Innovative agroforestry designs for tropical plantation landscapes – the TRAILS project

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Abstract

TRAILS stands for "climaTe Resilient lAndscapes for wIldLife conServation"; it is a multidisciplinary research project aimed at assessing innovative solutions for wildlife and people in oil palm-dominated landscapes in Sabah, Borneo Island, Malaysia. Mixed-tree forests can provide habitat in a context of industrial agriculture, as pioneer tree species are efficient in restoring healthy riparian forests and providing shelter for wildlife. Biodiversity corridors also contribute to climatic resilience, as agroforestry systems can mitigate climate change through the sequestration of atmospheric carbon dioxide in plants and soil. Mixed plantations also improve livelihoods: it is key to understand ecosystems services and wellbeing values attributed by local communities to the reforestation of riparian areas and the transition from monoculture plantations toward mixed-planted systems. TRAILS objective is to install oil-palm-based agroforestry systems, using selected oil palm seedlings and native forest tree species grown in locally run village nurseries. The project also aims at monitoring the dynamics of recolonization by wildlife in areas covered with mixed-planting, riparian corridors, and oil palm plantations. The project monitors the agronomic performance of oil palms planted under agroforestry designs. TRAILS also aims at understanding key characters of climate resilience through the monitoring of bioclimatic condition of the parcels and their ability to provide environmental services. TRAILS builds on a complementary partnership, linking academic, NGOs, private and public stakeholders, thus enabling integrated approaches arising from various science fields, from agronomy and forestry to veterinary sciences, including a detailed socioeconomic approach.

Keywords: biodiversity, conservation, mixed plantings, oil palm, perennial crops, wildlife

INTRODUCTION

Southeast Asia is home to 20% of the remaining tropical forests. The region also has one of the highest rates of deforestation in the world because of urbanization, extractive activities and the expansion of commercial plantations. Malaysia harbors the largest forest areas in the region and one of the "megadiverse" areas for their rich biodiversity. The expansion of tree-crop plantations (including oil palm) is one of the main vectors of deforestation (Vijay et al., 2016). Driven by growing world demand, palm oil production has expanded dramatically in recent years. Palm oil is the most consumed vegetable oil globally and the demand has accelerated with the emergence of new outlets in the agrofuel sector, adding to traditional food and oleo-chemical uses (Rival and Levang, 2014). This strong growth has undeniably contributed to the economic development of the main producing countries, mainly Indonesia and Malaysia, which now supply 87% of world production.

Oil palm plantations managed as agroforestry systems (Bhagwat and Willis, 2008) can support conservation efforts. When oil palm is cultivated in mixed-tree orchards rather than monoculture plantations, such complex systems can provide habitat for forest-dwelling species (Ancrenaz et al., 2021). Mixed plantations within the landscape act as buffer zones and biodiversity corridors, and they are able to connect distant forest reserves. More, forest

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and agricultural resources in mixed plantation landscapes provide livelihood to local people.

Agricultural practices in tree crop plantations are changing as a response to growing social and environmental concerns (Bessou et al., 2017). Indeed, plantation management increasingly relies on agro-environmental services, which means that basic agricultural functions such as soil preservation, pollination, or pest control can be performed by living organisms (plants, insects, microbes).

Agroforestry trials of various designs aim at assessing the ability of a forest species (either as single-species or mixed planting) to be successfully associated with oil palm and create viable complex systems, able to support wildlife on a sustainable way. The project relies on the assumption that mixed forest species associated with oil palms will be able to generate a new type of more resilient plantations (da Silva Maia et al., 2021).

The objective of the TRAILS project is to assess the capacity of oil palm-based agroforests to improve the climatic resilience of tropical agricultural landscapes and their role in wildlife conservation around protected areas.

Various planting designs are studied by TRAILS in order to answer to several key questions:

- What mix of forest species should be chosen to constitute mixed plantations with oil palms?
- What is the impact on oil productivity of reducing oil palm planting density from the standard 143 palms ha^{-1} motif?
- What type of management of understorey vegetation when the oil palm density is reduced?
- What effects are expected on FFB production in palms, and on tree growth and biodiversity?

MATERIAL AND METHODS

Location of the project

The TRAILS project is hosted by the Hutan NGO, on the banks of the Kinabatangan River in Sabah, Malaysia, where the “Kinabatangan Orang Utan Conservation Program” or KOCP is developed for more than 20 years. TRAILS is presently implementing agroforestry experimental trials on sites selected by Melangking Oil Palm Plantations (MOPP) in the District of Sandakan and Kinabatangan, Sabah. There are five different sites allocated to the TRAILS project by MOPP, amounting a total acreage of 269.75 ha for agroforestry trials.

Mixed plantings using selected native forest species

The project builds on the previous planting of selected tree species in riparian areas along the rivers crossing the MOPP oil palm plantation. The TRAILS project is currently planting a first batch of 17,000 native forest trees originating from 17 different species (Table 1). Pioneer tree species were preferably selected, as experience showed that the plantation of fruit trees to attract wildlife is not necessary, as animals progressively bring seeds during the colonization of space.

Monitoring of the reforestation processes (growth of newly planted seedlings) is implemented by measuring seedlings size in sample plots on a regular basis: survival (yearly percentage of plants still alive), and growth rates (monitoring of height of the seedlings).

Microclimate measurements

A key hypothesis supporting TRAILS is that agroforestry systems confer a stronger resistance to extreme climatic events (like El Nino) than monocrop plantations. Changes in microclimate are followed by two independent data capture systems located in selected areas (oil palm plots and young riparian forest). We installed two ZL6 PRO METER (USA) Advance Data Loggers, each one being connected to an ATMOS-41 Microclimate Monitoring System which measures 12 weather variables including: air temperature, relative humidity, vapor pressure, barometric pressure, wind speed, gust and direction; solar radiation, precipitation, lightning strike counter and distance. Besides, an APOGEE SQ-521 Quantum PAR Sensor

(Meter, USA) measures the photosynthetic photon flux density (PPFD) in µmol m^{-2} s^{-1} from a field of view of 180 degrees. In addition, leaf area index (LAI) is measured in both oil palms and forest species. Using a LAI-2200C Plant Canopy Analyzer enables accurate and non-destructive measurements inferring leaf area from measurements of how radiation is intercepted by the canopy, making use of a simple light interception model. This Canopy Analyzer equipment will be complemented, in the coming months, with a LI-7810 CH_4/CO_2/H_2O Gas Analyzer for atmospheric monitoring and analyses of soil gas flux.

Table 1. List of 27 native forest species selected for agroforestry plantings in TRAILS.

Family	Species	Vernacular name
Anacardiaceae	*Koordersiodendron pinnatum*	Ranggu
Anacardiaceae	*Pentaspadon motleyi*	Pelajau
Anacardiaceae	*Dracontomelon* sp.	Sengkuang
Annonaceae	*Meiogyne* sp.	Karai
Combretaceae	*Terminalia catappa*	Ketapang Paya
Dilleniaceae	*Dillenia borneensis*	Simpoh Gajah
Dilleniaceae	*Dillenia excelsa*	Simpoh laki
Ebenaceae	*Diospyros* sp.	Kayu Malam
Euphorbiaceae	*Croton oblongus*	Lokon
Euphorbiaceae	*Mallotus muticus*	Mallatus Paya
Euphorbiaceae	*Glochidion borneensis*	Obah Nasi
Euphorbiaceae	*Excoecaria indica*	Apid Apid
Lauraceae	*Cinnamommum* spp.	Tiga urat
Malvaceae	*Pterospermum javanicum*	Bayor
Meliaceae	*Toona sureni*	Limpaga
Moraceae	*Ficus septica*	Lintotobu
Moraceae	*Ficus benjamina*	Lamba - banyan
Myrtaceae	*Eugenia cerassiformis*	Obah Jangkang
Myrtaceae	*Eugenia* sp.	Obah Putih
Myrtaceae	*Syzygium malaccense*	Makopa
Myrtaceae	*Eugenia cerasiformis*	Obah merah
Rubiaceae	*Nauclea subdita*	Bangkal aiskrim/kuning
Rubiaceae	*Nauclea orientalis*	Bangkal Daun Besar
Rutaceae	*Murraya paniculata*	Kemuning
Tiliaceae	*Microcos crassifolia*	Kerodong Damak-damak
Verbenaceae	*Vitex pinnata*	Kulimpapa

Soil, plant and water analyses are subcontracted to a specialized laboratory. Soil analyses include measurements of pH, nitrogen, phosphorus, potassium, calcium, magnesium, carbon, electrical conductivity, and cation-exchange capacity (CEC). Plants (oil palms and forest species) are analyzed for foliar elements, namely: nitrogen, phosphorus, potassium, calcium, magnesium, boron, copper and zinc (Zn). Rivers and streams waterways in the study area are analyzed for nitrate as N, phosphorus as phosphate, potassium as K, zinc, glyphosate, *Escherichia coli*, and faecal streptococci. In waste water/effluents, the following parameters are monitored: temperature, pH, BOD5 at 20°C, COD, suspended solids, mercury, cadmium, chromium, hexavalent, arsenic, cyanide, lead, copper, chromium, trivalent, manganese, nickel, tin, zinc, boron, iron, phenol, free chlorine as Cl_2, sulphide as S^{2-}, oil and grease, silver, aluminum, selenium, barium, fluoride, formaldehyde, and ammoniacal nitrogen.

Wildlife management and monitoring

Over the years, Hutan has developed simple, efficient, and practical ways to monitor populations of various species. Taxa being monitored (Shia, 2020) include small mammals (trapping and release); primates (direct and indirect sightings, calls); amphibians and reptiles (direct sightings); birds (calls); terrestrial animals (camera trapping. The project also monitors invertebrate species via trapping (fall-traps and light trapping) or bioacoustics to assess micro fauna in agricultural landscapes. Standard operating procedures for wildlife monitoring are developed and they can be applied and replicated in an oil palm context.

The Rasig Corridor Project is located close to the Kinabatangan River, less than 10 km away from the TRAILS project. The HUTAN team recently completed the third year of Biodiversity Monitoring activities at the Rasig corridor. This project consists of 30 small plots located in three different treatment areas: 10 plots are in pure oil palm plantations; 10 in disturbed and protected forests; 10 in a reforestation plot (where seedlings are planted under mature and unharvested palm plants). Every year, the team uses a series of techniques to document this corridor's wildlife dynamic and recolonization (Shia, 2020). The results collected at Rasig are also processed and analyzed in order to test various statistical analyses that will then be applied to TRAILS' data. (diversity indexes for biodiversity value and species richness; non-metric multidimensional scaling analysis and general linear modeling to test the influence of environmental variables on the community structure).

Impact on local communities

The TRAILS project focuses on the identification of economic opportunities linked to the implementation of ecosystem services by local communities (Ancrenaz et al., 2007). For several years, Hutan has been supporting initiatives from local communities through the creation and management of trees nurseries for reforestation, the implementation of reforestation activities and wildlife monitoring. More recently, these initiatives were complemented by the development of an ecotourism program involving families' homestays in the project's area. In addition, some villagers are combining various activities from artisanal fisheries to smallholding oil palm farming.

The socioeconomic focus of the TRAILS project consists in identifying ecosystems services and wellbeing values attributed by local communities to the reforestation of riparian areas, as the Kinabatangan river water quality is vital for the health and livelihood of these communities. The local perception of ecosystem services is being studied through individual interviews and collective workshops with villagers in the project area. TRAILS also undertakes a quantitative survey based on villages' population sampling, in order to determine the system of activities and the income mobilized by stakeholders.

Innovative planting designs

During the first years, the species that do not support the mixed plantation conditions will be quickly eliminated; then, among the species that best adapt to the association with the oil palm, it will take much longer to determine those whose behavior is really adapted to the desired functions of the mixed plantation. The TRAILS project relies on are two types of plantation designs: one is "interplanted rows" and the other is "forest islands".

1. Interplanted rows.

Oil palms are usually planted in line with a spacing of 9 m between the palm trees on the line and about 9 m between the lines, which makes about 143 palm trees ha^{-1}. Forest plantations for the production of timber wood are often planted at 3×3 m, with a density of 1,111 trees ha^{-1}.

A planting design using randomized complete blocks is installed, in order to identify the most suitable layout associating forest trees and palms, without excessively affecting the productivity of oil palms (Figure 1). This type of plantation design involves randomized plots with 5 blocks at minimum. Each block consists of 3 plots with different treatments, plus a control which is a pure oil palm plot of the same size. In Plot 1, forest trees are planted in a line every 4.5 m in the inter-row of oil palms, thus forming a rather dense plantation. In Plot 2, forest trees are planted in the inter-rows of palms every 9 m on the line, staggered in relation to the palms. In Plot 3, every other palms rows are removed (or not planted with palms) and planted with three rows of trees every 4.5 m. The trees rows are staggered and 1.5 m apart, which limits competition with palms. Plot 4 is the control treatment, consisting of oil palm plantation alone, without any other trees species. This block or repetition is composed of 4 treatments and each block is repeated at least 5 times.

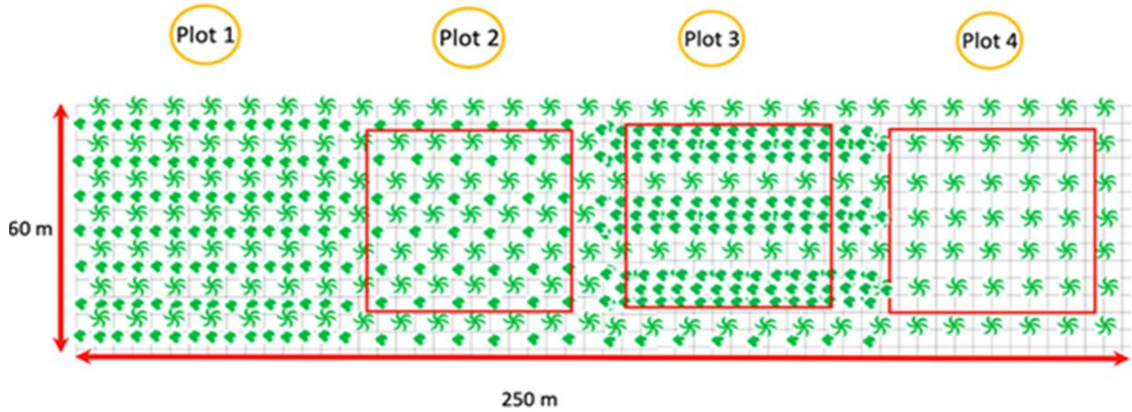

Figure 1. Planting design mixing oil palm and native forest species at various different densities.

In each plot, we implement dendrometric measurements, namely Root collar diameter (RCD), diameter at breast height (DBH), total tree height, live crown length (LCL), crown radius, and crown diameter (CD). We also estimate the production of Fresh Fruit Bunches from palms, and analyze soil health parameters using the Biofunctool Kit.

2. Forest islands.

Inside oil palm plantations, patches of forests are created in order to increase the connectivity between wild spaces.

The experimental layout described here combines two approaches: i) planting forest species randomly and assessing which ones support this type of planting design. In this case, the gregarious species – which do not support the proximity of other species – might be eliminated. A second design consists of plots made of one single species, with trees planted densely in small groups, called nuclides or Anderson's plots. This design generates more "messy-looking" forested areas than a classic plantation, but it offers much greater biological diversity. As the canopy is not closing rapidly, such design have some interest for biological diversity and wildlife circulation.

Figure 2 illustrates an example of 3 plots of different planting densities; two types of treatments, the species inside the plot 1 is a treatment and the trees arrangement is another treatment. In Plot 1, the objective is twofold, firstly to compare several different forest species from Table 1, each species being considered as a statistical treatment. These species are randomly mixed and 25 trees species^{-1} are measured in the plot. The second objective consists in comparing the type of design (the design is then the analyzed treatment, here species in mixed plantation at 3×3 m), with nuclides in Plots 2 and 3. The planted density is 1,111 trees ha^{-1}. In Plot 2, we study the effect of the nuclide layout on restoration. The nuclides have a spacing of 9×9 m, which corresponds to the classic spacing of oil palms. This can further allow the use of results by integrating them into an oil palm plantation design. In Plot 2, there are five trees of the same species per nuclide, inside the plot there are 5 different species selected from Table 1, the nuclides being randomly mixed. In this plot, 25 nuclides will be measured, i.e. 5 nuclides species^{-1}, or 25 trees species^{-1}. The planted density is 617 trees ha^{-1}. In Plot 3, the nuclides have a spacing of 15×15 m, there are 10 trees of the same species (Table 1) per nuclide, inside the plot there are 5 different species, the same species as in plot 2, the nuclides are randomly mixed. The planted density is 444 trees ha^{-1}.

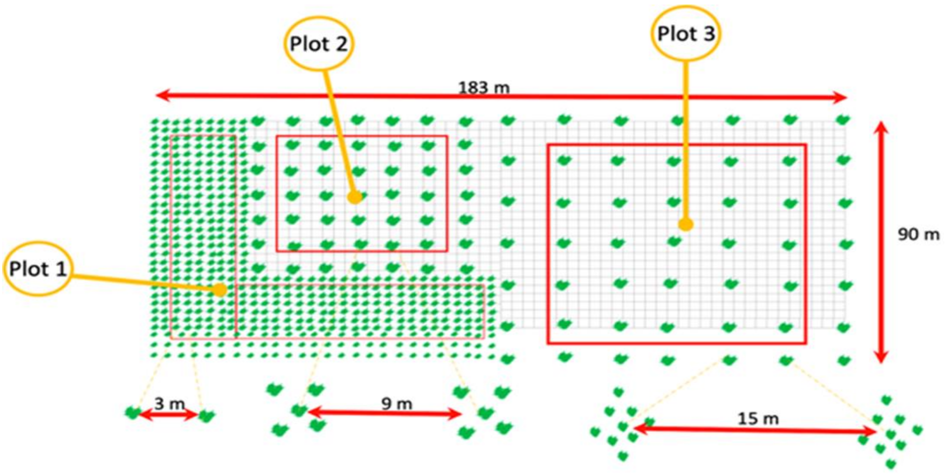

Figure 2. Planting design for the installation of forest trees islands inside oil palm plantations.

EXPECTED RESULTS

The agroforestry plantings are currently underway at MOPP plantations, and baseline studies are documenting the status of parcels at time zero of the project. Simultaneously, soil and water analysis are providing data on the respective status of each type of parcel at the initial stage of experiments.

The TRAILS project is expected to create a prototype for future planting designs based on oil palm agroforestry. It is now of paramount importance to challenge the monospecific plantation system in place in tropical landscapes for more than a century (Abram et al., 2014; Zemp et al., 2019).

At the end of the TRAILS project, we hope to be able to decide on: 1) the ability of native tree species to grow in association with oil palms, and the capacity of oil palms to support this association; 2) their function as service providers, such as legumes to improve N in soil or fruit trees to attract wildlife; and 3) the precise assessment of risks, as the nature and pathogenicity toward the oil palm of the microflora colonizing the soil of mixed plantations must be carefully monitored.

CONCLUSIONS

The TRAILS project is of modest size when compared to the huge oil palm-cultivated area in the region: nevertheless, its comparative value resides in its role as a prototype and a catalyzer.

We hope that TRAILS will inspire and initiate the implementation of many other projects on oil palm-based agroforestry under various different agroecological contexts.

Given the uncertainties faced by the sector (climatic resilience, dependence on labor), the multisite assessment of the capacities of oil palm-based agroforestry system must be a priority for scientists, policy makers, and the oil palm industry in all producing countries (Purwanto et al., 2020).

Since the pioneering work initiated in 2007 by Miccolis et al. (2019) on 18 ha in Brazilian Amazon, such initiatives remain rather scarce and they are disconnected, thus efforts are needed to gain and share knowledge.

The Chinese proverb should say: “The best time to plant a palm-based agroforestry system was 20 years ago. The second best time is now”.

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