0.397 ± 0.108 *
Ficus hirta	-0.386 ± 0.123 *
Oroxylum indicum	0.375 ± 0.094 *
Dalbergia cultrata	-0.359 ± 0.114 *
Pavetta tomentosa	-0.356 ± 0.123 *
Spondias pinnata	-0.347 ± 0.100 *
Aporosa villosa	0.317 ± 0.119 *

Dependent variable: pH
Model: All surveyed species **AIC:** 29.1

Explanatory variable	**Stand. coeff.**
Intercept	4.290 ± 0.067 *
Colona floribunda	0.183 ± 0.065 *
Fallow age	0.068 ± 0.097 *
Phoebe cathia	0.057 ± 0.024 *
Memecylon umbellatum	0.019 ± 0.007 *
Goniothalamus laoticus	0.016 ± 0.006 *
Eurya acuminata	-0.007 ± 0.003 *

Explanatory variable	Stand. coeff.
Mitragyna rotundifolia	0.305 ± 0.103 *
Castanopsis acuminatissima	-0.301 ± 0.105 *
Macaranga denticulata	0.296 ± 0.135 *
Schima wallichii	-0.294 ± 0.092 *
Lithocarpus lindleyanus	-0.270 ± 0.093 *
Horsfieldia amygdalina	0.254 ± 0.096 *
Syzygium siamense	0.249 ± 0.109 *
Litsea glutinosa	0.248 ± 0.103 *
Mangifera caloneura	0.228 ± 0.095 *
Engelhardia serrata	-0.225 ± 0.091 *
Symplocos macrophylla subsp. *sulcata*	-0.220 ± 0.097 *
Phyllanthus emblica	-0.195 ± 0.092 *
Quercus vestita	-0.186 ± 0.103

The best fit farmers' indicator model to predict BD included exposition and two tree species as independent variables. Exposition was the most influential predictor, while *Prismatomeris tetrandra* and *Tristaniopsis burmanica* var. *rufescens* were not significant at the 0.05 level. Both had been described as hard soil indicators, which was confirmed by the positive correlation between tree abundance and BD for *P. tetrandra*, but not for *T. rufescens* (negative correlation). Regarding SOM, the best fit farmers' indicator model included fallow age, altitude, and two species as components. Among these, fallow age and altitude with positive correlations, were more influential predictors than the tree species *Dalbergia cultrata* and *Ficus hispida*.

The best fit farmers' indicator model for P_{av} included fallow age, topographic factors (exposition and slope), and two indicator species, i.e. *Macaranga denticulata* and *Cratoxylum formosum* subsp. *pruniflorum,* which were characterized by lower standardized coefficients than topographic factors, but higher standardized coefficients than for fallow age.

During the group interviews, farmers did not mention indicator species for acidic soil conditions. However, the best fit farmers' indicator model for soil pH, taking into account fallow age and altitude included *E. acuminata* as an explanatory variable. All predictors were negatively correlated to pH. Among the three components, altitude was the most and fallow age the least influential predictor.

Vegetation survey data used for prediction of soil properties

We inventoried 10,101 trees representing 115 species, 90 genera and 41 families. Influence of tree species abundances on measured soil properties was estimated by multiple regression analysis (Table 6).

For BD, exposition was most influential variable and BD on north-western and northern slopes was significantly (*p*-value < 0.001) lower than on other expositions (Figure 16a). Among 21 surveyed species selected as explanatory variables by the model, 14 species were negatively and seven were positively correlated to BD. Among all selected species, two (*C. roxburghii* and *T. burmanica)* were part of the farmers' indicator list and their correlation directions in agreement with interview data. Two species, *Litsea monopetala* (positive correlation) and *Markhamia stipulata* (negative correlation), were more influential than *C. roxburghii*.

For the SOM model, fallow age, altitude, both positively correlated, were more influential than 22 tree species selected as explanatory variables. Although exposition was not an explanatory variable in the best fit model, SOM on NW and N slopes was significantly (*p*-value < 0.001) higher than on other expositions (Figure 16b). Farmers' indicator species included in the model were *D. cultrata, Ficus hirta* and *T. burmanica.* Positive correlation of *D. cultrata and Ficus hispida* species (good soil indicators) and the negative correlation of *T. burmanica* (hard soil indicator) to SOM were in agreement with the interview results. Three survey species (*Craibiodendron stellatum, Terminalia bellirica* and *Horsfieldia amygdalina*) had a stronger positive influence on organic matter than *D. cultrata.* For P_{av}, three topographic variables and 31 species were selected by the model. Altitude was negatively correlated to P_{av}, while slope was positively correlated. We found that P_{av} at E and SE facing slopes were significantly (p-value = 0.005) lower than on other slopes (Figure 16c). The model included four species from the farmers' 'good soil' indicator list. However, in the survey only *Ficus hispida* and *M. denticulata* were positively while *Ficus hirta* and *Dalbergia cultrata* were negatively correlated to P_{av}. Three species (*Lagerstroemia cochinchinensis* var. *ovalifolia, Polythia simiarum* and *Aporosa octandra*) were more influential for P_{av} than *F. hirta.*

Fallow age and five surveyed species, among these only *E. acuminata* from the farmers' indicator list, were selected for the pH model. The survey species *Colona floribunda*, *Phoebe cathia, Memecylon umbellatum* and *Goniothalamus laoticus* had higher standardized coefficients than *E. acuminata* and were positively correlated with pH. *C. floribunda* was even more influential than fallow age. Although exposition was not an explanatory variable in the best fit model, pH on SW and W slopes was significantly (p-value < 0.001) higher than on other slopes (Figure 16d).

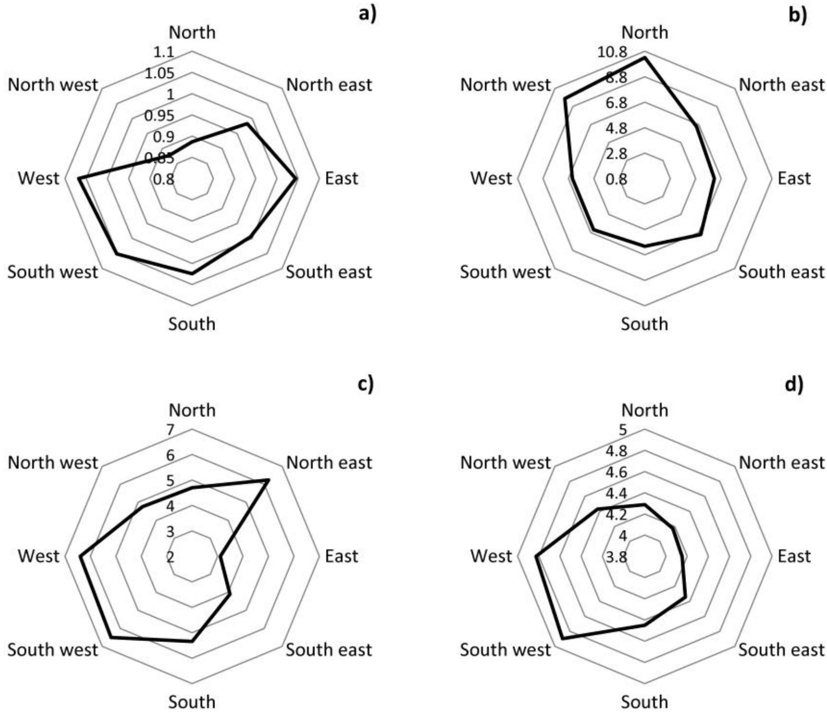


*Figure 16: (**a**) Average bulk density (g cm^{-3}), (**b**) organic matter (%), (**c**) available Phosphorus (mg kg^{-1}) and (**d**) pH in 1 to 10 year fallow plots (n= 135) of different exposition*

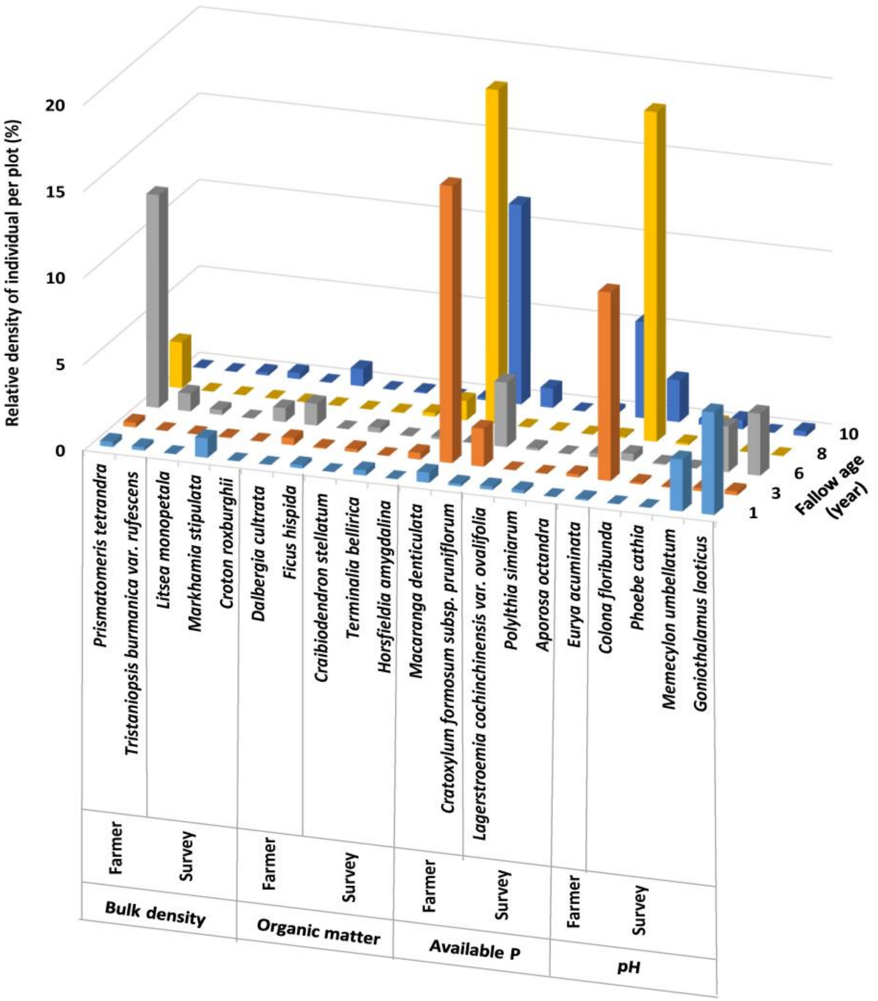


Figure 17: Relative density (number of respective indicator species over all individuals); averages over all plots. All farmer indicator species, but only those species from survey models of bulk density, organic matter, available Phosphorus and pH with higher explanatory power than farmers' indicators are shown.

Farmers' indicator species ideally occur in high abundances so that they can be easily recognized in the field. Figure 17 shows that the relative density of indicator trees *P. tetrandra, M. denticulata, C. formosum* and *E. acuminata* were high compared to the most other influential predictor species from the surveys.

Highest relative density of hard soil indicators, of *P. tetrandra* and *T. burmanica* and *C. formosum* coincided with the phase of lowest soil fertility in year 6 and 7. On the other hand, the high relative densities of *M. denticulata* (good soil indicator, P_{av} predictor) and *E. acuminata* (bad soil indicator, pH predictor) in years 3 and 8 were influenced by plot locations (6-year plot positions in Figure 1) and altitudes (Figure 13) which outweighed species effects.

Combining farmer indicators and surveyed tree species

For every soil parameter, several tree species from the vegetation survey showed higher predictive power (i.e. standardized coefficients) than indicator species (Table 6). Although survey species were less common than indicator species (Figure 17), they can contribute to improving the predictive power of the regression model. There were 10 addition species had the potential to improve the indicator model. These additional species are listed for each soil parameter in Table 7; their AIC improvements for BD, SOM and P_{av} where 48.2, 61.1 and 89.2, respectively, compared to the indicator models (Table 6). For pH, all survey species had higher standardized coefficients than *E. acuminata*, resulting in the same pH model as in Table 6.

Table 7: Improved multiple regression analyses predicting soil properties from abundance of indicator species and additional indicator species from the model that included all species. Akaike Information Criterion *estimates relative model fit (lower values indicating better fit); Standardized Coefficients show the relative explanatory power of the variables; asterisks stand for significance (f-test) at 0.05 level.*

Dependent variable	AIC	Explanatory variable	Standardized Coefficients
Bulk density	-281	Intercept	0.881 ± 0.020 *
		Exposition	0.113 ± 0.039 *
		Litsea monopetala	0.015 ± 0.008 *
		Tristaniopsis burmanica var. *rufescens*	-0.014 ± 0.007
		Prismatomeris tetrandra	0.013 ± 0.008
Organic matter	434.8	Intercept	5.518 ± 0.216 *
		Fallow age	2.705 ± 0.510 *
		Altitude	2.384 ± 0.474 *
		Craibiodendron stellatum	0.382 ± 0.105 *
		Dalbergia cultrata	0.316 ± 0.102 *
		Horsfieldia amygdalina	0.311 ± 0.105 *
		Terminalia bellirica	0.220 ± 0.101 *
Available Phosphorus	528.7	Intercept	6.071 ± 0.921 *
		Exposition	-1.306 ± 1.000 *
		Slope	0.896 ± 0.298 *
		Polylthia simiarum	0.565 ± 0.190 *
		Macaranga denticulata	0.471 ± 0.223 *
		Cratoxylum formosum subsp. *pruniflorum*	0.355 ± 0.160 *
		Lagerstroemia cochinchinensis var. *ovalifolia*	0.277 ± 0.160 *
		Fallow age	-0.231 ± 0.908 *

4.2.2. Discussion

Impact of fallow age on soil fertility restoration in swidden systems

Building on the analysis of fallow vegetation dynamics in Nong Khao (Tongkoom et al., 2018), this study aimed to link farmers' indicator species to soil fertility restoration. We hypothesised that farmers choose meaningful indicators to determine the optimal timing to reinitiate cropping after a fallow period. In accordance with Roder et al. (1995) and Hepp et al. (2018), we assumed that in the absence of mineral fertiliser application, soil fertility was critical for rice cultivation and yields. After cropping soil fertility would be slowly restored during ten years of fallow. To reflect farmers' criteria for 'good soil' and 'soil not appropriate for cropping rice' we assessed SOM, P_{av} and pH as corresponding scientific soil fertility parameters. BD was chosen as a soil physical measure reflecting farmers' 'hard soil' criterion. Based on the laboratory analyses, we accept our fourth hypothesis that soil fertility and BD change during ten years of fallow and the criteria chosen by farmers were thus meaningful. On the other hand, soil fertility status did not continuously recover during fallowing, but decreased shortly after fallow establishment. P_{av} and pH recovered by the end of the fallow period after minima in year 8, showing the appropriateness of ten years fallow duration. SOM remained low but profited at slashing from the built-up biomass. The regression for BD increased from a minimum in year 3 until the next soil preparation and cropping cycle.

We measured lowest BD and highest SOM, P_{av} and pH in year 1, while year zero values (before rice cultivation) were relatively similar to year 10. Correspondingly, high P_{av} concentrations in the first year, after burning of fallow vegetation, have been observed by Widiyatno et al. (2017) and attributed to deposition of ashes. Such initially elevated soil fertility values would be due to input of slashed biomass, seedbed preparation and burning before cultivation. Similarly, increasing P_{av} and pH in the topsoil immediately after burning and persisting after planting have been observed by Roder et al.(1995). Ramakrishnan and Toky (1981) similarly observed declining P_{av} levels after cropping until the fifth fallow year followed by subsequent slow recovery until fallow year 50. This trend corresponds to our findings until year 10 and may relate to increased P uptake by vigorously growing plants before nutrient recycling from deeper soil horizons via plants sets in (Dung et al., 2008).

BD increased from year one to six and then remained stable around 1.0, suggesting that the initial very low BD of 0.7 and 0.9 was a result of seedbed preparation. SOM peaked in year 3 with >8% and then continuously decreased until the end of the fallow period. Although statements on carbon stocks cannot be made here (because thickness of horizons was not monitored), we interpret the initially high and then declining SOM concentrations as response to litter inputs from fallow vegetation with an initial lag phase for decomposition. Slashing would lead to high litter inputs and maximum SOM in year 3. Subsequently the regrowing vegetation would produce moderate amounts of litter while SOM mineralisation sets in so that overall SOM concentrations decline. From year 8 onward, litter input and SOM mineralisation rates would equilibrate so that SOM concentrations remained stable. Elevated SOC stocks in the first fallow year and subsequent decrease have been observed by many authors (e.g. Hepp et al., 2018; Ramakrishnan and Toky, 1981) and attributed to the role of pioneer species, including weeds like *Chromolaena odorata*, that add high amounts of easily decomposable litter to the soil, while at the same time minimising erosion C losses. *C. odorata* is one of the main weeds in Nong Khao and known as an ‘excellent fallow species’ in rice systems (Roder et al., 1995) due to its rapid growth, soil coverage and weed suppression. As fallow age increases pioneers are replaced by species with typically more recalcitrant litter (Hepp et al., 2018; Tongkoom et al., 2018). In this context the concept of soil carbon saturation (Stewart et al., 2007), although not developed for tropical regions, is of interest, according to which maximum SOC stocks are constrained to a soil specific equilibrium; under continuous C inputs SOC storage capacity declines and SOC stocks asymptotically approach saturation level. In this sense the initially high SOM concentrations in Nong Khao decreased towards equilibrium on the 10-year fallow plots, which corresponded to forest reference plots of Nong Khao analysed earlier (Tongkoom 2009). We analysed BD, SOM, Pav and pH as corresponding parameters to farmers' criteria for soil fertility and suitability for rice cultivation (Table 5). These parameters and the ten tree species and one genus indicator species also represent neighbouring villages under the same agricultural practice, range of altitude, slope, soil type and forest type. However, depending on the natural environment, agricultural system and local knowledge of indicator species these parameters will differ between sites.

Recovery of soil fertility during long fallows has been under debated in the context of shortened fallow periods. Dressler et al. (2017), in a meta-analysis on conversion of long-fallow systems to continuous annual cropping, found a decline in SOC and cation exchange capacity (CEC), also for perennials plantations. This shows the risk of soil degradation under shortened fallow periods, particularly with respect to SOM. Topsoil SOM and litter contribute only part of total ecosystem carbon (Borchard et al., 2019; Bruun et al. 2018), but located in the biologically most active part of the soil, where it provides structure, rooting space and bindings sites for plant nutrients, and improves water holding capacity. It has been stated that soil properties are more relevant for fine root growth than stand age (Powers and Peréz-Aviles, 2013).

For Nong Khao, reducing fallow periods would imply cutting the supply with fresh litter, so that in the medium-run SOM concentrations would probably level to a lower equilibrium. Our regression curves also show clearly that recovery of soil fertility (increase of P_{av} and pH, stabilisation of SOM and BD) only sets in from year 8. As shown in Tongkoom et al. (2018) for vegetation dynamics, a reduction of fallow duration would also compromise soil fertility dynamics. In turn, an extension of fallow duration beyond 10 years would be beneficial to take advantage of the recovery phase. To come to a full assessment of C stocks and better understanding of soil fertility restoration processes, monitoring O (litter) horizon thickness should be included in future studies.

Concordance of indicator tree species and measured soil fertility parameters

Our fifth hypothesis was that farmers' indicator tree species for cropping decisions were in agreement with measured soil fertility parameters. During our interviews farmers had a clear idea of species that represent certain soil conditions for crop growth (Table 5) and which they classified into three groups: four species and one genus as 'good soil' indicators, five species as 'hard soil' indicators and one species as 'not good soil for rice' indicator. In East Borneo, Indonesia, farmers also use vegetation species to classify fertile, infertile, sand and moist soils (Siahaya et al., 2016). Our multiple regressions showed that indicator species were significant in explaining part of the variability of soil conditions (Table 6), so that our fifth hypothesis can be accepted for Nong Khao. For example, the SOM model and interviews agreed that *D. cultrata*, a leguminous plant, and *Ficus hispida* were related to fertile soils. The first species is a deciduous Fabacea that might contribute to soil fertility through its high turnover of nitrogen rich litter. *Ficus spp.* is said to preserve soil moisture between its dense fine roots. In Ifugao, The Philippines, farmers have to role not to harvest for timber and fuel wood of *Ficus* tree because they believe that *Ficus* helps to maintain sufficient ground water supply (Camacho et al., 2016). Farmers' selection of *P. tetrandra* and *T. burmanica* as hard soil indicators were confirmed by the BD model. On the other hand, *C. formosum*, farmers' hard soil indicator, was selected as a significant predictor for P_{av} but not for BD. The latter have both been mentioned as indicators of frequently burned areas, with *C. formosum* being a pioneer and the other two climax species. All three species are known for resprouting quickly after burning or coppicing (Vaidhayakarn and Maxwell, 2010). Furthermore, *M. denticulata* as good soil indicator was a positively correlated predictor of P_{av}, in accordance with its role as P scavenger and recycler (Yimyam et al. 2003). *F. hispida* was also positively correlated to P_{av}, in agreement with farmers' soil fertility assessment, while *F. hirta* and *D. cultrata* were negatively correlated to P_{av}. For these, SOM (positive correlation, see above) appeared to be more influential on farmers' overall judgement on soil fertility than P_{av}. Dominance of the pioneer *E. acuminata* (in contrast to coexistence with other indicators like *M. denticulata* in our 8-year plots) was interpreted by farmers as indicator of inappropriate conditions for rice cultivation. This coincided with its negative correlation to soil pH in the regression models. Thus, while our study results confirm the value of indigenous knowledge of the tree species – soil property relationship, judgements on soil fertility should not be made based on knowledge related to individual species, but in combination with other indicators.

Potential extensions to farmers' indicator list

Departing from models limited to farmers' indicator trees, the fit of all four models (BD, organic matter, P_{av} and pH; see Table 6) was improved when including additional tree species from our systematic vegetation surveys (Table 7), thus confirming our sixth hypothesis. A decrease of AIC of at least 2 dimensionless units served as criterion for such improvement. Apart from the higher number of predictors this was also owed to the fact that not all indicator trees occurred on all plots.
Given the superior predictive power of the survey data models, one could assume that adding species to the indicator list would improve the basis of farmers' land use decisions. Currently, farmers prefer indicator species that occur in large numbers and can thus be quickly spotted in the field. In addition, plants that are of traditional or commercial use to farmers – and thus well-known – could be added. For example, *M. denticulata* is used as disinfectant in traditional medicine and *E. acuminata* leaves are used as green manure (Faridah Hanum and van der Maesen, 2007). While the recognition of additional species in the field should not be difficult for local farmers, and trees should be sufficiently abundant to cover spatial variability of soils. As an important part of this study, feedback of farmers of Nong Khao regarding additional indicator species and concepts of soil fertility shall be requested.

Apart from soil fertility restoration, weed suppression is an important aspect of plot suitability for cropping in agricultural systems without herbicides. For instance, Roder et al. (1995) found that Laotian farmers perceived weed pressure as the major limiting factor for rice yields, prior to low soil fertility status (still, they found a significant positive correlation between SOM and rice yield). Although soil fertility was seen as the main limitation for cropping, farmers in Nong Khao also mentioned that attempts to plant two successive rice crops failed due to weed pressure. The main weeds in rice fields and fallows of Nong Khao are gramineous species (e.g. *Imperata cylindrica*) and *Chromolaena odorata (L.) R.M.King & H.Rob. (Eupatorium odoratum L.)*. Tree abundance is directly related to canopy cover and thus the potential by trees to shade out weeds until the seed bank in the soil has been significantly depleted. Autotoxicity could be another reason for farmers not to grow upland rice for more than one year (Fageria and Baligar, 2003). Where fallow duration is reduced or the cropping period extended, herbicides often become as indispensable as mineral fertilisers; this was shown in a comparative case study between Nong Khao and Bor Krai, an intensified agricultural system (Tongkoom et al. 2018). Although farmers may have implicitly considered the aspect of weed suppression when asked about indicators (e.g. for *M. denticulata* with highest canopy coverage), there might be potential for inclusion of further species with effective canopy cover. For example, *M. denticulata* and *E. acuminata* have been included in forest restoration projects in Northern Thailand as so-called framework species due to their rapid growth and canopy cover, ability to shade out weeds and attract birds and bats, and because they are easy to propagate in nurseries (Pakkad et al. 2002). Further framework species that were also considered good soil indicators in Nong Khao are *D. cultrata* and *S. wallichii*. Other species with potential are *Aporosa villosa* and *Lithocarpus polystachys*, which in our previous study significantly contributed to canopy cover from year six onwards (Tongkoom et al. 2018).

Influence of topography and plot location on soil properties

Nong Khao is located in a transition zone of evergreen and deciduous forest ecotones, where typical deciduous species are representative for drier climates and better adapted to drought stress (Maxwell, 2004). Higher abundance of drought-tolerant plants characterises more disturbed stands. When looking at the ecological niches of the indicator species, vegetation surveys in mountainous Northern Thailand by Maxwell (2007) showed that all indicator species except *Tristaniopsis burmanica* var. *rufescens* are typical for secondary growth in disturbed areas. Elevation and exposition influence relative humidity and thus species composition (Maxwell, 2004) and were crucial in our regression models. For SOM, altitude was influential, and the lower elevation of the 1-year fallow plots was an important motivation to differentiate mixed model means and raw data medians in Figure 12b. Topography is meaningful for farmers during plot selection among different hills and should be considered, also in the context with seed dispersal, when evaluating abundances of indicator species. Our study showed that relatively short distances or differences in altitude can be of significant. For soil fertility restoration during fallows, SOM dynamics are influenced by microclimate, particularly air and soil temperature and relative humidity and soil moisture; local rainfall differs between windward and leeward slopes. Figure 16 shows that SOM was highest on Northern slopes, which receive least sunshine and are assumedly cooler than other expositions. This can be associated to slower decomposition of litter and SOM. Associated with the highest SOM was the lowest BD on Northern slopes. Given that all pH values were below 6, higher P_{av} values were found at places of highest pH, namely on Southwestern slopes. In summary, topography influences site conditions, soils and indirectly tree species composition (van Breugel et al., 2019). On the other hand, farmers often have little choice regarding topographical position of plots, so that shifting species composition of secondary forests remain the most relevant direct criterion for farmers to assess soil fertility status.

General discussion

5.1. Assessing potentials for reduction of fallow periods by tree community succession patterns from a soil fertility perspective

The fundamental question this work set out to answer is whether fallow periods at two swidden sites in Northern Thailand, one extensively and the other intensively farmed, could be reduced from the perspective of ecosystem recovery. The associated methodological question was whether variables representing tree species diversity and stand structure were appropriate indicators to judge ecosystem recovery at two contrasting sites. The aim of the study was to provide a decision support tool for fallow duration.

The physical properties of the chosen sites did not play as significant of a role as fallow age. To further distinguish and define fallow stages, the LS-means and quadratic regressions of the selected indicator response variables could be used. Usually, fallow periods are not long enough for vegetation to reach a late successional or climax stage. In these cases, it is difficult to judge whether a response variable reached a plateau or a peak during the fallow, however, the LS-means and regressions can facilitate these decisions. It is important to note knowledge of the specific area and of key criteria (e.g. presence of red list species, carbon stocks, soil conservation) is indispensable before using this approach for decision support. Also, knowledge of the benefits of long fallows (like the presence of firewood-species *Xylia xylocarpa* var. *kerrii* in Bor Krai) should be taken into account.

In order to come to a balanced decision, single variables should not be viewed in isolation. According to location, weighting of variables could account for specific features and ecosystem functions. For example, preserving high species diversity plays an important role in Nong Khao being part of a nature reserve. Whereas in Bor Krai, stand structural indicators are of utmost importance to prevent soil erosion (Schuler et al., 2006). In Nong Khao, a potential reduction of fallow period could only be justified based on our analysis of tree density, which alone was still not considered sufficient for a sustainable decision. Closed canopy cover and species turnover in old fallow plots reflected the development of succession from competition among pioneer or fast-growing trees to more dominant shade tolerant species. The latter succession stage also suppresses weeds and provides more seeds of shade tolerant species into soil. Farmers in Nong Khao judge the time to initiate a new cropping cycle by density, stem diameter of certain trees and amount of weed and as a result have maintained extended fallow periods for decades. Indigenous traditional knowledge and scientific methods have arrived at the same conclusion, i.e. reducing the fallow period is not advisable from a productivity and ecological perspective. However, the people of Nong Khao are facing increasing food insecurity as communication is improving and the population is growing. This gave some villagers the idea of converting certain land use plots from growing crops solely for consumption to commercial production. Agricultural expansion into the forest may conceal intensification and stable fallow duration, but only at the plot, not at the landscape scale. Thanks to improved technology and education, some plots were changed into terraced paddy fields to increase production efficiency and reduce work loads of weeding. Meanwhile, Bor Krai has already moved towards more intensive agricultural production. Intensive maize production for pig feed may have limited agricultural expansion in space, but at an ecological cost, which cannot be offset by further optimization of nutrient cycles. Proximity of undisturbed forest appears highly influential for stand regeneration in terms of both biodiversity and structure. Consequently, the spatial arrangement of plots can be a mitigating factor in regard to environmental degradation, a topic that deserves further investigation.

5.2. Linking tree species as traditional soil fertility indicators to scientific measurements of soil parameters

In fallow plots characterized by high tree species diversity in Nong Khao, farmers use traditional knowledge to determine appropriate timing and place for rice cropping in swidden farming systems after multi-year fallow periods. This study showed that a selection of 10 farmers' indicator tree species and one genus typically used to assess soil properties were largely in agreement with measured changes in soil fertility status (SOM, bulk density, P_{av}, and pH) during ten-year fallow periods. The predictive power of the multiple regressions relating the four soil parameters to indicator species could be significantly improved by adding more tree species from our botanical inventories. Adding these species into the farmers' decision criteria selection has the potential to improve their decisions, assuming it is successfully adopted by the community.

Farmers' criteria for tree indicators were mainly occurrence and abundance of tree species on a potential cropping plot. These could be added to other structural parameters easily observable on site, e.g. average or maximum tree height, stem diameter, 80% canopy cover or undergrowth, so that additional farmers' criteria for cropping – like weed suppression – could be better represented.

5.3. Extending the view to criteria other than soil fertility

Based on studies of tree community composition, recovery patterns of stand structure, and species composition at two different sites, a reduction in fallow periods would not benefit soil fertility. However, it has been indicated that the main motive for farmers to maintain long fallow periods lies in weed suppression rather than soil fertility restoration. When considering only farmers' benefits from canopy cover for weed suppression (de Rouw, 1995; Kameda and Nawata, 2017) there may be potential to reduce fallow periods in Nong Khao from 10 to 6 years. In this context, ecosystem functions and services related to stand structure, soil conditions, and species composition should however, be considered holistically so that the advantages and disadvantages can be assessed for fallow reduction.

Fallow duration of 10 years (no reduction)

The number of stems was lowest in the 10-year fallow plots, implying fewer individuals, but of larger size for slashing. The largest average tree size includes the highest average DBH, height, and aboveground biomass, meaning a higher quality of construction and firewood. Soil bulk density, P_{av}, and pH were not different from those found in rice fields, which indicated the recovery to suitable soil conditions for cropping. *Macaranga denticulata* (good soil indicator) also was the most dominant species in these fallow plots (Tongkoom et al., 2018). Based on level of stand structure, recovery of some soil properties and good soil species indicator, the fallow plot hats a good potential for a further cycle of soil cropping.

Fallow duration of 8 years (2-year reduction)

The number of stems exceeded that of the 10-year-fallow, but the average stem size per tree was not different. Soil P_{av} and pH were the lowest among all measured fallow systems, while bulk density and organic matter were not different from the 10-year-fallow. The low pH was consistent with the number of *Eurya acuminata*, being tolerant to acidic conditions, and the most dominant species in the fallow plots. And diversity of tree species was significantly lower than in the 10-year-fallow. Therefore, the low pH had not only an effect on rice production, but also affected the composition plant communities.

Fallow duration of 6 years (4-year reduction)

The number of tree stems in the 6-year-fallow exceeded those in 8-and 10-year-fallows, but average tree size was smaller. Soil bulk density, organic matter, and P_{av} were not different from those in rice fields, but pH was lower. Although the average bulk density was not different from that in the rice fields or the 8- and 10- year-fallows, more *Prismatomeris tetrandra* were found in this fallow than in the 8- and 10-year fallow plots. This indicated that some part of the fallow area might have harder soil than other parts.

Considering all indicators to evaluate and compare the order of each factor, which is beneficial to the demise of the fallow selection gives the ranking shown in Table 8.

Table 8: Summarised scores for ecosystem function indicators for system alternatives of different fallow age at Nong Khao. Scores differ where indicators differed statistically with 1 being the best ranking.

		Fallow age		
Group	Variable	6	8	10
Structural	Stem density	3	2	1
	Size of stem	2	1	1
	Canopy cover	1	1	1
Soil	Bulk density	1	1	1
	organic matter	1	2	2
	P_{av}	1	2	1
	pH	2	3	1
Species indicator				
Good soil	*Macaranga denticulata*	3	1	2
Hard soil	*Prismatomeris tetrandra*	3	2	1
pH	*Eurya acuminata*	1	3	2
	Total score*	18	18	13

*The lowest total score is the best selection.

Taking into account all studied indicators and soil conditions, a fallow period of 10 years appears to be the most sustainable. Observations and interviews with farmers showed that a reduction of fallow periods was not pursued because labor costs for weeding is a major limitation. The agricultural system in Nong Khao is subsistence-based, and farmers often cannot afford to buy herbicides.

Bor Krai, and its intensive agricultural production systems, is located on the main road. Therefore, villagers used this opportunity to establish their local market. The cultivation systems are diverse, crops for household consumption (upland rice and vegetables), livestock feed (local maize), and sale at the market (sticky rice, cucumber, and hybrid maize). Farmers sell their crops not only to middlemen, but also directly at their own market for direct marketing of local crops and vegetables and seasonal wild products such as bamboo shoot, wild fruits and mushroom. Therefore, the villagers generally had low income throughout the year. However, since 2008, some farmers could even afford to buy cars thanks high yield and returns due to hybrid maize production. As a result, many farmers decided to shorten fallow periods to the extent that all of our 4-year fallow plots in 2011 were changed to hybrid maize in 2012.

Our research on the dynamics of fallow vegetation indicates that stem density, DBH, aboveground biomass and dominant species between the 4-and 6-year fallows did not differ significantly. However, canopy cover in a 3-year- fallow was only about 40%, whereas in a 6- year-fallow it was around 70%. As a result, any reduction in the fallow period could lead to greater weed pressure. However, increased income from more intensive production systems mean herbicides are becoming affordable and reduce workload.

5.4. Outlook

As a prerequisite of our approach for indicator-based fallow and soil assessment we recommend that the observation period should fully cover the current fallow duration at the time of study. Further, reference data from mature successional stages of the same vegetation type should be included for greater robustness of the approach. Response variables should be selected based on previous knowledge of the site and can be added or omitted according to environment, adding to the flexibility and applicability of the approach. In contrast to a classical environmental impact assessment, our approach applies flexible, ecosystem-dependent values rather than absolute thresholds. On the other hand, this makes the procedure laborious, and the potential for simplifications (e.g. rapid appraisal techniques for certain variables) should be explored.

The study on tree species indicators of soil fertility from traditional and scientific survey data offers potential for further research, such as the influence of species indicators on each soil parameter and the possibility of applying it to other forest ecosystems in Northern Thailand. Our approach is flexible in so far as, depending on site and local knowledge, other or additional soil parameters could be used for prediction by indicator species. In Nong Khao, the agricultural system has not changed much during the last hundred years, and a homogeneous knowledge base in the community is due to collective cultivation. This may be different for other hilltribe villages of Northern Thailand, where swidden agriculture has already been replaced by more intensive systems.

Summary

Crop rotations in today's swidden systems of Northern Thailand typically include five to ten years of fallow. Regarding ecosystem functions, these systems are relatively close to secondary forests when compared to modern agricultural systems; but they are under pressure for intensification, i.e. shortened fallow periods. In general, criteria are needed to decide whether fallow duration can be reduced, safeguarding ecosystem restoration and provision of food and income for farmers. Acknowledging that a comprehensive assessment would cover multiple aspects, our study focuses on the role of fallow duration on tree community succession and use abundances of tree species considered as soil fertility indicators.

We studied recovery indicators of tree communities at two potential broad-leaved forest climax sites that differ in soils, forest type and agricultural intensification: An intensive system of one-year upland rice, then one- to two-year maize cultivation with synthetic inputs followed by six years fallow; and an extensive system with one-year upland rice cultivation without agrochemicals and ten years fallow. In a case study village of extensive site, we investigated in how far abundance of indicator tree species corresponded to measured soil fertility parameters and whether an extended list of indicator species could improve prediction of these soil properties. Contrasting systems were chosen to test the applicability of our indicators, not to compare their management practices. From 2010 to 2011, eight variables related to stand structure and tree diversity and four soil properties were either monitored or surveyed in chronosequence plots representing different fallow ages. For each variable, means per fallow year were compared by least squares means (LS-means), and quadratic regressions from mixed models were fitted. Significant differences between LS-means and optima of regressions served to distinguish fallow stages and served as indicators of recovery and system stability. Stepwise multiple regressions confirmed fallow age as main determinant for most variables. Tree species indicator also identify by the component of multiple linear regressions function of each interested soil properties.

Numbers of tree species and diversity index recovered to levels of the previous rotation within the respective fallow time, but in both systems were far from climax communities, probably due to seed-bank depletion and shift toward resprouting species. While species dominance changed over time in the extensive system, the intensive system was dominated by a single species.

In the extensive system only tree density passed a peak during the fallow period, while biomass-related variables approached plateaus. In combination with the replacement of early fallow species, this points to the onset of competition and transition between successional stages. For the intensive system, no structural variable passed a maximum. With only one of eight indicators on the extensive site fulfilling the statistical criterion of passing a peak during the prevailing fallow time, reducing fallow periods is not recommended for our cases. Generally, combining LS-means and quadratic regression allowed assessing fallow duration based on distinct successional stages at different sites. The approach should include various relevant site-specific indicators, in our case representing biomass and carbon storage, species and structural diversity, considered crucial for both sites.

From interview on the extensive site, farmers listed 11 tree species that relate to certain soil quality related properties. They named indicators of good soils for cropping, inappropriate soils for upland rice cropping and hard soils. Botanical tree inventories on 135 plots of one to ten years fallow age were conducted. Abundances of farmers' indicator on one hand as well as inventory species on the other were introduced into different regression models to predict soil fertility parameters measured on the same plots. Both models were then compared regarding predictive power.

Measured fertility parameters such as soil organic matter (SOM), pH, plant available phosphorus (P_{av}) - related to farmers' criteria 'good soil' or 'inappropriate for rice cropping' - as well as bulk density (BD, for 'hard soil'), changed significantly during the fallow period, initially towards temporary pessima in years 6 to 7 followed by recovery towards year ten. Most indicator species, like *Macaranga denticulata* for P_{av} or *Dalbergia cultrata* for SOM, were clearly related to the soil quality characteristics attributed to them by farmers. Only in one case a species used as farmer indicator for hard soils was selected by multiple regression as predictor for high P_{av}. Including all tree species found during inventories into multiple regressions significantly improved predictions of measured soil parameters by AIC > |2|. Ten additional species from the survey model had potential to improve the farmer indicator model.

Relative density, i.e. abundance of indicator tree species over abundance of all species, did not always match soil properties dynamics, so that the use of the regressions appears more informative for cropping decisions. Our approach to relate indicator species and measured soil parameters is not site-specific, but parameters are. Applicability of the approach could be extended if further farmer criteria such as weed suppression, represented by tree structure parameters as predictors of adequate fallow age, would complement soil fertility indicators.

Based on the development of the multiple indicators of recovery of ecosystem services and soil fertility, it is not recommended to reduce fallow age at the two investigated study sites.

Zusammenfassung

In typischen *swidden cultivation* Systemen in Nordthailand, das sind zumeist reis- oder maisbasierte Brandrodungswanderfeldbau-Systeme, folgen auf ein bis zwei Anbaujahre fünf bis zehn Jahre Brache. Hinsichtlich ihrer Ökosystemfunktionen sind *swidden* Systeme natürlichen Sekundärwäldern deutlich näher als moderne Landbausysteme. Andererseits geraten diese Systeme zunehmend unter Druck die Brachezeiten zu verkürzen. Daher besteht ein Bedarf an Beurteilungskriterien, ob auch Systeme mit verkürzten Brachen die Regeneration der Flächen zwischen den Anbauzyklen und langfristig die Ernährungs- und Einkommenssicherung der Landwirte gewährleisten können.

Diese Studie beschränkte sich auf die Auswirkungen verkürzter Brachezeiten auf Baumartenzusammensetzung und Habitus sowie die Rolle von Baumarten als Indikatoren von Bodenfruchtbarkeitsparametern, auch wenn für eine umfassende Bewertung verkürzter Brachezeiten eine Vielzahl weiterer Kriterien mitberücksichtigt werden müssen.

Zwei Laubwald-Klimax-Standorte wurden ausgewählt, die sich hinsichtlich Bodentypen, Waldtyp und Intensivierungsgrad der Anbausysteme unterschieden: Zum einen eine intensivierte Fruchtfolge von einem Jahr Reis-, gefolgt von ein bis zwei Jahren Maisanbau und sechs Jahren Brache; in diesem System am Standort Bor Krai kamen synthetische Dünger und Biozide zum Einsatz. Andererseits ein extensives System in Nong Khao mit einem Jahr Reisanbau und nachfolgend zehn Jahren Brache; hier werden traditionell keine Agrochemikalien eingesetzt. Die unterschiedlichen Standorte wurden dabei gewählt um die generische Anwendbarkeit der Indikatoren zu testen, nicht um die Anbausysteme zu vergleichen. An letzterem Standort wurde zudem

untersucht inwieweit Abundanzen von Zeigerarten (ausschließlich Bäume) mit gemessenen Bodenparametern übereinstimmten und ob eine erweiterte Artenliste die Vorhersage von Bodenparametern (als Entscheidungsgrundlage für erneuten Reisanbau) verbessern kann. Ein Hybridansatz aus Monitoring der selben Flächen 2010 und 2011 sowie falschen Zeitreihen wurde verwendet, um in unterschiedlich langen Brachezeiten acht Parameter zu Baumhabitus und –arten sowie vier Bodenparameter zu messen. Mittelwerte der Pflanzenparameter (über jeweils drei Hänge x drei Hangpositionen) je Brachejahr wurden mittels LS means Statistik (kleinste quadratische Abweichungen) verglichen. Zudem wurden Verläufe der jeweiligen Parameter über die Brachedauer mittels quadratischer Gleichungen modelliert. Statistisch signifikante Unterschiede der Mittelwerte zwischen den Jahren sowie die Optima der Regressionen dienten der Unterscheidung von Brachestadien und als Indikatoren für Rehabilitation und Stabilität der Systeme. *Stepwise multiple regressions* zeigten, dass die Brachedauer maßgeblichen Einfluss auf die meisten Pflanzenparameter hatte. Multiple Regressionen wurden ebenso angewendet um die relative statistische Aussagekraft der Abundanzen verschiedener Baumarten sowie topographischer Faktoren auf Bodenparameter zu beurteilen.

Artenzahl und Diversitätsindex erreichten zwar in beiden Fruchtfolgen nach Beendigung der Brache den jeweiligen Ausgangspunkt, jedoch nicht das Niveau benachbarter Klimaxgesellschaften. Gründe hierfür könnten die starke Abnahme der Samenbank im Boden oder eine Verschiebung hin zu Arten die sich per Stockausschlag regenerieren sein. Die Dominanz in der Baumartenzusammensetzung verschob sich mit der Zeit am extensiven Standort, während die Brachevegetation am intensiv genutzten Standort durchgehend von einer Art dominiert wurde. Unter extensivem Anbau überschritt nur einer von acht Pflanzenparametern während der Brachezeit ein Maximum, Kriterium für mögliche Verkürzung der Brachezeit. Alle anderen Pflanzenparameter erreichten oder näherten sich einem Plateau. Da zugleich Pionierarten verdrängt wurden, kann einsetzende Konkurrenz und ein Übergang zwischen Sukzessionsstufen vermutet werden.

Im intensiven Anbausystem überschritt keine Variable ein Maximum. Somit kann für keinen der beiden Standorte eine Verkürzung der Brachezeit empfohlen werden. Methodisch betrachtet ermöglichte die Kombination von LS means und Regressionen die Bewertung verschiedener Brachezeiten über unterschiedliche Sukzessionsstadien und Standorte. Dieser Ansatz erfordert jedoch stets die Berücksichtigung mehrerer standortspezifischer Kriterien, in unserem Fall Biomasse und Kohlenstoffspeicherung, Arten- und strukturelle Vielfalt, welche für die beiden Standorte besonders relevant sind.

Der zweite Teil dieser Arbeit befasste sich mit der Bewertung lokaler Indikatoren (Abundanzen von Baumarten als Zeiger für Bodenfruchtbarkeitsparameter) in Zusammenhang mit gemessenen Bodenwerten. Dieser Teil bezog sich ausschließlich auf den extensiv bewirtschafteten Standort Nong Khao. Interviews mit Landwirten ergaben eine Liste von 11 Indikator-Baumarten für Bodenqualitätsparameter wie ‚gute Eignung zum Anbau von Reis und Gemüse', ‚ungeeignet für Reis' oder ‚verhärteter Boden'. Die Daten aus den in Teil 1 beschriebenen botanischen Aufnahmen auf 135 Parzellen mit Brachedauer zwischen einem und zehn Jahren wurden als Basis auch für diesen bodenbezogenen Teil der Studie verwendet. Verschiedene statistische Regressionsmodelle zur Schätzung der Bodenfruchtbarkeitswerte, die einerseits auf den Abundanzen ausschliesslich der Indikatorarten, andererseits zusätzlich auf den Abundanzen der kompletten Artenlisten basierten, wurden dann hinsichtlich ihrer Aussagekraft verglichen. Die Messparameter organische Bodensubstanz (OBS), pH, pflanzenverfügbarer Phosphor (P_{av}) repräsentierten dabei die Kriterien der Landwirte für geeigneten bzw. ungeeigneten Boden zum Reis-/Gemüseanbau, und Trockenraumdichte (BD, für bulk density) stand für das Kriterium Bodenverhärtung. Diese Parameter veränderten sich während der Brachezeit signifikant, erreichten von anfänglich relativ höchsten Werten Minima in Jahr sechs und sieben, bevor eine allmähliche Verbesserung zum Ende der Brachezeit hin einsetzte. Die Mehrzahl der Indikatorarten, wie z.B. *Macaranga denticulata* für P_{av} oder *Dalbergia cultrata* für die OBS, waren zugleich auch klar zu den Qualitätskriterien der Bauern korreliert. Nur in einem Fall wurde ein Bauernindikator für verhärtete Böden durch die statistische Regression als P-Zeiger eingeordnet.

Die Erweiterung der Modelldatenbasis um weitere Inventurdaten verbesserte die Aussagekraft der Modelle für die verschiedenen Bodenparameter deutlich um einen AIC Wert von mindestens |2|. Zehn der zusätzlich einbezogenen Arten konnten das ursprüngliche Modell eindeutig verbessern. Im Gegensatz dazu stimmte die Betrachtung der Dynamik relativer Dichten, das heißt Abundanzen einer Art relativ zur Gesamtindividuenzahl über alle Arten, nicht immer mit der Dynamik der Bodenparameter überein. Als Entscheidungsgrundlage für den Beginn eines neuen Anbauzyklus erscheinen die Ergebnisse der Regressionsmodelle besser geeignet.

Der hier beschriebene Ansatz von Indikatorarten auf Bodeneigenschaften zu schließen kann als generisch im Sinne von standortunabhängig betrachtet werden. Dabei sollten jedoch die Bodenparameter standortspezifisch gewählt werden. Die Aufnahme weiterer Kriterien von Landwirten, wie zum Beispiel Unkrautunterdrückung (bei der Wahl der Brachezeit oft wichtiger als Bodenfruchtbarkeit) repräsentiert durch Baumhabitusparameter, könnte dabei Bodenfruchtbarkeitskriterien sinnvoll ergänzen. Dadurch würde die Relevanz der Methode in der Anwendung insgesamt erhöht.

Angesichts vielfältiger Entscheidungskriterien der Rehabilitation von Ökosystem- und Bodenfunktionen kann im konkreten Fall dieser Studie eine Verkürzung der Brachezeiten an beiden Standorten nicht empfohlen werden.

Appendices

Appendix 1 Description of tree species in different fallow period during the survey in 2010 and 2011.

Village: Nong Khao
Fallow age: 1 year

Family	Species	2010 Density (stem/ha)	2010 Average DBH (cm)	2010 Average height (m)	2010 Above ground biomass (kg/ha)	2010 Canopy cover (%)	2011 Density (stem/ha)	2011 Average DBH (cm)	2011 Average height (m)	2011 Above ground biomass (kg/ha)
Adoxaceae	*Viburnum inopinatum* W. G. Craib	11	3.3	3.1	13.7	0.19	11	4.1	4.1	27.1
Anacardiaceae	*Buchanania glabra* Wall. ex Engl.	63	2.3	2.1	35.1	0.42	63	2.9	2.7	63.4
	Gluta obovata Craib	1470	2.3	2.2	822.1	9.57	1441	2.8	2.8	1410.2
	Mangifera caloneura Kurz	37	1.3	1.7	5.2	0.10	37	1.7	2.0	9.6
	Rhus chinensis Mill.	11	1.8	2.8	5.5	0.05	7	3.2	4.3	12.4
	Spondias pinnata (L. f.) Kurz	7	3.8	3.0	13.5	0.10	7	4.6	3.5	22.2
Annonaceae	*Goniothalamus laoticus* (Finet & Gagnep.) Bân	585	1.8	2.4	201.6	2.35	570	2.2	3.0	365.8
	Polyalthia simiarum (Buch.-Ham. ex Hook. f. & Thomson) Benth. ex Hook. f. & Thomson	7	1.1	2.1	0.8	0.03	-	-	-	-
Aquifoliaceae	*Ilex umbellulata* (Wall.) Loes.	4	2.6	3.7	3.4	0.02	4	3.1	4.1	5.2
Bignoniaceae	*Markhamia stipulata* (Wall.) Seem.	67	2.7	2.4	56.6	0.66	67	3.1	2.8	82.2
	Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	44	2.0	3.0	22.0	0.17	44	2.3	3.3	29.6
	Stereospermum neuranthum Kurz	19	1.6	2.3	5.8	0.10	11	1.8	2.5	3.8
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb.	63	3.4	2.9	92.0	0.37	63	3.7	3.3	120.1
Dilleniaceae	*Dillenia parviflora* Griff. var. *kerrii* (Craib) Hoogl.	11	2.2	1.5	4.6	0.13	11	2.5	1.8	6.8
Ebenaceae	*Diospyros coaetanea* Flet	181	2.1	2.2	87.2	1.00	167	2.6	2.8	150.9
	Diospyros glandulosa Lace	63	2.2	3.1	44.9	0.62	63	2.5	3.6	66.1
Euphorbiaceae	*Croton argyratus* Blume	289	2.5	2.8	244.5	4.13	289	2.9	3.2	352.6
	Macaranga denticulata (Blume) Müll.Arg.	30	2.0	2.6	15.8	0.35	30	2.4	3.1	24.2
	Mallotus philippensis (Lam.) Müll.Arg.	19	1.9	2.6	7.4	0.08	19	2.2	2.9	10.8
Fagaceae	*Castanopsis acuminatissima* (Blume) A.DC.	41	4.6	3.9	132.7	0.60	41	5.4	4.6	203.9
	Castanopsis tribuloides (Sm.) A. DC.	126	2.8	2.5	115.2	0.79	122	3.3	2.9	161.5
	Lithocarpus polystachyus (Wall. ex A.DC.) Rehder	104	3.3	3.0	150.7	0.75	104	4.1	3.7	267.9
Hypericaceae	*Cratoxylum formosum* subsp. *pruniflorum* (Kurz) Gogelein	11	1.4	2.4	2.3	0.06	7	1.8	3.1	2.8
Juglandaceae	*Engelhardia serrata* Bl. var. *serrata*	352	2.0	2.5	164.0	2.07	348	2.4	3.1	282.2
	Engelhardia spicata Lechen. ex Bl.	7	2.9	2.4	5.7	0.03	7	3.3	2.8	8.9
Lamiaceae	*Callicarpa arborea* Roxb.	19	2.3	2.7	14.3	0.14	19	2.5	3.2	18.6
	Gmelina arborea Roxb.	15	3.4	3.2	22.1	0.41	15	3.7	3.5	27.9
	Vitex peduncularis Wall. ex Schauer	4	33.7	7.0	809.3	0.19	4	35.6	7.9	1008.0
Lauraceae	*Beilschmiedia intermedia* C.K.Allen	59	1.7	2.3	19.4	0.32	59	2.0	2.6	29.4
	Cinnamomum iners Reinw. ex Blume	56	1.7	2.0	15.1	0.28	52	2.1	2.5	23.9
	Litsea glutinosa (Lour.) C.B. Rob.	641	2.1	2.6	393.5	3.98	619	2.4	3.0	522.5
	Machilus gamblei King ex Hook. f.	148	2.6	2.7	128.5	0.71	144	3.1	3.3	200.3
	Phoebe cathia (D. Don) Kosterm.	4	1.3	2.0	0.5	0.03	4	2.2	2.8	1.9
	Phoebe lanceolata (Wall. ex Nees) Nees	641	1.9	2.3	259.5	2.67	633	2.3	2.8	426.6

Fallow age: 1 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Leguminosae	*Albizia odoratissima* (L.f.) Benth.	4	1.3	2.2	0.5	0.01	4	1.9	2.7	1.4
	Archidendron clypearia (Jack) I.C.Nielsen	7	1.2	1.6	0.7	0.02	-	-	-	-
	Dalbergia cultrata Benth.	7	3.5	3.6	17.1	0.23	7	3.6	3.9	19.2
	Dalbergia oliveri Prain	81	2.5	2.6	64.3	0.49	81	3.0	3.1	107.9
	Erythrina subumbrans (Hassk.) Merr.	7	2.9	2.7	6.0	0.11	7	3.2	3.1	8.6
	Indigofera cassioides DC.	30	2.0	2.3	13.3	0.34	22	3.0	3.3	27.1
Lythraceae	*Lagerstroemia cochinchinensis* Pierre var. *ovalifolia* Furt. & Mont.	7	2.8	3.6	7.6	0.06	7	3.1	3.8	9.9
Magnoliaceae	*Magnolia baillonii* Pierre	59	3.3	3.7	105.3	0.65	59	3.8	4.3	154.9
Malvaceae	*Grewia abutilifolia* Vent. ex Juss.	52	2.6	2.9	48.3	0.90	52	3.1	3.3	71.3
	Pterospermum semisagittatum Buch.-Ham. ex Roxb.	196	2.5	2.4	126.7	1.40	196	2.9	2.7	182.6
Melastomataceae	*Memecylon umbellatum* Burm.f.	296	1.5	2.1	79.7	1.43	296	1.8	2.4	116.8
Moraceae	*Artocarpus thailandicus* C.C. Berg	89	1.7	2.3	26.9	0.48	85	1.9	2.7	36.9
	Ficus hirta Vahl	4	3.0	2.6	3.2	0.03	4	3.9	3.0	6.0
	Ficus hispida L.f.	11	1.1	2.8	1.6	0.03	11	1.5	3.2	3.1
	Ficus semicordata Buch.-Ham. ex Sm.	11	1.4	1.7	1.6	0.03	11	2.2	2.5	5.2
Moringaceae	*Moringa oleifera* Lam.	4	1.1	2.4	0.4	0.03	-	-	-	-
Myrtaceae	*Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C.Gaur	15	1.1	1.8	1.3	0.09	15	1.3	2.1	2.1
	Syzygium siamense (Craib) Chantaran. & J.Parn.	59	2.5	2.9	62.4	0.32	59	2.9	3.3	87.4
	Tristaniopsis burmanica var. *rufescens* (Hance) J.Parn. & NicLugh.	56	1.8	2.6	24.9	0.22	56	2.3	3.2	45.1
Oleaceae	*Olea salicifolia* Wall. ex G.Don	111	2.4	3.0	89.3	0.66	111	2.8	3.5	127.0
Phyllanthaceae	*Antidesma acidum* Retz.	26	1.5	1.9	5.6	0.17	26	1.8	2.3	8.7
	Antidesma bunius (L.) Spreng. var. *bunius*	4	1.4	2.1	0.6	0.02	4	1.6	2.4	0.9
	Aporosa villosa (Lindl.) Baill.	915	2.1	2.2	417.3	3.72	844	2.6	2.7	638.9
	Bridelia glauca Bl. var. *glauca*	7	2.5	2.0	3.9	0.13	7	3.0	2.2	5.9
	Glochidion sphaerogynum (M.-A.) Kurz	193	2.9	3.0	205.6	1.45	193	3.6	3.6	357.0
	Phyllanthus emblica L.	41	1.9	2.0	13.0	0.42	41	2.1	2.3	18.0
Primulaceae	*Maesa ramentacea* (Roxb.) A. DC.	22	1.7	2.3	7.9	0.17	22	2.2	3.0	14.8
Rubiaceae	*Canthium parvifolium* Roxb.	7	1.3	2.3	1.2	0.06	7	1.4	2.5	1.5
	Gardenia sootepensis Hutch.	7	3.5	3.9	14.5	0.05	7	4.1	4.5	22.8
	Ixora cibdela Craib	7	1.1	1.3	0.5	0.02	7	1.4	1.6	1.0
	Pavetta tomentosa Roxb. ex Sm.	37	3.5	3.4	65.0	0.46	37	3.9	3.8	83.8
	Prismatomeris tetrandra (Roxb.) K.Schum.	44	1.4	1.6	6.1	0.14	44	1.7	2.0	10.2
	Wendlandia tinctoria (Roxb.) DC.	26	2.2	2.3	12.7	0.18	26	2.6	2.7	19.8
Salicaceae	*Flacourtia indica* (Burm.f.) Merr.	237	2.0	2.3	92.0	1.06	237	2.1	2.5	116.4

Fallow age: 1 year

Family	Species	2010 Density (stem/ha)	2010 Average DBH (cm)	2010 Average height (m)	2010 Above ground biomass (kg/ha)	2010 Canopy cover (%)	2011 Density (stem/ha)	2011 Average DBH (cm)	2011 Average height (m)	2011 Above ground biomass (kg/ha)
Sapindaceae	*Dimocarpus longan* Lour.	604	1.5	2.1	154.3	2.22	581	1.8	2.4	211.4
	Sapindus rarak DC.	4	1.0	1.7	0.3	0.02	4	1.1	2.0	0.4
Styracaceae	*Styrax benzoides* W. G. Craib	11	2.7	3.8	11.9	0.09	11	3.0	4.2	16.2
Symplocaceae	*Symplocos cochinchinensis* (Lour.) S. Moore	11	1.6	1.7	1.9	0.05	11	2.0	2.4	4.7
Theaceae	*Eurya acumminata* DC.	4	2.2	2.5	1.7	0.03	4	2.4	2.8	2.2
	Schima wallichii Choisy	52	3.3	3.5	78.2	0.18	52	3.7	4.0	110.1

Fallow age: 3 year

Family	Species	2010 Density (stem/ha)	2010 Average DBH (cm)	2010 Average height (m)	2010 Above ground biomass (kg/ha)	2010 Canopy cover (%)	2011 Density (stem/ha)	2011 Average DBH (cm)	2011 Average height (m)	2011 Above ground biomass (kg/ha)
Adoxaceae	*Viburnum inopinatum* W. G. Craib	74	1.1	2.3	10.1	0.47	48	1.7	2.9	19.2
Anacardiaceae	*Buchanania glabra* Wall. ex Engl.	204	2.5	2.5	158.1	1.07	215	3.2	3.0	310.5
	Gluta obovata Craib	15	3.1	2.8	14.9	0.10	15	3.0	3.8	20.3
	Rhus chinensis Mill.	333	1.6	2.6	122.5	1.44	356	2.1	3.2	258.0
	Spondias pinnata (L. f.) Kurz	4	1.1	2.1	0.4	0.05	11	1.5	2.9	3.0
Annonaceae	*Goniothalamus laoticus* (Finet & Gagnep.) Bân	19	1.1	1.8	1.9	0.06	7	1.4	2.7	1.6
Aquifoliaceae	*Ilex umbellulata* (Wall.) Loes.	163	2.6	3.0	177.0	1.27	189	3.1	3.6	329.7
Bignoniaceae	*Markhamia stipulata* (Wall.) Seem.	7	1.7	1.8	1.5	0.01	7	1.9	2.0	2.0
	Oroxylum indicum (L.) Kurz	11	2.5	2.6	9.0	0.13	-	-	-	-
	Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	4	0.9	1.4	0.2	0.01	4	1.5	1.7	0.6
	Stereospermum neuranthum Kurz	11	2.4	2.8	7.7	0.02	11	2.8	3.9	15.4
Burseraceae	*Canarium subulatum* Guillaumin	59	2.3	2.9	45.4	0.59	59	2.7	3.4	66.5
	Garuga pinnata Roxb.	4	2.3	2.8	2.0	0.15	4	2.4	3.1	2.4
	Protium serratum (Wall. ex Colebr.) Engl.	7	1.7	2.2	2.1	0.05	7	2.3	2.9	5.0
Cannabaceae	*Trema orientalis* (L.) Blume	11	1.5	2.5	4.3	0.09	11	1.9	2.9	6.1
Dilleniaceae	*Dillenia parviflora* Griff. var. *kerrii* (Craib) Hoogl.	70	2.0	2.8	41.0	0.36	78	2.3	3.3	70.8
Dipterocarpaceae	*Shorea roxburghii* G. Don	1359	1.9	2.5	679.2	8.87	1363	2.3	2.9	1119.6
Ebenaceae	*Diospyros glandulosa* Lace	233	1.9	2.9	143.6	1.80	215	2.2	3.2	182.1
Ericaceae	*Craibiodendron stellatum* (Pierre) W.W. Sm.	-	-	-	-	-	22	1.5	2.8	5.2
Euphorbiaceae	*Macaranga denticulata* (Blume) Müll.Arg.	2781	1.2	2.4	607.0	12.33	2826	1.7	3.0	1268.8
	Phyllanthus emblica L.	256	1.9	3.0	145.7	2.93	289	2.2	3.3	257.9

Fallow age: 3 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Fagaceae	*Castanopsis acuminatissima* (Blume) A.DC.	48	1.5	2.5	15.7	0.63	44	2.1	2.9	28.7
	Castanopsis diversifolia (Kurz) King ex Hook.f.	85	2.8	3.7	116.9	0.82	81	4.1	4.9	292.7
	Lithocarpus lindleyanus (Wall. ex A.DC.) A.Camus	4	3.3	3.8	5.6	0.06	4	5.0	4.5	14.1
	Lithocarpus polystachyus (Wall. ex A.DC.) Rehder	215	1.9	2.8	142.0	1.94	233	2.2	3.3	251.2
	Quercus kerrii Craib	48	3.2	3.6	72.2	0.93	63	3.8	4.3	175.6
	Quercus vestita Griff.	70	1.9	2.5	41.4	0.51	81	2.8	3.3	141.4
Hypericaceae	*Cratoxylum cochinchinense* (Lour.) Blume	26	1.4	2.2	5.9	0.20	26	1.3	2.5	6.2
	Cratoxylum formosum subsp. *pruniflorum* (Kurz) Gogelein	489	1.1	2.6	121.0	2.74	470	1.3	3.0	129.1
Juglandaceae	*Engelhardia serrata* Bl.	70	2.2	2.8	44.2	0.85	104	2.7	3.2	122.5
	Engelhardia spicata Lechen. ex Bl.	11	2.6	3.0	11.4	0.18	26	2.6	3.0	30.9
Lamiaceae	*Gmelina arborea* Roxb.	4	1.1	3.0	0.5	0.01	4	1.4	3.6	1.0
	Vitex peduncularis Wall. ex Schauer	7	1.6	2.4	1.9	0.03	7	1.9	2.6	2.9
Lauraceae	*Beilschmiedia intermedia* C.K.Allen	100	1.9	2.7	47.1	0.79	133	2.5	3.6	134.8
	Litsea cubeba (Lour.) Pers.	93	1.2	3.3	23.1	0.44	89	1.6	4.0	43.6
	Litsea glutinosa (Lour.) C.B. Rob.	141	1.7	2.5	87.2	0.78	122	2.3	3.2	142.2
	Machilus gamblei King ex Hook. f.	470	1.9	2.9	249.0	2.46	463	2.2	3.4	390.5
	Phoebe cathia (D. Don) Kosterm.	7	1.3	2.4	1.2	0.04	7	1.3	2.7	1.4
	Phoebe lanceolata (Wall. ex Nees) Nees	333	1.5	2.4	108.7	2.05	367	2.0	2.9	214.0
Leguminosae	*Albizia odoratissima* (L.f.) Benth.	11	2.0	3.4	10.0	0.87	19	5.5	5.9	120.6
	Archidendron clypearia (Jack) I.C.Nielsen	7	2.7	3.7	7.9	0.04	7	3.0	4.0	10.4
	Dalbergia cultrata Benth.	111	1.6	2.8	46.9	0.52	100	2.0	3.0	70.4
Leguminosae	*Dalbergia oliveri* Prain	4	2.5	2.9	2.5	0.02	4	3.2	3.6	4.8
	Indigofera cassioides DC.	178	1.9	3.5	99.8	2.71	215	2.3	4.1	200.0
Magnoliaceae	*Magnolia baillonii* Pierre	126	1.8	2.8	59.8	0.87	122	2.2	3.4	104.9
Malvaceae	*Colona floribunda* (Kurz) Craib	15	2.5	3.6	14.4	0.16	15	2.8	4.5	21.2
	Grewia abutilifolia Vent. ex Juss.	63	1.6	2.8	22.1	0.59	59	1.8	3.5	31.2
	Pterospermum semisagittatum Buch.-Ham. ex Roxb.	4	1.5	1.8	0.6	0.01	4	1.8	2.0	0.9
	Sterculia balanghas L.	11	0.5	1.3	0.2	0.02	7	1.6	2.3	2.0
Melastomataceae	*Memecylon umbellatum* Burm.f.	22	0.6	1.4	0.4	0.06	22	1.1	1.7	2.0
Moraceae	*Ficus hirta* Vahl	7	1.4	3.0	2.2	0.08	11	1.4	3.5	4.1
	Ficus hispida L. f.	11	1.0	2.3	1.6	0.05	11	1.5	2.8	3.1
Myristicaceae	*Horsfieldia amygdalina* (Wall.) Warb.	44	1.5	2.0	9.9	0.15	44	2.1	2.2	19.1

Fallow age: 3 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
	Tristaniopsis burmanica var. *rufescens* (Hance) J.Parn. & NicLugh.	26	1.9	3.0	14.1	0.17	63	1.7	3.1	30.8
Oleaceae	*Olea salicifolia* Wall. ex G.Don	215	2.0	2.7	122.7	1.33	222	2.8	3.8	351.6
Phyllanthaceae	*Antidesma acidum* Retz.	48	0.8	1.9	2.9	0.16	52	1.1	2.1	6.6
	Aporosa octandra (Buch.-Ham. ex D.Don) Vickery	52	1.5	2.4	15.4	0.26	44	2.1	2.6	24.7
	Aporosa villosa (Lindi.) Baill.	1711	2.0	2.6	999.2	10.40	1807	2.3	3.0	1533.4
	Glochidion sphaerogynum (Müll.Arg.) Kurz	533	2.5	3.4	571.9	2.62	537	3.1	4.1	965.0
Pinaceae	*Pinus kesiya* Royle ex Gordon	4	1.2	2.5	0.6	0.00	-	-	-	-
Primulaceae	*Maesa ramentacea* (Roxb.) A. DC.	1522	1.5	3.0	595.7	11.57	1559	2.0	3.6	1217.9
Rubiaceae	*Canthium parvifolium* Roxb.	200	0.8	1.9	14.7	1.28	178	1.0	2.1	20.1
	Gardenia sootepensis Hutch.	11	0.8	1.7	0.7	0.04	-	-	-	-
	Ixora cibdela Craib	15	0.9	1.1	0.5	0.03	4	1.2	1.4	0.3
	Mitragyna rotundifolia (Roxb.) Kuntze	4	1.0	1.6	0.3	0.02	4	1.4	2.1	0.6
	Morinda tomentosa Hey. ex Roth	96	1.3	2.2	18.4	0.31	89	1.6	2.9	31.8
	Prismatomeris tetrandra (Roxb.) K.Schum.	37	1.2	1.9	6.6	0.20	37	1.3	2.1	8.2
	Wendlandia tinctoria (Roxb.) DC.	985	1.7	3.0	474.5	5.50	948	2.1	3.5	778.4
Sapindaceae	*Dimocarpus longan* Lour.	11	1.4	2.1	2.4	0.05	11	1.9	2.6	8.8
Styracaceae	*Styrax benzoides* W. G. Craib	415	2.9	3.8	586.2	5.55	485	3.3	4.3	986.9
Symplocaceae	*Symplocos macrophylla* Wall. ex DC. ssp. *sulcata* (Kurz) Noot. var. *sulcata*	7	2.0	2.9	2.9	0.07	4	3.2	4.5	6.0
	Symplocos cochinchinensis (Lour.) S. Moore	26	1.3	1.6	3.4	0.11	19	1.0	2.1	2.8
Pentaphylacaceae	*Anneslea fragrans* Wall.	163	1.5	2.1	45.9	0.57	141	2.0	2.5	81.7
	Ternstroemia gymnanthera (Wight & Arn.) Sprague	22	2.6	3.1	17.8	0.12	22	3.0	3.4	25.5
Theaceae	*Camellia sinensis* var. *assamica* (J.W.Mast.) Kitam.	7	0.9	1.4	0.4	0.02	7	1.0	1.9	0.6
	Eurya acumminata DC.	1848	1.6	3.0	812.3	10.92	1733	2.3	3.9	1717.6
	Schima wallichii Choisy	219	3.1	3.8	440.5	3.08	233	3.9	4.7	928.0

Fallow age: 6 year		2010					2011			
Family	**Species**	**Density (stem/ha)**	**Average DBH (cm)**	**Average height (m)**	**Above ground biomass (kg/ha)**	**Canopy cover (%)**	**Density (stem/ha)**	**Average DBH (cm)**	**Average height (m)**	**Above ground biomass (kg/ha)**
Juglandaceae	*Engelhardia serrata* Bl.	70	4.2	4.9	280.4	2.06	70	4.4	5.4	333.1
	Engelhardia spicata Lechen. ex Bl.	26	2.9	3.2	39.5	0.30	26	3.2	3.6	48.7
Lamiaceae	*Clerodendrum serratum* var. *wallichii* C.B.Clarke	7	1.7	2.4	2.6	0.07	7	2.0	2.6	3.4
	Gmelina arborea Roxb.	11	4.4	8.4	61.1	1.48	11	5.0	9.0	82.6
	Vitex peduncularis Wall. ex Schauer	85	2.4	2.7	73.6	1.07	81	2.6	2.9	83.0
Lauraceae	*Beilschmiedia intermedia* C.K.Allen	207	3.2	4.4	468.6	2.39	207	3.5	4.7	564.1
	Cinnamomum iners Reinw. ex Blume	4	1.5	3.7	1.2	0.10	4	1.7	3.8	1.5
	Cryptocarya amygdalina Nees	41	2.3	2.9	40.2	0.51	37	2.6	3.3	45.9
	Litsea glutinosa (Lour.) C.B. Rob.	70	1.5	2.8	31.6	0.78	63	1.8	3.3	38.5
Lauraceae	*Litsea monopetala* (Roxb.) Pers.	44	2.1	3.1	28.7	0.74	41	2.5	3.6	39.5
	Machilus gamblei King ex Hook. f.	74	2.3	3.9	73.5	0.48	70	2.5	4.2	84.7
	Phoebe lanceolata (Wall. ex Nees) Nees	370	2.1	3.2	324.7	3.62	348	2.7	3.6	598.5
Leguminosae	*Albizia odoratissima* (L.f.) Benth.	7	1.9	2.6	4.7	0.02	7	2.2	2.9	6.0
	Dalbergia cultrata Benth.	156	3.3	3.9	323.6	2.48	156	3.4	4.1	361.5
	Erythrina subumbrans (Hassk.) Merr.	4	3.6	4.0	6.7	0.14	4	3.9	4.5	8.7
	Indigofera cassioides DC.	248	3.3	4.7	573.7	9.05	248	3.5	5.0	675.5
Lythraceae	*Lagerstroemia cochinchinensis* Pierre var. *ovalifolia* Furt. & Mont.	48	5.2	5.4	307.3	1.34	44	5.5	5.6	333.1
Magnoliaceae	*Magnolia baillonii* Pierre	52	5.6	6.0	509.4	1.56	52	6.0	6.4	601.0
Malvaceae	*Bombax anceps* Pierre	4	2.7	3.2	3.3	0.06	4	2.9	3.6	4.1
	Colona floribunda (Kurz) Craib	7	3.5	4.4	23.4	0.24	7	3.7	4.7	27.3
	Grewia abutilifolia Vent. ex Juss.	89	2.3	3.4	109.4	1.52	85	2.6	3.7	131.8
	Sterculia balanghas L.	41	1.7	2.5	13.8	0.34	41	1.9	2.7	19.2
Melastomataceae	*Memecylon umbellatum* Burm.f.	507	1.2	2.0	75.5	2.72	504	1.3	2.2	91.3
Moraceae	*Ficus hirta* Vahl	33	1.4	2.4	6.4	0.14	33	1.5	2.5	8.2
	Ficus semicordata Buch.-Ham. ex Sm.	4	0.8	1.5	0.2	0.01	4	1.4	1.8	0.5
Myristicaceae	*Horsfieldia amygdalina* (Wall.) Warb.	19	3.5	4.2	67.2	0.20	19	3.9	4.4	83.2
Myrtaceae	*Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C.Gaur	326	2.5	3.3	484.8	2.36	322	2.7	3.6	558.8
	Syzygium siamense (Craib) Chantaran. & J.Parn.	700	2.6	3.6	1071.0	5.47	674	2.9	4.0	1276.0
	Tristaniopsis burmanica var. *rufescens* (Hance) J.Parn. & NicLugh.	174	2.3	3.4	167.5	1.06	167	2.6	3.7	216.9
Oleaceae	*Olea salicifolia* Wall. ex G.Don	626	3.2	4.1	1526.0	5.64	619	3.5	4.5	1873.5
Phyllanthaceae	*Antidesma acidum* Retz.	226	1.4	2.0	46.5	1.77	211	1.5	2.2	54.5
	Antidesma sootepense Craib	7	0.7	2.1	0.3	0.12	7	0.9	2.5	0.6
	Aporosa octandra (Buch.-Ham. ex D.Don) Vickery	30	1.7	2.1	8.9	0.33	26	2.1	2.4	13.0
	Aporosa villosa (Lindl.) Baill.	1715	2.7	3.2	2260.3	19.10	1674	3.0	3.4	2696.7

Fallow age: 6 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Phyllanthaceae	*Bridelia glauca* Blume	19	1.8	3.1	9.5	0.23	15	1.6	3.2	6.1
	Glochidion eriocarpum Champ.	4	0.6	1.4	0.1	0.03	-	-	-	-
	Glochidion sphaerogynum (Müll.Arg.) Kurz	100	3.3	4.3	259.1	1.22	100	3.6	4.6	318.7
	Phyllanthus emblica L.	230	3.1	4.1	624.2	3.85	226	3.2	4.3	681.5
Primulaceae	*Maesa ramentacea* (Roxb.) A. DC.	470	2.0	3.5	354.1	6.48	463	2.2	3.8	441.5
Rubiaceae	*Canthium parvifolium* Roxb.	285	1.1	2.1	41.1	3.79	267	1.3	2.3	52.6
	Catunaregam tomentosa (Blume ex DC.) Tirveng	4	1.2	2.2	0.5	0.10	-	-	-	-
	Gardenia sootepensis Hutch.	44	1.8	2.6	26.6	0.51	37	1.9	2.7	18.3
	Ixora cibdela Craib	181	1.1	1.8	20.0	0.97	167	1.3	2.0	26.2
	Mitragyna rotundifolia (Roxb.) Kuntze	37	5.7	7.3	429.4	0.87	33	6.3	8.2	475.6
	Morinda tomentosa Hey. ex Roth	7	1.5	2.1	1.5	0.02	7	1.6	2.4	1.9
	Pavetta tomentosa Roxb. ex Sm.	11	2.0	2.2	4.4	0.17	7	2.3	2.5	4.4
	Prismatomeris tetrandra (Roxb.) K.Schum.	2152	1.1	1.7	222.3	8.13	2030	1.2	1.9	280.5
	Wendlandia tinctoria (Roxb.) DC.	1819	3.2	4.4	3860.1	18.38	1778	3.5	4.7	4614.9
Salicaceae	*Flacourtia indica* (Burm.f.) Merr.	30	2.7	3.1	44.4	0.25	30	2.9	3.3	54.8
Styracaceae	*Styrax benzoides* W. G. Craib	722	4.0	5.2	2932.4	13.14	715	4.3	5.5	3442.9
Symplocaceae	*Symplocos macrophylla* Wall. ex DC. ssp. *sulcata* (Kurz) Noot. var. *sulcata*	4	1.5	3.1	1.0	0.06	4	1.7	3.5	1.4
	Symplocos cochinchinensis (Lour.) S. Moore	70	3.0	3.0	210.3	1.19	70	3.2	3.2	237.8
	Symplocos racemosa Roxb.	26	1.7	2.9	11.0	0.28	26	1.9	3.2	14.5
Pentaphylacaceae	*Anneslea fragrans* Wall.	293	2.1	2.7	249.6	1.67	281	2.3	2.9	313.3
Theaceae	*Camellia sinensis* var. *assamica* (J.W.Mast.) Kitam.	4	2.1	4.4	2.7	0.11	4	2.2	4.6	3.2
	Eurya acumminata DC.	130	3.3	4.6	361.5	1.80	126	3.6	5.0	408.5
	Schima wallichii Choisy	93	6.6	7.3	2013.7	2.23	93	7.2	7.6	2416.0

Fallow age: 8 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Adoxaceae	*Viburnum inopinatum* W. G. Craib	111	2.0	3.8	96.3	1.95	111	2.4	4.0	119.3
Anacardiaceae	*Buchanania glabra* Wall. ex Engl.	44	4.6	4.7	185.8	0.67	44	4.9	5.1	223.5
	Gluta obovata Craib	52	5.0	5.3	285.0	0.75	52	5.4	5.7	352.4
	Mangifera caloneura Kurz	22	4.5	5.1	123.5	0.27	22	4.8	5.4	143.1
	Rhus chinensis Mill.	152	4.3	6.4	810.8	5.78	152	4.5	6.6	906.5
Apocynaceae	*Holarrhena pubescens* Wall. ex G.Don	7	6.6	6.6	73.5	0.23	7	7.4	7.0	96.3
Aquifoliaceae	*Ilex umbellulata* (Wall.) Loes.	163	5.3	6.4	1434.8	3.82	163	5.6	6.8	1665.4
Araliaceae	*Aralia thomsonii* Seem. ex C.B.Clarke	4	5.1	6.7	21.5	0.11	-	-	-	-
Bignoniaceae	*Markhamia stipulata* (Wall.) Seem.	4	4.9	7.4	21.5	0.35	4	5.1	7.7	24.4
	Oroxylum indicum (L.) Kurz	26	2.8	5.0	40.9	0.39	7	2.9	4.3	9.4
	Stereospermum neuranthum Kurz	4	1.3	3.4	0.8	0.05	4	1.3	3.6	0.9
Burseraceae	*Canarium subulatum* Guillaumin	4	3.0	6.3	7.5	0.11	4	3.2	6.7	8.7
	Garuga pinnata Roxb.	15	3.9	6.2	52.9	0.23	15	4.2	6.5	61.1
Cannabaceae	*Trema orientalis* (L.) Blume	7	5.4	7.9	57.0	0.28	7	5.9	8.8	74.7
Clusiaceae	*Garcinia cowa* Roxb. ex Choisy	4	2.8	3.3	3.5	0.07	4	2.9	3.5	4.0
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb.	44	9.0	7.3	1329.6	1.03	44	9.6	7.6	1550.5
Dilleniaceae	*Dillenia parviflora* Griff. var. *kerrii* (Craib) Hoogl.	63	3.2	4.7	164.6	1.34	56	4.0	5.4	219.4
Dipterocarpaceae	*Shorea roxburghii* G. Don	207	4.0	5.0	862.8	3.46	200	4.3	5.5	958.8
Ebenaceae	*Diospyros glandulosa* Lace	81	3.2	5.0	213.7	2.35	78	3.4	5.3	239.1
Ericaceae	*Craibiodendron stellatum* (Pierre) W.W. Sm.	4	1.1	1.7	0.3	0.03	4	1.3	2.0	0.5
Euphorbiaceae	*Croton argyratus* Blume	19	4.3	4.8	86.7	0.73	19	4.6	5.1	98.2
	Macaranga denticulata (Blume) Müll.Arg.	2044	3.5	6.3	9053.9	51.94	1922	4.0	6.9	10767.5
Fagaceae	*Castanopsis acuminatissima* (Blume) A.DC.	4	1.5	3.2	1.0	0.04	4	1.8	3.7	1.6
	Castanopsis diversifolia (Kurz) King ex Hook.f.	170	6.1	6.9	2011.5	5.84	174	6.6	7.4	2467.7
	Castanopsis tribuloides (Sm.) A. DC.	56	4.7	6.0	455.3	2.43	56	5.1	6.5	582.2
Fagaceae	*Lithocarpus polystachyus* (Wall. ex A.DC.) Rehder	215	3.5	4.7	881.5	4.44	215	4.1	5.2	1146.4
	Quercus kerrii Craib	7	8.0	6.5	101.3	0.12	7	8.3	7.0	117.8
	Quercus vestita Griff.	33	6.9	6.6	422.6	1.30	33	7.4	7.0	521.4
Hypericaceae	*Cratoxylum cochinchinense* (Lour.) Blume	15	2.5	4.4	14.2	0.19	15	2.6	4.7	17.0
Juglandaceae	*Engelhardia serrata* Bl.	100	4.1	5.5	520.9	2.47	100	4.4	5.8	618.0
	Engelhardia spicata Lechen. ex Bl.	4	0.7	1.8	0.1	0.00	-	-	-	-
Lamiaceae	*Gmelina arborea* Roxb.	4	50.0	10.6	2536.2	0.74	4	51.0	10.9	2704.2
	Vitex peduncularis Wall. ex Schauer	-	-	-	-	-	4	0.7	1.8	0.1

Fallow age: 8 year		2010					2011			
Family	**Species**	**Density (stem/ha)**	**Average DBH (cm)**	**Average height (m)**	**Above ground biomass (kg/ha)**	**Canopy cover (%)**	**Density (stem/ha)**	**Average DBH (cm)**	**Average height (m)**	**Above ground biomass (kg/ha)**
Lauraceae	*Beilschmiedia intermedia* C.K.Allen	70	3.8	5.6	374.2	1.23	67	4.4	6.2	458.8
	Cryptocarya amygdalina Nees	96	3.8	4.9	387.6	2.27	96	4.0	5.2	428.2
	Litsea cubeba (Lour.) Pers.	19	2.2	4.1	29.4	0.32	11	3.3	5.2	33.7
	Litsea glutinosa (Lour.) C.B. Rob.	233	2.5	4.0	364.9	4.35	219	2.8	4.5	424.8
	Litsea monopetala (Roxb.) Pers.	7	2.0	4.2	5.7	0.09	7	2.2	4.6	7.8
	Machilus gamblei King ex Hook. f.	493	3.3	5.0	1656.5	6.94	489	3.7	5.4	1987.8
	Phoebe cathia (D. Don) Kosterm.	104	5.5	6.6	1246.2	2.85	104	5.9	7.0	1478.0
	Phoebe lanceolata (Wall. ex Nees) Nees	130	2.5	4.2	167.3	1.96	130	2.7	4.6	215.0
Leguminosae	*Albizia odoratissima* (L.f.) Benth.	33	5.8	7.6	466.6	2.12	26	7.2	8.6	524.2
	Archidendron clypearia (Jack) I.C.Nielsen	19	8.4	9.0	423.2	0.68	19	9.1	9.6	514.6
	Dalbergia oliveri Prain	22	1.7	3.0	9.9	0.30	22	1.9	3.1	11.6
	Indigofera cassioides DC.	163	4.0	5.7	641.8	5.49	159	4.2	5.9	686.9
Magnoliaceae	*Magnolia baillonii* Pierre	215	3.7	5.4	876.5	3.78	204	4.1	6.0	1027.5
Malvaceae	*Colona floribunda* (Kurz) Craib	4	2.2	2.9	2.0	0.03	4	2.5	3.2	2.8
	Grewia abutilifolia Vent. ex Juss.	11	4.6	4.9	67.6	0.95	11	4.9	5.1	77.2
	Sterculia balanghas L.	19	1.4	3.5	5.7	0.29	15	1.8	3.8	8.1
Moraceae	*Artocarpus thailandicus* C.C. Berg	26	3.0	4.2	58.3	1.26	22	2.8	4.4	44.9
	Ficus hirta Vahl	30	1.2	3.0	5.7	0.20	30	1.5	3.1	10.1
	Ficus semicordata Buch.-Ham. ex Sm.	15	2.6	5.0	19.4	0.30	15	2.8	5.2	24.2
Myristicaceae	*Horsfieldia amygdalina* (Wall.) Warb.	93	3.8	4.5	313.2	1.60	93	4.0	4.8	373.0
Myrtaceae	*Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C.Gaur	93	3.8	5.2	320.7	1.22	89	4.2	5.5	381.1
	Syzygium siamense (Craib) Chantaran. & J.Parn.	22	2.0	3.0	16.4	0.21	22	2.4	3.3	22.7
Oleaceae	*Olea salicifolia* Wall. ex G.Don	104	4.3	6.6	573.2	1.33	100	4.8	6.9	662.2
Phyllanthaceae	*Antidesma acidum* Retz.	7	0.9	1.9	0.5	0.04	7	1.0	2.1	0.7
	Aporosa octandra (Buch.-Ham. ex D.Don) Vickery	7	2.2	2.1	4.8	0.13	7	2.4	2.3	6.0
	Aporosa villosa (Lindl.) Baill.	437	3.1	3.8	898.0	7.29	419	3.4	4.1	1038.0
	Glochidion sphaerogynum (Müll.Arg.) Kurz	193	5.2	6.7	1970.4	3.60	193	5.7	7.1	2332.7
	Phyllanthus emblica L.	115	3.6	5.2	429.8	2.50	115	3.9	5.5	495.7
Pinaceae	*Pinus kesiya* Royle ex Gordon	4	15.0	13.8	330.8	0.35	4	16.5	14.7	421.0
Primulaceae	*Maesa ramentacea* (Roxb.) A. DC.	437	2.6	4.4	958.9	7.42	422	2.8	4.7	1088.3
Rubiaceae	*Canthium parvifolium* Roxb.	15	0.9	2.0	1.1	0.22	11	1.1	2.4	1.4
	Ixora cibdela Craib	22	1.8	2.8	17.0	0.25	22	2.1	3.0	22.4
	Prismatomeris tetrandra (Roxb.) K.Schum.	211	1.6	2.9	121.4	1.64	207	2.0	3.3	173.1
	Wendlandia tinctoria (Roxb.) DC.	378	3.4	5.1	1322.3	8.20	378	3.8	5.5	1621.1

Fallow age: 8 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Santalaceae	*Scleropyrum pentandrum* (Denn.) Mabb.	11	5.4	4.0	85.8	0.08	7	7.4	5.5	93.5
Sapindaceae	*Dimocarpus longan* Lour.	44	2.1	3.1	35.2	0.26	44	2.2	3.3	40.5
Styracaceae	*Styrax benzoides* W. G. Craib	378	5.0	6.6	2662.7	10.13	374	5.5	6.9	3361.6
Symplocaceae	*Symplocos macrophylla* Wall. ex DC. ssp. *sulcata* (Kurz) Noot. var. *sulcata*	100	3.1	5.0	266.9	1.68	96	3.4	5.4	314.4
	Symplocos cochinchinensis (Lour.) S. Moore	19	2.3	3.9	23.4	0.32	19	2.6	4.2	30.8
Pentaphylacaceae	*Anneslea fragrans* Wall.	44	2.9	4.4	104.5	0.52	44	3.3	4.8	134.5
Theaceae	*Camellia sinensis* var. *assamica* (J.W.Mast.) Kitam.	52	1.6	3.1	22.5	0.57	52	1.8	3.3	27.4
	Eurya acumminata DC.	2085	3.6	5.7	8628.5	40.45	2022	4.0	6.2	10062.1
	Schima wallichii Choisy	37	8.3	8.1	837.8	1.67	37	9.0	8.5	977.2

Fallow age: 10 year		2010				
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)
Adoxaceae	*Viburnum inopinatum* W. G. Craib	63	2.3	4.3	69.9	1.61
Anacardiaceae	*Buchanania glabra* Wall. ex Engl.	63	4.4	4.0	222.0	1.11
	Buchanania lanzan Spreng.	4	4.1	2.8	6.3	0.04
	Gluta obovata Craib	26	3.0	3.7	58.0	0.66
	Rhus chinensis Mill.	56	3.1	5.3	133.8	0.85
	Spondias pinnata (L. f.) Kurz	4	10.3	8.1	97.6	0.22
Annonaceae	*Goniothalamus laoticus* (Finet & Gagnep.) Bân	70	2.3	3.5	76.4	1.14
	Polyalthia simiarum (Buch.-Ham. ex Hook. f. & Thomson) Benth. ex Hook. f. & Thomson	11	0.8	1.4	0.4	0.06
Apocynaceae	*Holarrhena pubescens* Wall. ex G.Don	78	2.2	3.0	75.0	1.70
Aquifoliaceae	*Ilex umbellulata* (Wall.) Loes.	70	3.7	4.7	244.2	1.62
Araliaceae	*Aralia thomsonii* Seem.	4	1.4	6.0	1.6	0.05

Fallow age: 10 year		2010				
Family	**Species**	**Density (stem/ha)**	**Average DBH (cm)**	**Average height (m)**	**Above ground biomass (kg/ha)**	**Canopy cover (%)**
Bignoniaceae	*Fernandoa adenophylla* (Wall. ex G.Don) Steenis	7	1.1	1.8	0.9	0.01
	Markhamia stipulata (Wall.) Seem.	15	2.7	3.0	19.1	0.23
	Oroxylum indicum (L.) Kurz	96	5.1	5.0	746.8	2.59
	Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	15	2.3	2.9	28.9	0.36
Burseraceae	*Canarium subulatum* Guillaumin	70	5.6	5.5	740.6	2.10
	Garuga pinnata Roxb.	7	2.5	4.0	8.5	0.24
	Protium serratum (Wall. ex Colebr.) Engl.	7	3.6	5.7	31.4	0.40
Cannabaceae	*Trema orientalis* (L.) Blume	4	4.4	4.0	10.0	0.14
Clusiaceae	*Garcinia cowa* Roxb. ex Choisy	26	2.9	3.9	45.6	0.56
Dilleniaceae	*Dillenia parviflora* Griff. var. *kerrii* (Craib) Hoogl.	41	5.1	4.7	278.5	1.78
Dipterocarpaceae	*Shorea obtusa* Wall. ex Blume	19	5.7	5.6	123.8	0.23
	Shorea roxburghii G. Don	296	3.3	4.2	811.7	7.17
Ebenaceae	*Diospyros glandulosa* Lace	33	4.5	7.1	452.6	0.73
	Diospyros malabarica var. *siamensis* (Hochr.) Phengklai	22	3.8	3.2	58.3	0.50
Ericaceae	*Craibiodendron stellatum* (Pierre) W.W. Sm.	4	3.1	3.9	5.0	0.08
Euphorbiaceae	*Macaranga denticulata* (Blume) Müll.Arg.	811	5.2	7.6	7527.0	33.15
	Mallotus philippensis (Lam.) Müll.Arg.	30	1.9	3.1	20.4	0.16
Fagaceae	*Castanopsis acuminatissima* (Blume) A.DC.	37	5.2	6.5	588.3	2.52
	Castanopsis diversifolia (Kurz) King ex Hook.f.	63	5.2	5.9	541.2	2.65
	Castanopsis tribuloides (Sm.) A. DC.	56	2.4	3.4	293.2	1.39
	Lithocarpus lindleyanus (Wall. ex A.DC.) A.Camus	26	8.3	6.7	440.7	1.03
	Lithocarpus polystachyus (Wall. ex A.DC.) Rehder	526	5.0	5.6	5833.3	16.66
	Quercus kerrii Craib	56	3.8	5.0	226.2	1.42
	Quercus vestita Griff.	33	5.1	4.4	306.8	0.99
Hypericaceae	*Cratoxylum cochinchinense* (Lour.) Blume	152	1.7	3.0	117.5	2.30
	Cratoxylum formosum subsp. *pruniflorum* (Kurz) Gogelein	196	2.2	3.6	347.9	3.54
Juglandaceae	*Engelhardia serrata* Bl.	119	5.0	5.5	946.7	4.54
	Engelhardia spicata Lechen. ex Bl.	19	6.0	6.2	194.0	0.68
Lamiaceae	*Clerodendrum serratum* var. *wallichii* C.B.Clarke	7	2.7	4.0	9.1	0.14
	Gmelina arborea Roxb.	15	10.3	7.9	770.6	1.95
	Vitex peduncularis Wall. ex Schauer	33	2.9	3.8	69.6	1.06
Lauraceae	*Beilschmiedia intermedia* C.K.Allen	11	1.8	3.4	5.0	0.05
	Cryptocarya amygdalina Nees	4	2.2	4.3	2.8	0.11

Fallow age: 10 year		2010				
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)
	Litsea glutinosa (Lour.) C.B. Rob.	4	1.3	2.2	0.6	0.03
	Litsea monopetala (Roxb.) Pers.	7	4.9	6.3	38.6	0.04
	Machilus gamblei King ex Hook. f.	111	3.8	5.9	576.1	2.17
	Phoebe cathia (D. Don) Kosterm.	56	2.7	3.4	90.9	1.09
	Phoebe lanceolata (Wall. ex Nees) Nees	452	3.0	4.5	903.4	7.11
Leguminosae	*Archidendron clypearia* (Jack) I.C.Nielsen	4	5.6	7.2	27.0	0.11
	Dalbergia cultrata Benth.	81	2.6	3.0	156.3	1.95
	Erythrina subumbrans (Hassk.) Merr.	4	3.0	5.5	6.5	0.03
	Indigofera cassioides DC.	30	5.3	6.0	201.7	1.80
Magnoliaceae	*Magnolia bailloni* i Pierre	7	7.2	7.3	135.5	0.35
Malvaceae	*Bombax anceps* Pierre	26	5.4	4.1	178.6	0.26
	Colona floribunda (Kurz) Craib	19	3.6	4.7	80.3	0.70
	Grewia abutilifolia Vent. ex Juss.	107	2.3	3.7	165.7	2.67
	Helicteres elongata Wall. ex Bojer	7	2.4	6.0	8.6	0.71
	Sterculia balanghas L.	122	2.0	3.2	99.6	1.32
Moraceae	*Artocarpus thailandicus* C.C. Berg	11	1.9	2.7	7.2	0.15
	Ficus hirta Vahl	15	4.3	4.9	69.5	0.17
	Ficus semicordata Buch.-Ham. ex Sm.	56	4.4	4.8	354.8	3.04
Myristicaceae	*Horsfieldia amygdalina* (Wall.) Warb.	7	6.5	6.6	70.8	0.61
Myrtaceae	*Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C.Gaur	100	4.4	5.7	687.5	1.43
	Syzygium siamense (Craib) Chantaran. & J.Parn.	252	2.9	4.0	528.8	3.45
Oleaceae	*Olea salicifolia* Wall. ex G.Don	115	4.3	5.1	504.2	1.60
Phyllanthaceae	*Antidesma acidum* Retz.	107	1.5	1.9	34.1	1.31
	Antidesma sootepense Craib	33	1.8	2.9	17.2	0.39
	Aporosa octandra (Buch.-Ham. ex D.Don) Vickery	474	2.9	3.5	983.4	6.33
	Aporosa villosa (Lindl.) Baill.	767	4.0	4.0	2566.2	14.98
	Glochidion rubrum Blume	11	2.8	3.5	18.4	0.18
	Glochidion sphaerogynum (Müll.Arg.) Kurz	193	4.6	6.0	1323.8	4.22
	Phyllanthus emblica L.	70	3.9	5.1	314.7	1.58
Pinaceae	*Pinus kesiya* Royle ex Gordon	4	8.4	7.0	58.2	0.23
Primulaceae	*Maesa ramentacea* (Roxb.) A. DC.	507	2.7	4.3	1080.2	12.09
Rubiaceae	*Canthium parvifolium* Roxb.	59	1.5	2.5	20.6	1.02
	Gardenia sootepensis Hutch.	22	2.8	3.5	47.7	0.40
	Ixora cibdela Craib	37	1.2	1.9	5.3	0.22

Fallow age: 10 year

Family	Species	2010 Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)
Rubiaceae	*Mitragyna rotundifolia* (Roxb.) Kuntze	7	2.3	3.9	10.8	0.11
	Pavetta tomentosa Roxb. ex Sm.	22	4.5	4.8	203.7	1.24
	Wendlandia tinctoria (Roxb.) DC.	237	3.2	4.5	822.9	5.37
Salicaceae	*Flacourtia indica* (Burm.f.) Merr.	59	3.5	4.5	234.3	2.14
Santalaceae	*Scleropyrum pentandrum* (Denn.) Mabb.	26	0.9	2.0	1.9	0.23
Sapindaceae	*Dimocarpus longan* Lour.	7	4.6	7.5	46.3	0.08
Styracaceae	*Styrax benzoides* W. G. Craib	137	4.5	6.3	932.1	4.15
Symplocaceae	*Symplocos macrophylla* Wall. ex DC. ssp. *sulcata* (Kurz) Noot. var. *sulcata*	4	0.8	1.6	0.2	0.04
	Symplocos cochinchinensis (Lour.) S. Moore	59	2.8	3.4	111.8	1.46
	Symplocos racemosa Roxb.	4	1.5	1.1	0.4	0.03
Pentaphylacaceae	*Anneslea fragrans* Wall.	74	3.6	4.2	249.2	1.08
	Ternstroemia gymnanthera (Wight & Arn.) Sprague	11	2.9	4.4	15.5	0.10
Theaceae	*Camellia sinensis* var. *assamica* (J.W.Mast.) Kitam.	4	1.4	1.7	0.5	0.02
	Eurya acumminata DC.	185	2.2	4.0	274.3	3.16
	Schima wallichii Choisy	281	7.2	8.0	5338.3	8.22

Village: Bor Krai
Fallow age: 1 year

Family	Species	2010					2011			
		Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Anacardiaceae	*Spondias pinnata* (L. f.) Kurz	-	-	-	-	-	4	3.2	2.9	3.9
Annonaceae	*Miliusa velutina* (A.DC.) Hook.f. & Thomson	-	-	-	-	-	11	3.1	1.9	7.5
	Polyalthia cerasoides (Roxb.) Bedd.	-	-	-	-	-	7	4.9	1.7	10.8
Apocynaceae	*Holarrhena pubescens* Wall. ex G.Don	85	0.9	1.4	4.7	0.39	78	2.8	2.0	50.9
Combretaceae	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr.	4	1.8	2.4	1.1	0.06	4	5.7	3.4	14.0
Ebenaceae	*Diospyros ehretioides* Wall. ex G.Don	41	0.8	1.7	2.2	0.27	41	3.6	2.6	61.8
	Diospyros mollis Griff.	7	1.1	1.5	0.5	0.10	7	4.1	2.9	13.3
Leguminosea	*Xylia xylocarpa* var. *kerrii* (Craib & Hutch.) I.C.Nielsen	74	2.3	2.8	95.0	1.49	74	5.4	4.3	460.1
Lythraceae	*Lagerstroemia macrocarpa* Wall. ex Kurz	15	1.1	1.7	1.6	0.09	15	4.2	2.3	23.7
	Lagerstroemia villosa Wall. ex Kurz	1130	1.3	2.0	261.2	16.69	1100	3.7	3.3	2217.2

Fallow age: 3 year		2010					2011			
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)
Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.	4	2.2	3.0	2.1	0.02	4	4.5	3.2	8.2
Annonaceae	*Miliusa velutina* (A.DC.) Hook.f. & Thomson	478	3.6	2.6	898.9	4.57	444	4.6	3.2	1542.1
	Polyalthia cerasoides (Roxb.) Bedd.	22	3.2	2.9	31.9	0.18	22	4.5	3.4	66.2
Apocynaceae	*Holarrhena pubescens* Wall. ex G.Don	159	2.1	2.2	74.4	1.13	148	3.0	2.6	151.2
Bignoniaceae	*Oroxylum indicum* (L.) Kurz	33	2.5	1.9	16.9	0.14	30	3.5	2.6	38.6
	Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	7	3.3	3.4	10.0	0.24	7	4.6	4.2	23.3
Burseraceae	*Garuga pinnata* Roxb.	4	1.6	2.0	0.7	0.02				
Cannabaceae	*Trema orientalis* (L.) Blume	4	3.8	4.5	8.5	0.07	4	6.4	5.9	28.9
Combretaceae	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr.	78	1.6	2.8	25.4	1.16	63	2.7	3.1	63.2
	Terminalia alata Roth	11	1.1	1.6	0.9	0.12	7	3.3	2.2	6.6
	Terminalia chebula Retz.	4	2.9	2.4	2.7	0.04	4	4.1	4.1	9.0
Dipterocarpaceae	*Shorea obtusa* Wall. ex Blume	7	3.7	1.6	6.7	0.05	7	4.3	2.3	13.7
Ebenaceae	*Diospyros ehretioides* Wall. ex G.Don	78	4.2	2.9	168.1	0.69	78	5.2	3.6	284.0
	Diospyros mollis Griff.	19	5.0	5.2	81.2	0.09	19	6.7	5.6	154.0
Euphorbiaceae	*Falconeria insignis* Royle	15	6.2	2.3	49.9	0.08	15	7.2	3.7	101.1
Fagaceae	*Quercus kerrii* Craib	107	4.6	2.8	281.9	1.34	104	6.3	3.7	612.4
Lamiaceae	*Tectona grandis* L.f.	133	5.4	3.7	549.3	1.91	133	6.5	4.3	908.4
Leguminosae	*Cassia fistula* L.	7	1.8	2.1	2.2	0.03	7	3.0	2.1	5.0
	Dalbergia cana Kurz	4	1.9	2.4	1.2	0.02	4	3.5	2.6	4.3
	Derris robusta (DC.) Benth.	26	2.3	2.4	15.1	1.25	26	3.5	3.7	47.9
	Pterocarpus macrocarpus Kurz	30	1.8	1.7	7.5	0.84	26	2.6	2.1	17.6
	Xylia xylocarpa var. *kerrii* (Craib & Hutch.) I.C.Nielsen	193	3.0	2.7	283.6	2.22	185	4.6	3.4	637.1
Loganiaceae	*Strychnos nux-vomica* L.	152	2.9	1.9	114.9	0.98	144	3.9	2.2	215.0
Lythraceae	*Lagerstroemia cochinchinensis* Pierre var. *ovalifolia* Furt. & Mont.	4	2.2	3.3	2.3	0.05	4	3.2	3.4	4.6
	Lagerstroemia floribunda Jack	15	5.8	4.8	94.2	0.19	15	6.6	5.5	144.0
	Lagerstroemia macrocarpa Wall. ex Kurz	174	3.8	2.5	272.7	1.19	163	4.6	2.9	409.4
	Lagerstroemia villosa Wall. ex Kurz	2952	2.6	2.8	3174.1	24.50	2256	3.8	3.4	5401.1
Malvaceae	*Sterculia pexa* Pierre	11	2.0	1.9	4.7	0.05	11	2.8	2.4	11.3
Moraceae	*Ficus hispida* L.f.	4	1.0	1.3	0.2	0.01	4	2.5	1.5	1.4
Myrtaceae	*Syzygium fruticosum* DC.	4	2.2	3.0	2.1	0.10	4	7.0	4.0	24.0
Phyllanthaceae	*Antidesma acidum* Retz.	7	1.0	2.2	0.6	0.04	7	1.9	2.5	2.5
	Aporosa villosa (Lindl.) Baill.	26	2.9	2.2	23.1	0.25	26	3.9	2.9	44.0
	Bridelia ovata Decne.	4	4.7	3.9	10.9	0.03	4	6.4	4.0	20.0
	Phyllanthus columnaris Müll.Arg.	7	1.1	1.8	0.7	0.09	7	1.6	2.1	1.6

Fallow age: 3 year

Family	Species	2010 Density (stem/ha)	2010 Average DBH (cm)	2010 Average height (m)	2010 Above ground biomass (kg/ha)	2010 Canopy cover (%)	2011 Density (stem/ha)	2011 Average DBH (cm)	2011 Average height (m)	2011 Above ground biomass (kg/ha)
Rhamnaceae	*Ziziphus rugosa* Lam.	26	2.6	2.0	21.4	0.16	15	4.8	2.9	37.3
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	22	5.7	4.5	120.7	0.32	22	8.0	5.3	283.9
	Hymenodictyon orixense (Roxb.) Mabb.	44	3.0	2.3	42.0	0.30	41	4.6	3.1	107.8
Salicaceae	*Homalium ceylanicum* (Gardner) Benth.	244	3.4	2.9	363.0	2.49	222	4.6	3.4	654.2
Sapindaceae	*Schleichera oleosa* (Lour.) Merr.	11	1.4	1.2	0.8	0.02	11	1.9	1.6	1.7
Solanaceae	*Solanum verbascifolium* L.	4	1.6	2.0	0.7	0.01	4	3.2	2.7	3.7

Fallow age: 6 year

Family	Species	2010 Density (stem/ha)	2010 Average DBH (cm)	2010 Average height (m)	2010 Above ground biomass (kg/ha)	2010 Canopy cover (%)
Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.	4	8.6	6.9	59.4	0.22
	Spondias pinnata (L. f.) Kurz	19	5.5	4.5	140.3	0.33
Annonaceae	*Miliusa velutina* (A.DC.) Hook.f. & Thomson	56	4.1	3.9	216.6	1.46
	Polyalthia cerasoides (Roxb.) Bedd.	100	3.0	3.8	172.2	2.65
Apocynaceae	*Holarrhena pubescens* Wall. ex G.Don	122	3.1	3.5	207.4	2.31
	Wrightia arborea (Dennst.) Mabb.	7	1.0	1.9	0.6	0.09
Bignoniaceae	*Oroxylum indicum* (L.) Kurz	33	4.5	4.1	144.8	0.76
	Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	7	1.6	1.5	1.1	0.05
Burseraceae	*Garuga pinnata* Roxb.	7	9.0	5.8	110.0	0.46
Cannabaceae	*Trema orientalis* (L.) Blume	4	3.0	2.7	3.3	0.21
Combretaceae	*Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr.	348	3.4	3.4	874.2	8.21
	Terminalia alata Roth	22	7.5	4.7	377.1	0.77
Ebenaceae	*Diospyros ehretioides* Wall. ex G.Don	100	4.2	3.7	345.2	2.30
	Diospyros mollis Griff.	7	3.2	3.5	12.6	0.05
Euphorbiaceae	*Falconeria insignis* Royle	4	1.3	1.2	0.3	0.01
Fagaceae	*Quercus kerrii* Craib	7	5.9	3.6	41.1	0.07
Lamiaceae	*Tectona grandis* L.f.	44	9.3	5.3	752.1	1.24
Leguminosae	*Cassia fistula* L.	4	4.5	4.4	11.1	0.19
	Pterocarpus macrocarpus Kurz	159	2.2	2.2	87.7	2.47
	Xylia xylocarpa var. *kerrii* (Craib & Hutch.) I.C.Nielsen	274	6.7	5.9	3305.3	9.35

Fallow age: 6 year		2010				
Family	Species	Density (stem/ha)	Average DBH (cm)	Average height (m)	Above ground biomass (kg/ha)	Canopy cover (%)
Loganiaceae	*Strychnos nux-vomica* L.	44	3.4	2.0	40.1	0.50
Lythraceae	*Lagerstroemia floribunda* Jack	226	5.1	6.4	1624.0	6.92
	Lagerstroemia macrocarpa Wall. ex Kurz	41	4.0	3.4	94.6	0.40
	Lagerstroemia villosa Wall. ex Kurz	3141	4.3	4.6	15165.7	84.22
Malvaceae	*Sterculia pexa* Pierre	7	11.6	8.5	259.6	0.35
Moraceae	*Broussonetia papyrifera* (L.) L'Hér. ex Vent.	11	6.9	5.9	266.0	0.77
Phyllanthaceae	*Antidesma acidum* Retz.	59	2.2	1.8	22.4	0.43
	Aporosa octandra (Buch.-Ham. ex D.Don) Vickery	67	5.0	5.5	389.7	2.36
	Aporosa villosa (Lindl.) Baill.	22	2.9	2.3	36.1	0.27
	Phyllanthus emblica L.	22	2.4	2.6	20.5	0.47
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	7	14.2	8.0	357.8	0.53
	Hymenodictyon orixense (Roxb.) Mabb.	19	3.1	4.0	36.3	0.25
Salicaceae	*Homalium ceylanicum* (Gardner) Benth.	63	5.1	4.3	546.0	1.96
Solanaceae	*Solanum verbascifolium* L.	4	2.0	1.3	0.8	0.01

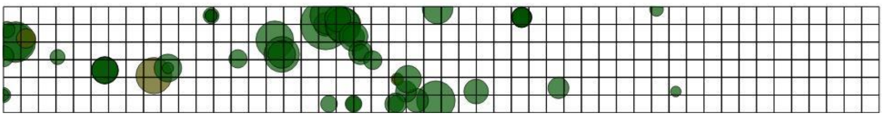
Appendix 2 Georeferenced canopy cover of trees in different chronosequence sample plots in Bor Krai and Nong Khao. Canopy cover layers were arranged by the highest percent cover per species and plot. Diagram's gird size is 1 m x 1 m.

Dominant species and color code

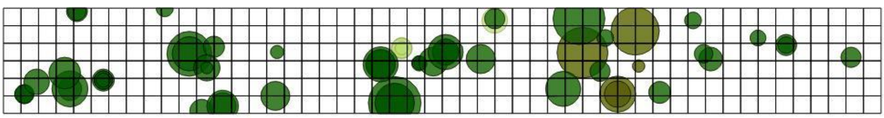
- *Gluta obovata*
- *Macaranga denticulata*
- *Lagerstroemia villosa*
- *Croton argyratus*
- *Wendlandia tinctoria*
- *Xylia xylocarpa*
- *Maesa ramentacea*
- *Eurya acuminata*
- *Miliusa velutina*
- *Aporosa villosa*
- *Lithocarpus polystachyus*
- other
- 1 m x 1 m

Village: Bor Krai

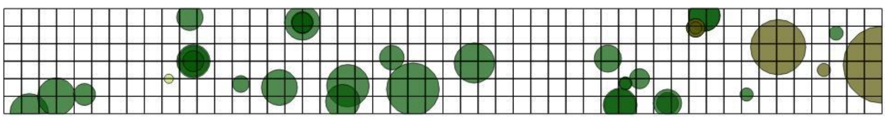
Fallow: 1 year plot: 1 position on hill: upper



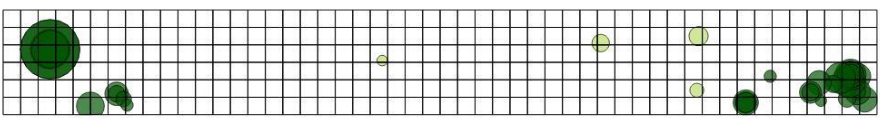
Fallow: 1 year plot: 1 position on hill: middle



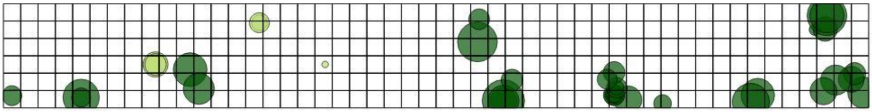
Fallow: 1 year plot: 1 position on hill: lower



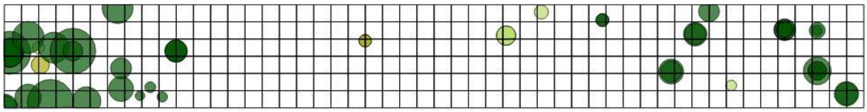
Fallow: 1 year plot: 2 position on hill: upper



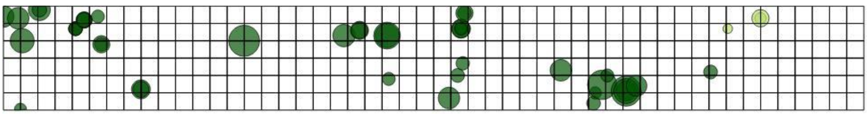
Fallow: 1 year plot: 2 position on hill: middle



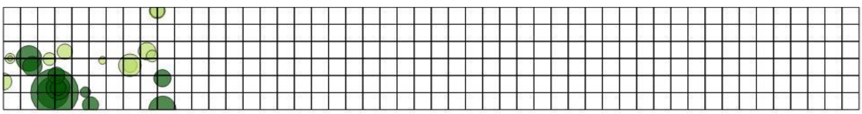
Fallow: 1 year plot: 2 position on hill: lower



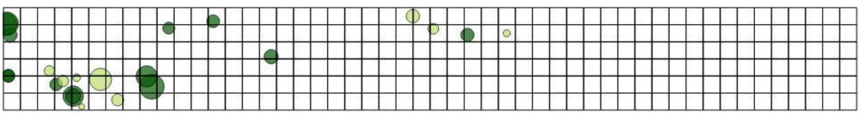
Fallow: 1 year plot: 3 position on hill: upper



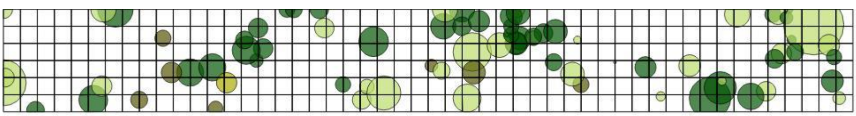
Fallow: 1 year plot: 3 position on hill: middle



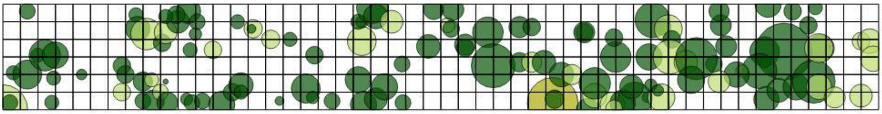
Fallow: 1 year plot: 3 position on hill: lower



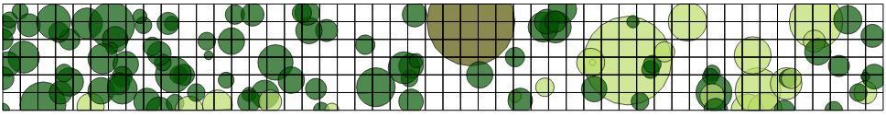
Fallow: 3 years plot: 1 position on hill: upper



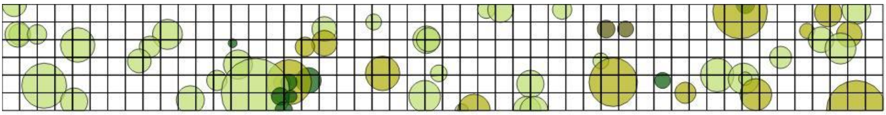
Fallow: 3 years plot: 1 position on hill: middle



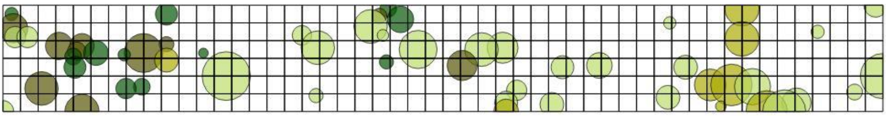
Fallow: 3 years plot: 1 position on hill: lower



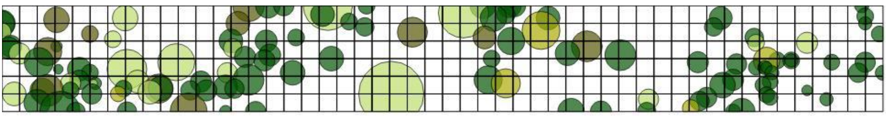
Fallow: 3 years plot: 2 position on hill: upper



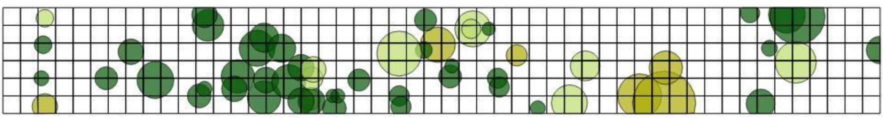
Fallow: 3 years plot: 2 position on hill: middle



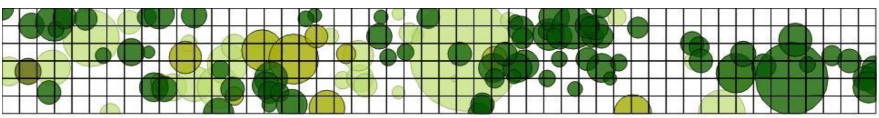
Fallow: 3 years plot: 2 position on hill: lower



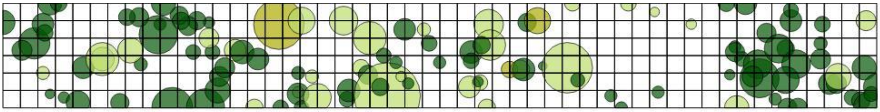
Fallow: 3 years plot: 3 position on hill: upper



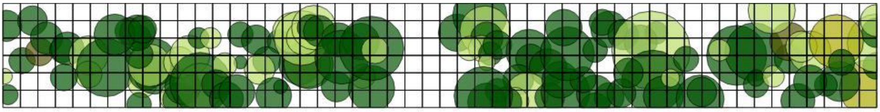
Fallow: 3 years plot: 3 position on hill: middle



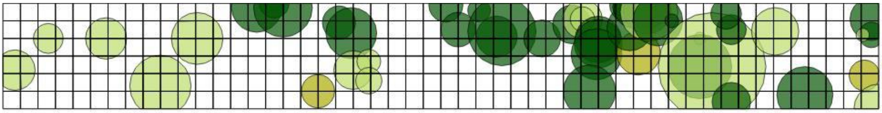
Fallow: 3 years plot: 3 position on hill: lower



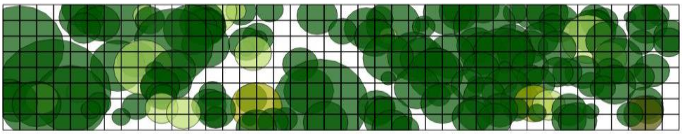
Fallow: 6 years plot: 1 position on hill: upper



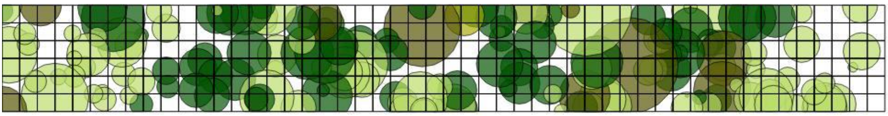
Fallow: 6 years plot: 1 position on hill: middle



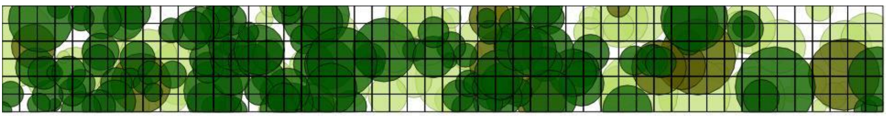
Fallow: 6 years plot: 1 position on hill: lower



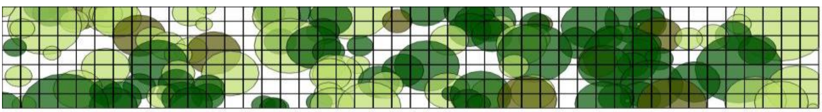
Fallow: 6 years plot: 2 position on hill: upper



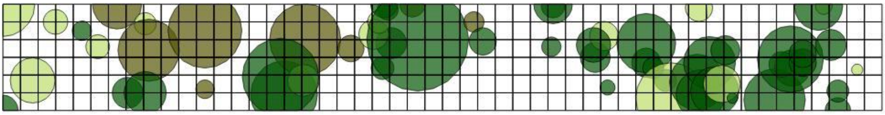
Fallow: 6 years plot: 2 position on hill: middle



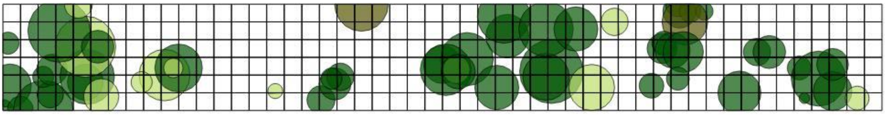
Fallow: 6 years plot: 2 position on hill: lower



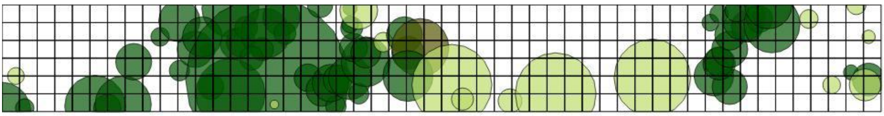
Fallow: 6 years plot: 3 position on hill: upper



Fallow: 6 years plot: 3 position on hill: middle

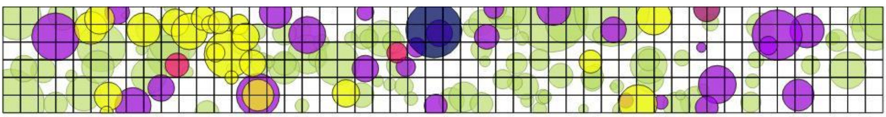


Fallow: 6 years plot: 3 position on hill: lower

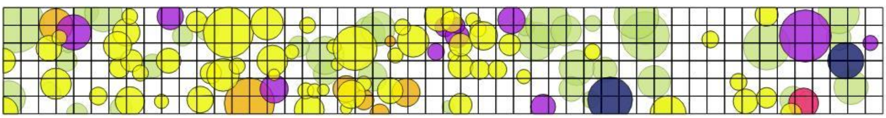


Village: Nong Khao

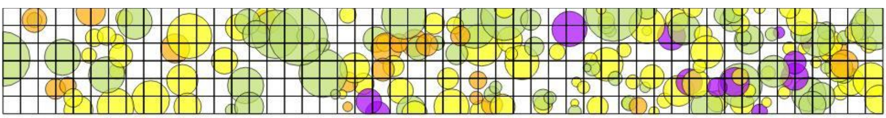
Fallow: 1 year plot: 1 position on hill: upper



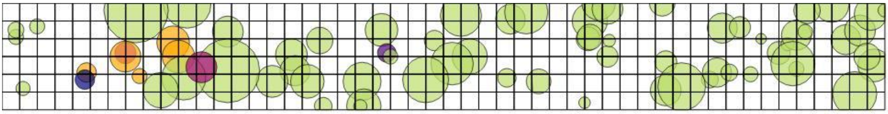
Fallow: 1 year plot: 1 position on hill: middle



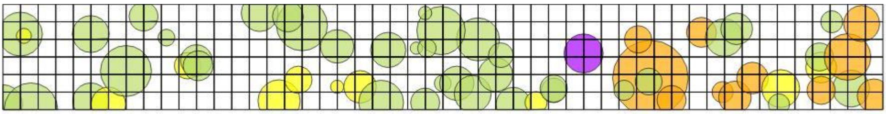
Fallow: 1 year plot: 1 position on hill: lower



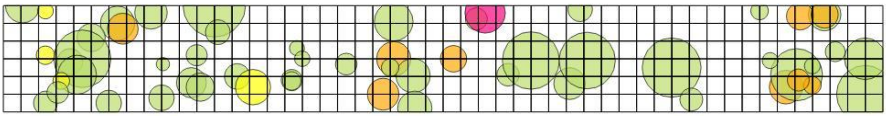
Fallow: 1 year plot: 2 position on hill: upper



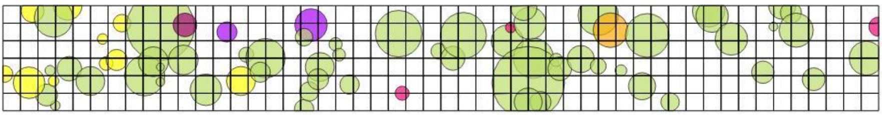
Fallow: 1 year plot: 2 position on hill: middle



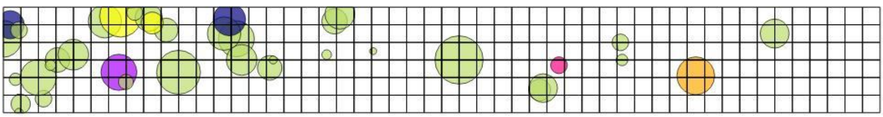
Fallow: 1 year plot: 2 position on hill: lower



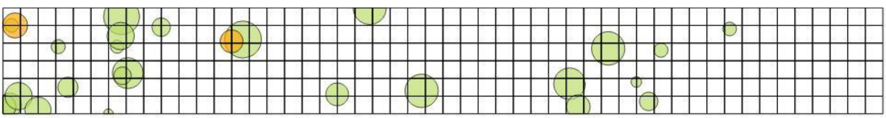
Fallow: 1 year plot: 3 position on hill: upper



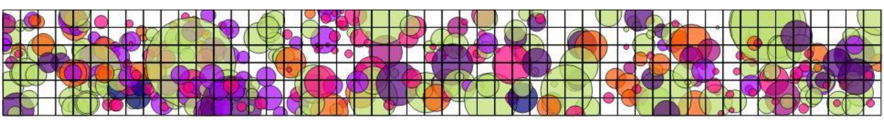
Fallow: 1 year plot: 3 position on hill: middle



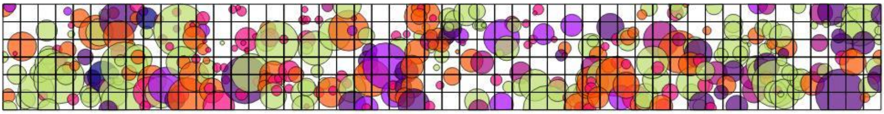
Fallow: 1 year plot: 3 position on hill: lower



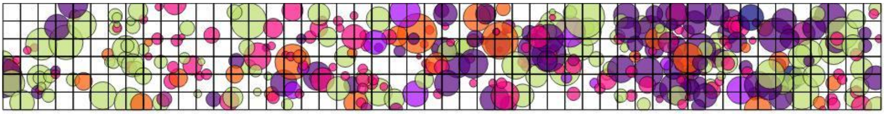
Fallow: 3 year plot: 1 position on hill: upper



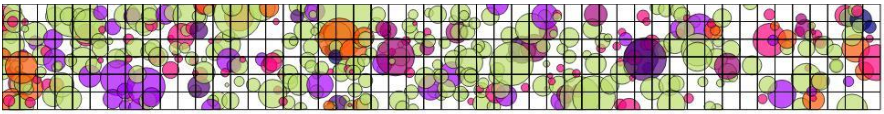
Fallow: 3 year plot: 1 position on hill: middle



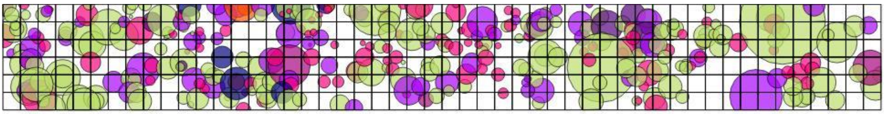
Fallow: 3 year plot: 1 position on hill: lower



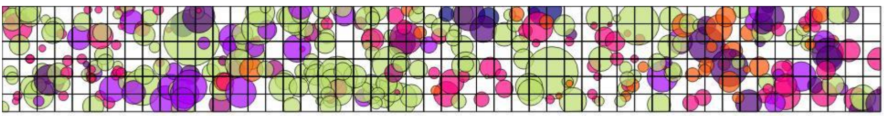
Fallow: 3 year plot: 2 position on hill: upper



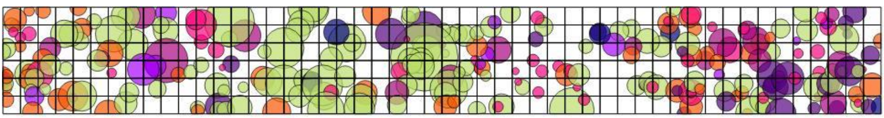
Fallow: 3 year plot: 2 position on hill: middle



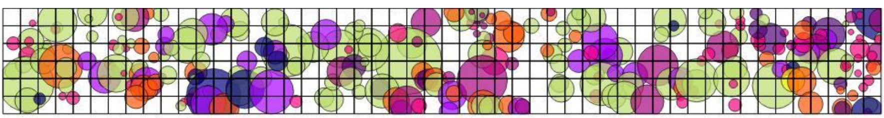
Fallow: 3 year plot: 2 position on hill: lower



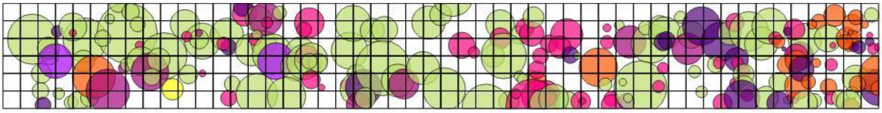
Fallow: 3 year plot: 3 position on hill: upper



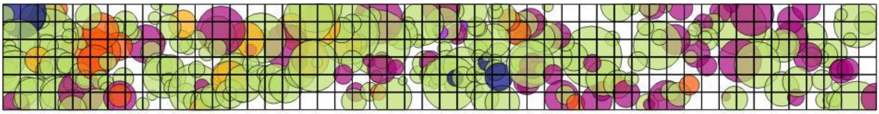
Fallow: 3 year plot: 3 position on hill: middle



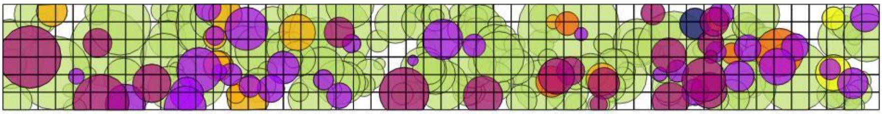
Fallow: 3 year plot: 3 position on hill: lower



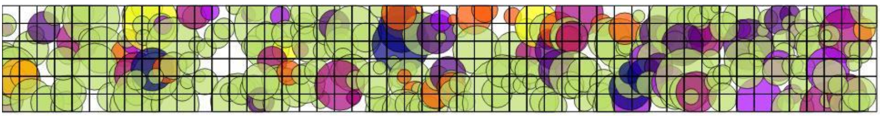
Fallow: 6 year plot: 1 position on hill: upper



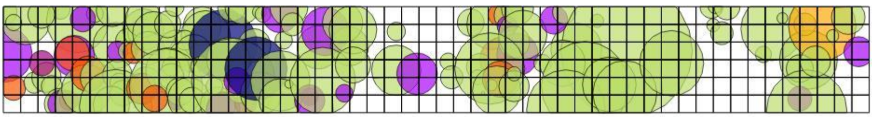
Fallow: 6 year plot: 1 position on hill: middle



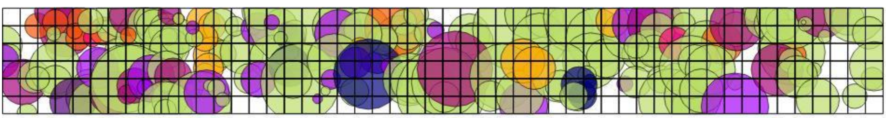
Fallow: 6 year plot: 1 position on hill: lower



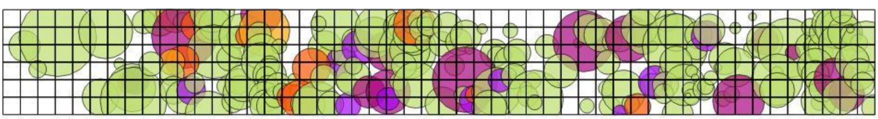
Fallow: 6 year plot: 2 position on hill: upper



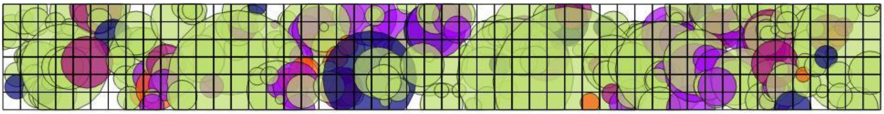
Fallow: 6 year plot: 2 position on hill: middle



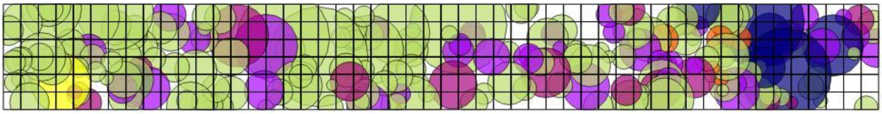
Fallow: 6 year plot: 2 position on hill: lower



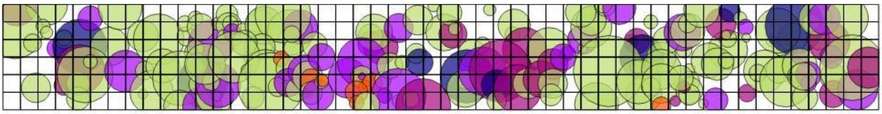
Fallow: 6 year plot: 3 position on hill: upper



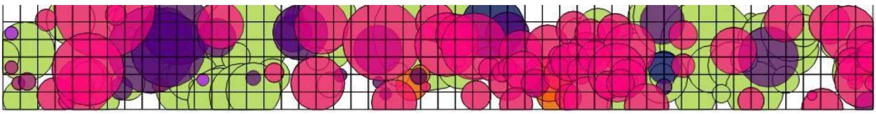
Fallow: 6 year plot: 3 position on hill: middle



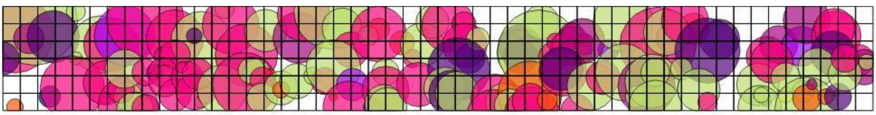
Fallow: 6 year plot: 3 position on hill: lower



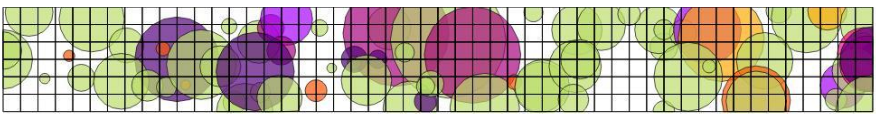
Fallow: 8 year plot: 1 position on hill: upper



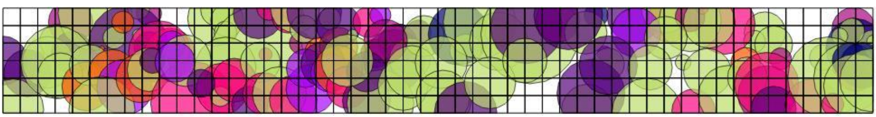
Fallow: 8 year plot: 1 position on hill: middle



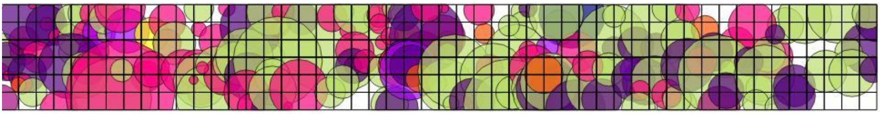
Fallow: 8 year plot: 1 position on hill: lower



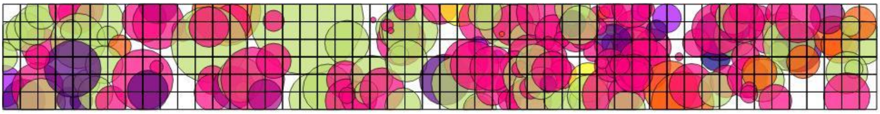
Fallow: 8 year plot: 2 position on hill: upper



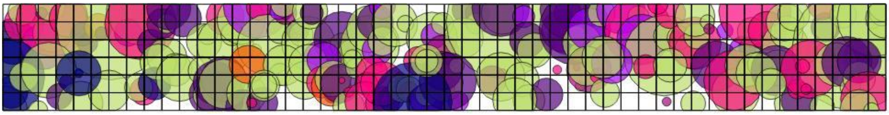
Fallow: 8 year plot: 2 position on hill: middle



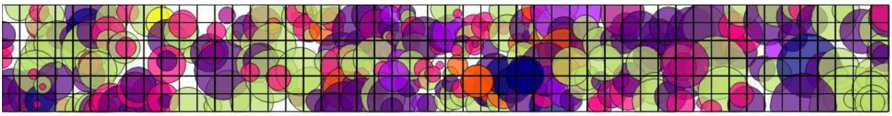
Fallow: 8 year plot: 2 position on hill: lower



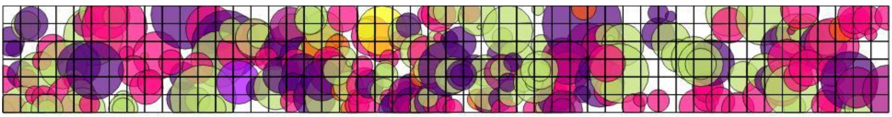
Fallow: 8 year plot: 3 position on hill: upper



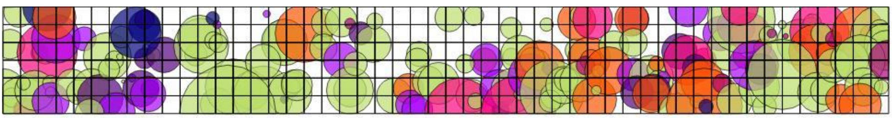
Fallow: 8 year plot: 3 position on hill: middle



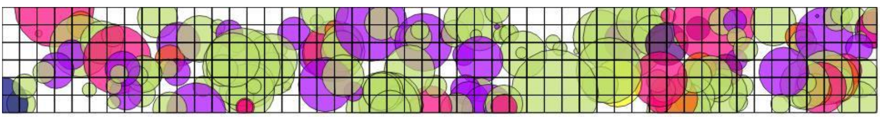
Fallow: 8 year plot: 3 position on hill: lower



Fallow: 10 year plot: 1 position on hill: upper



Fallow: 10 year plot: 1 position on hill: middle



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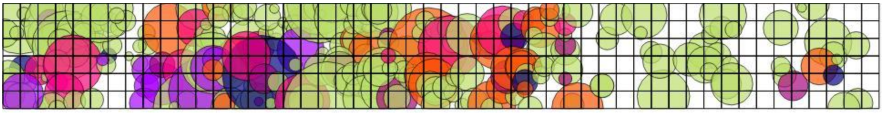
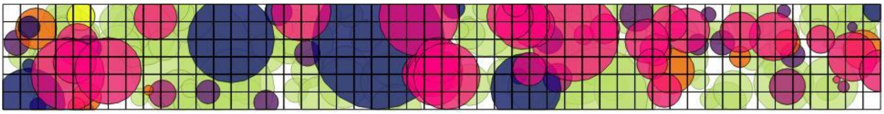
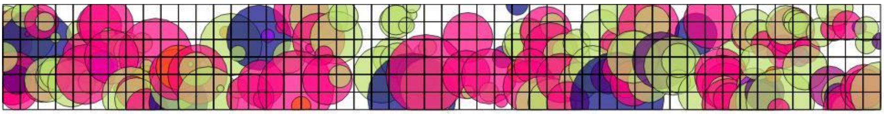


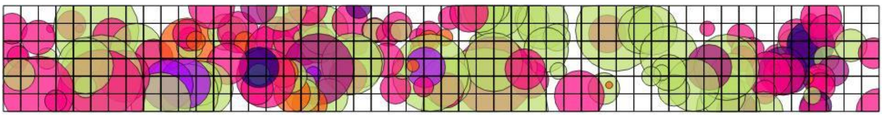
Fallow: 10 year plot: 2 position on hill: upper



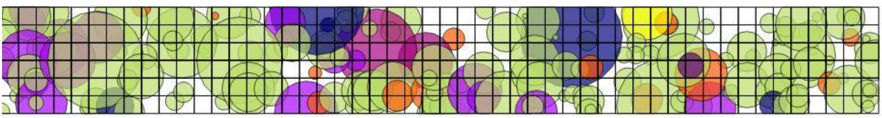
Fallow: 10 year plot: 2 position on hill: middle



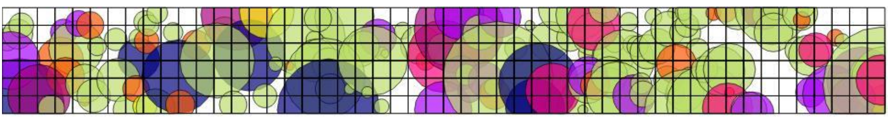
Fallow: 10 year plot: 2 position on hill: lower



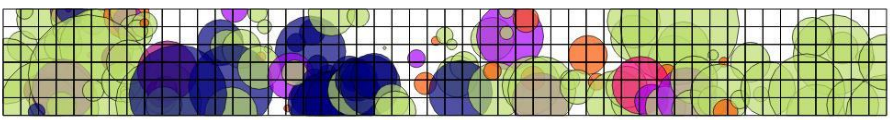
Fallow: 10 year plot: 3 position on hill: upper



Fallow: 10 year plot: 3 position on hill: middle



Fallow: 10 year plot: 3 position on hill: lower



Appendix 3 Soil profiles at the middle plot of each hill in Nong Khao.

1 year fallow plot 1

1 year fallow plot 2

1 year fallow plot 3

3 year fallow plot 1

3 year fallow plot 2

3 year fallow plot 3

6 year fallow plot 1

6 year fallow plot 2

6 year fallow plot 3

8 year fallow plot 1

8 year fallow plot 2

8 year fallow plot 3

10 year fallow plot 1

10 year fallow plot 2

10 year fallow plot 3

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