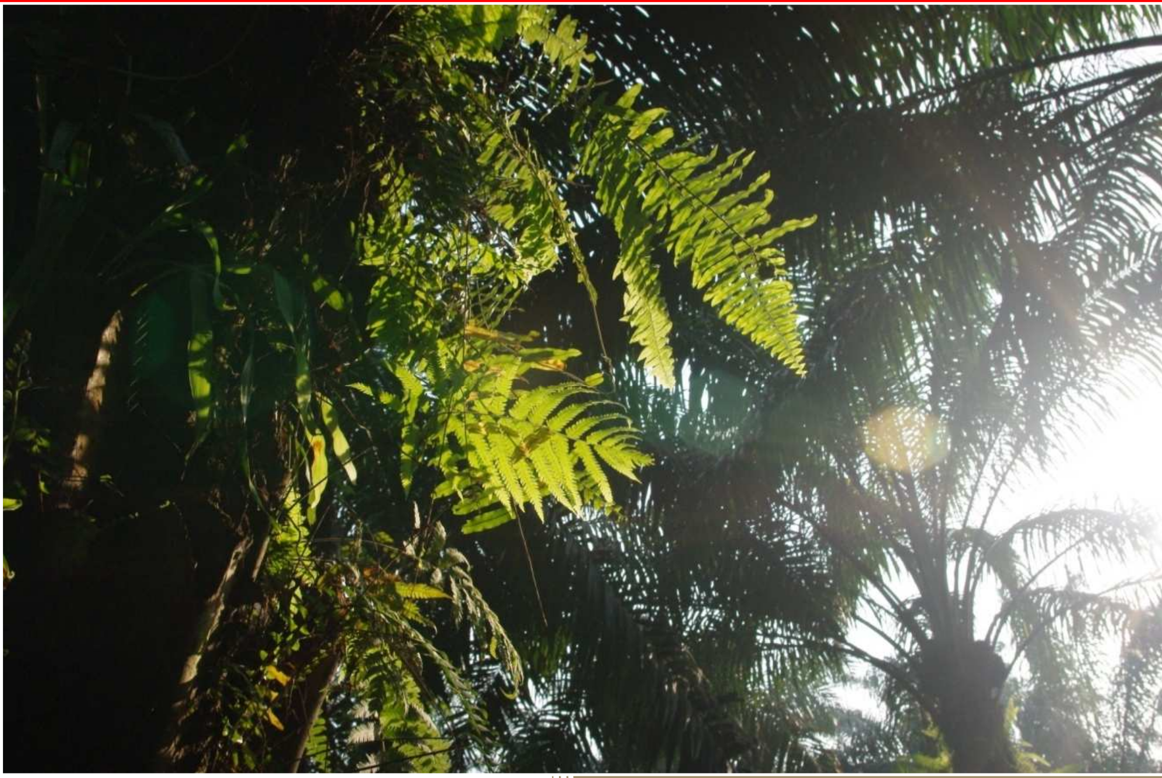
2009

Vascular plants biodiversity repartition in a high productive oil palm plantation

Riau, Sumatra, Indonesia



David Combaz

1st year MoS student

Ecological Engineering and Biodiversity Management

CIRAD

SMART Research Institute

1 Introduction 5
1.1 Oil palm economy and development issues 5
1.2 Meeting the demand 5
1.3 Environmental challenges 5
1.4 Stakes and knowledge on plantations' biodiversity 6
1.5 Long term objectives 6
1.6 Problematic 7
2 Material & methods 7
2.1 General description of the studied area 7
2.2 The plantation inner structure 9
2.3 Agricultural practices 9
2.4 Sampling stations definition 9
2.5 Sampling area and collection sites choice 10
2.6 Site description 11
2.7 Vegetable samples collection and identification 12
2.8 Data processing and analyses 13
3 Results 14
3.1 Survey quality and efficiency: 14
3.2 Biodiversity repartition among stations 16
3.3 Yield improvement 19
4 Discussion & Conclusion 22
4.1 Biodiversity repartition 22
4.2 Sampling protocol 24
4.3 Taxonomy: issues and perspectives 25
5 Acknowledgements 26
6 References 26
7 Annexe: list of species 28

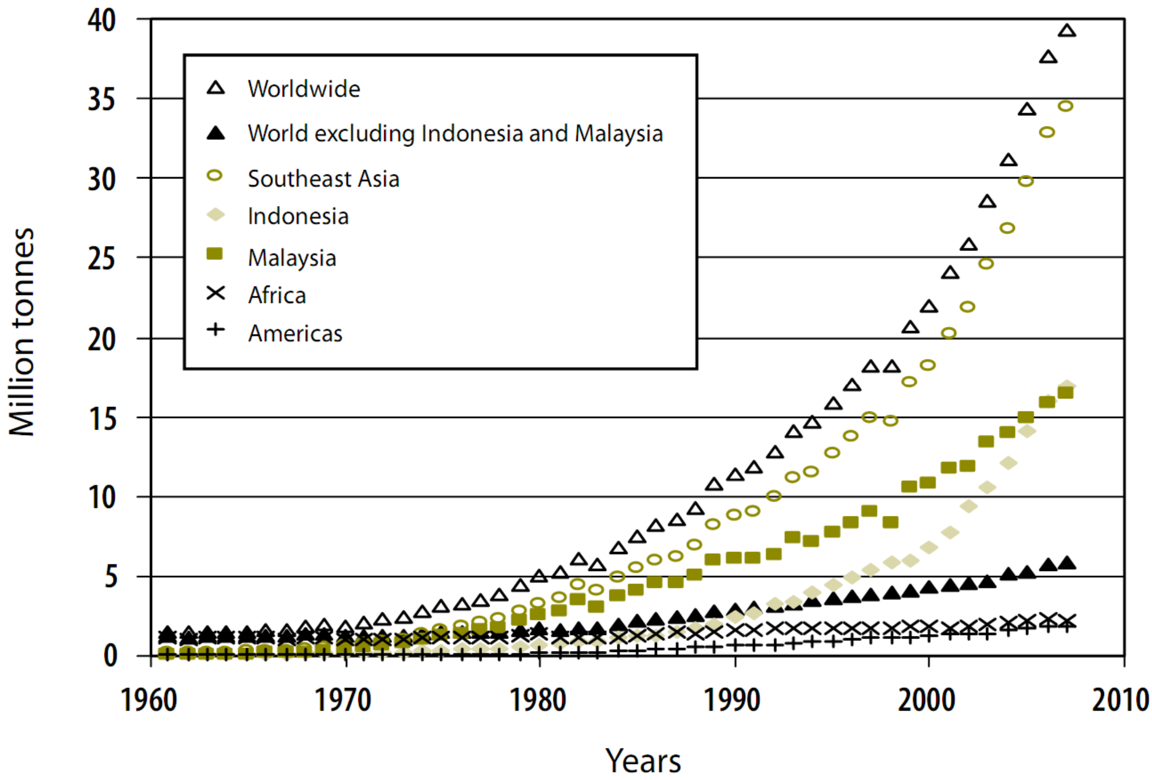


Figure 1: Oil palm production in different world areas. | Source: Sheil et al. 2009, from FAO stats.

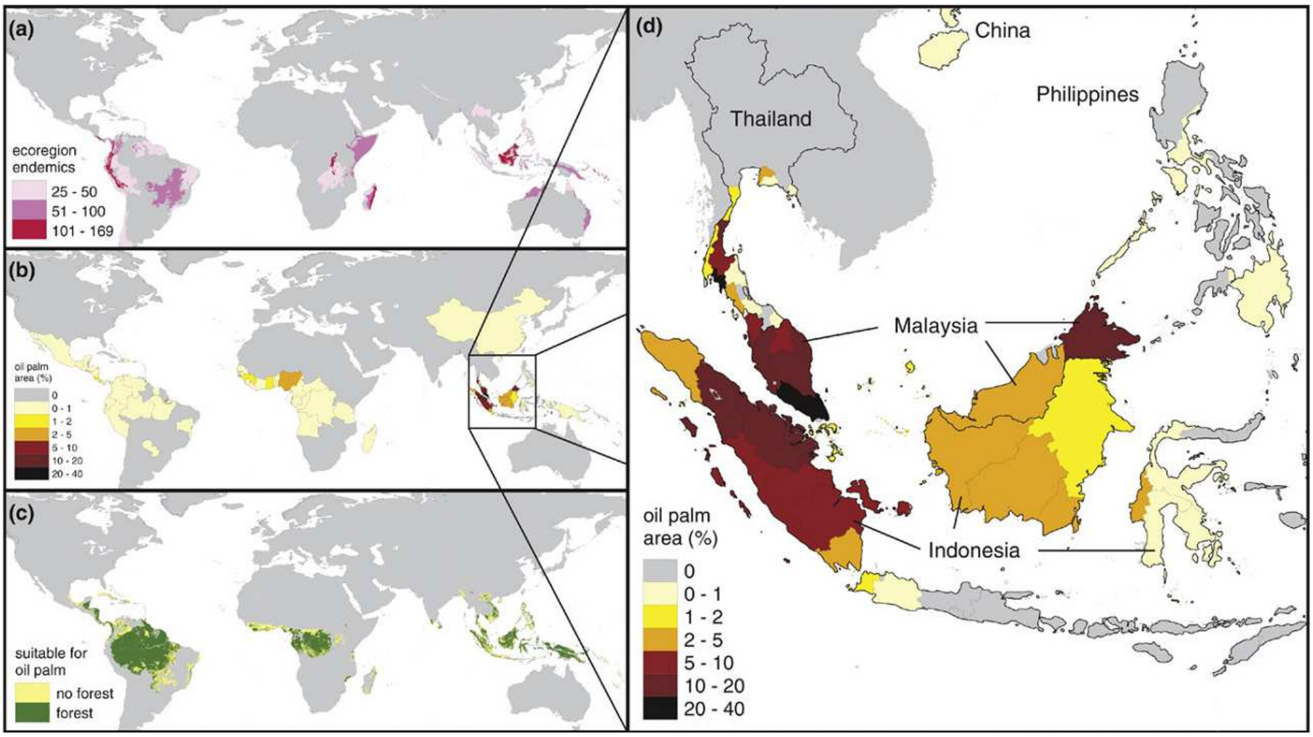


Figure 2: Global extent of oil palm and conservation problematic a) Principal vertebrate's endemism areas. b) Global repartition of oil palm areas in land-use percentage. c) Areas suitable for oil palm culture. d) Oil palm surfaces in Southeast Asia, in land use percentage. | Source: Fitherbert et al. 2008.

1 Introduction

1.1 Oil palm economy and development issues

Between 1983 and 2003, the share of palm oil – extracted from the oil palm *Elaeis guineensis* fruits – in vegetable oil international trade rose from 29% to 49%. It is expected to reach 70% in 2015 (Thoenes, 2006). This long trend (and nevertheless rapid) growth is mainly supported by two factors: a global increase in vegetable oil demand; and the high competitiveness of oil palm cultures.

The vegetable oil consumption in China and India is growing fast (29% between 2004 and 2005) and absorbs around 30% of global palm oil production (Sheil *et al.* 2009). In addition, the development of biodiesel, especially in European Union since 2003, diverts an increasing share of rapeseed's production from food market, for the benefit of palm oil (Thoenes 2006, European Commission 2006).

Actually, palm oil is the cheapest vegetable oil: 20% cheaper than soybean oil, the second in the list. This is mainly due to the high yields that oil palm agriculture allows, up to 6.6 tons of palm and kernel oils per hectare and year. Moreover, oil palm production costs are low for the labor costs are low, and it benefits from favorable development policies, especially in Malaysia and Indonesia from which more than 80% of global palm oil exportations come (Thoenes 2006, Abdullah & Hezri 2008).

Since the middle of the 1970's, these two countries' economics development partly relies on palm oil exportation incomes which accounted for $20 billion in 2007 (Nantha & Tisdell 2009), for the benefit of State and private companies and smallholders (18%, 50% and 32% of cultivated lands, respectively – Bangun 2006). Despite the cultural and social drawbacks attributed to the rapid oil palm expansion in rural areas (Sheil et al. 2009), at least 2 million people live from oil palm industry in Malaysia and Indonesia (Nantha & Tisdell 2009).

1.2 Meeting the demand

During the 2007-2008 periods, the global oil palm production was around 41 million tons (fig. 1), for planted areas over 13.5 million hectares (Sheil et al. 2009, Fitzherbert et al. 2008). Meeting the increasing demand leaves only two options: to reach better yields or to increase the cultivated areas.

Intensification of oil palm plantations could be realistic, for many smallholders are still far from the agronomic optimum that oil palm allows when top management practices are used (Bangun 2006). Moreover, further steps in genetic selection of cultivated varieties could help improving yields (Shiel et al. 2008). Nevertheless, these optimistic views seem to be denied by long term trends, showing a stagnation of yields over the last two decades (Thoenes 2006).

The other solution – expansion of cultivated areas – seems easier to carry on, economically and technically speaking: oil palm can be grown on all soil types in low altitude tropical plains (fig. 2 b & c), as long as rainfalls reach 1,800 annual millimeters and temperatures stay between 18°C and 34°C. (Jacquemard 1995).

1.3 Environmental challenges

When not disturbed by heavy human pressure, these tropical areas are covered with humid forests of critical importance for climate regulation, and present the richest biodiversity levels on Earth (fig. 2 a). When these forests come to be cleared and replaced by oil palm plantations, this biodiversity drops down because of the loss and fragmentation of the habitats needed for forest-specialized species to survive (Fitzherbert et al. 2008, Koh 2008, Koh & Wilcove 2008).

30% of all the forests of South and Southeast Asia[1] are located within the Indonesian boundaries. 55% of them are primary forests. Between 1995 and 2005, the deforestation rate reached 2% – 10 times the global average (FAO 2005). Obviously, part of this deforestation is due to oil palm estates creation. Whereas the figures are difficult to produce, it may represent 1.7 to 3 million hectares out of the 28.1 hectares of destroyed forest (Fitzherbert et al. 2009).

In reaction, NGOs such as WWF or Greenpeace targeted oil palm industry in public campaigns that spoiled the principal agro-alimentary and cosmetic, palm-oil-dependent lobbies' image for occidental consumers (Greenpeace 2007, Buckland 2005, WWF International 2003).

In 2004, the *Roundtable on Sustainable Palm Oil* (RSPO) was created to gather the main international stakeholders in palm oil industry – growers, millers, industrials, financers, and NGOs (Caliman et al. 2005, Omont et al. 2005, www.rspo.org: *History of RSPO* and *Member profile*). In 2005, 8 principles and 39 criteria were created, and then revised in 2007 to define the sustainability objectives to reach as a preamble to a certification system creation.

1.4 Stakes and knowledge on plantations' biodiversity

RSPO principle 5 is focused on reducing oil palm plantations' impacts on patrimonial species and high conservation value habitats, which are to be surveyed before acting to protect them (RSPO 2007). Yet the biodiversity that can be found inside the plantations is not considered as a whole, despite the geographical importance of oil palm systems: in Sumatra and Malaysia, oil palm plantations often cover between 5% and 20% of total lands, depending on the provinces (fig. 2 d, Fitzherbert et al. 2009) and occur frequently to be the matrix in which other landscape units are inserted.

Moreover, the knowledge on this oil-palm systems biodiversity is very little, especially on vegetable taxa (Fitzherbert et al. 2009, Turner 2008), whereas it is bound to many stakes: from a conservation point of view, it is important to know in what extent the landscape matrix allows biodiversity settlements and fluxes. This "connectivity" has effects on two major processes: local extinctions buffering with migratory effects among wildlife kernels, and the spreading of invasive species (Perfecto & Vandermeer 2008).

Furthermore, biodiversity in agricultural systems provides ecological services, as nutrient cycling, soil structuring, pest control, etc. (Clergue et al. 2005).

1.5 Long term objectives

Oil palm growers have to acquire the tools and skills that will allow them to anticipate the legal constraints that will sooner or later replace volunteer commitment for a better management of environmental impact, like the RSPO initiative.

This study is part of a long term reflection that CIRAD and PT SInarMas group – one of the biggest oil palm plantation owners worldwide – are holding together, trough a long term partnership between CIRAD's UPR 34 (performances of perennial crop systems) and PT SMART, the leading company of SinarMas's agro-business trust (Golden Agri-Resources).

In this partnership context, four agri-environmental indicators have been constructed for oil palm agriculture, to assess environmental impacts of practices related to nitrogen management (I_N), pest control (I_{PHY}), soil cover (I_{COUV}) and organic matter (I_{MO}) management. (Caliman *et al.* 2005, Girardin *et al*., 2007, Wohlfahrt *et al.* 2006). All these studies have been carried out in PT SMART research and development center, SMART Resarch Institute (SMARTRI).

---

[1] Bangladesh, Bhutan, Brunei, Cambodia, India, Indonesia, Laos, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Timor, Vietnam.

The next environmental aspect to focus on could be biodiversity. As SMARTRI has no experience in this topic, a 6 month internship has been proposed to a first year Master of Science student in ecological engineering and biodiversity management, in order to give a start to the project.

1.6 Problematic

Generally speaking, an indicator is a combination of variables which allow, when compared to a reference value, giving a good representation of a complex system's state without too much investment (Girardin et al. 2005). When applied to biodiversity, these variables may be of different types: direct indicators focus on biodiversity itself, whereas indirect indicators measure human activities that have impacts on biodiversity composition and structure (Levrel 2007).

Defining those variables can be done only for a given scale, and the variable choices will strongly influent the meaning of the indicator. As a management tool, a biodiversity indicator is not neutral, but answers precise questions linked with human representation of biodiversity (Levrel 2007, Clergue et al. 2008). Hence before the variables' choice, the system to represent must be precisely described, and influent variables must be found. And after the indicator has been defined, data must be collected in order to valid the indicator's predictions.

This study is aimed at giving a first insight of vascular plants biodiversity in a high productive oil palm estate, to propose efficient strategies for further surveys and analyses.

2 Material & methods

Oil palm plantations are structurally complex, and this complexity provokes environmental variation that could discriminate species to form different plant associations. On a little scale, it is assumed that different elements of the plantation's structure present different properties in terms of soil structure and contents, and receive different amount of light, fertilizers and herbicides.

To discover whether these structural elements – the sampling stations – have any effect on biodiversity composition, species' repartition and abundance were collected on them, before testing the similarities among observed species distribution. In order to allow further analyses on environmental effects, the collected sites also precisely described on environmental variables.

Protocol improvement was eventually proposed, testing the effects of stations redefinition in order to avoid redundancy in the communities sampled.

2.1 General description of the studied area

This study has been carried on Libo estate in the province of Riau, Sumatra (0.5° N, 101.5° E). It spreads over 4,000 hectares, included within a 7 estates complex of 125,000 hectares. All of them are properties of the Sinar Mas agro-business division, Golden Agri-Resources (GAR) (fig. 3).

Libo estate's productive activities are managed by PT Ivo Mas Tunggal, which is a subsidiary of GAR. All scientific activities are under Sinar Mas Agro-Resources and Technologies Research Institute (SMARTRI), which is the research and development division of PT SMART, the top company within the GAR lobby. Libo is a very high productive plantation, with yields around 6.6 tons of palm and kernel oils per hectare and year. All the palms inside of it have been planted between 1986 and 1990.

The topography inside the estate is diverse, whereas the total altitude variations don't exceed 50 m, between 20 an 70 m above sea level. Soils are acid rich in silica, and mostly sandy, the alluvial grounds being richer in silt. Hydrography is a compound of natural rivers and drains.

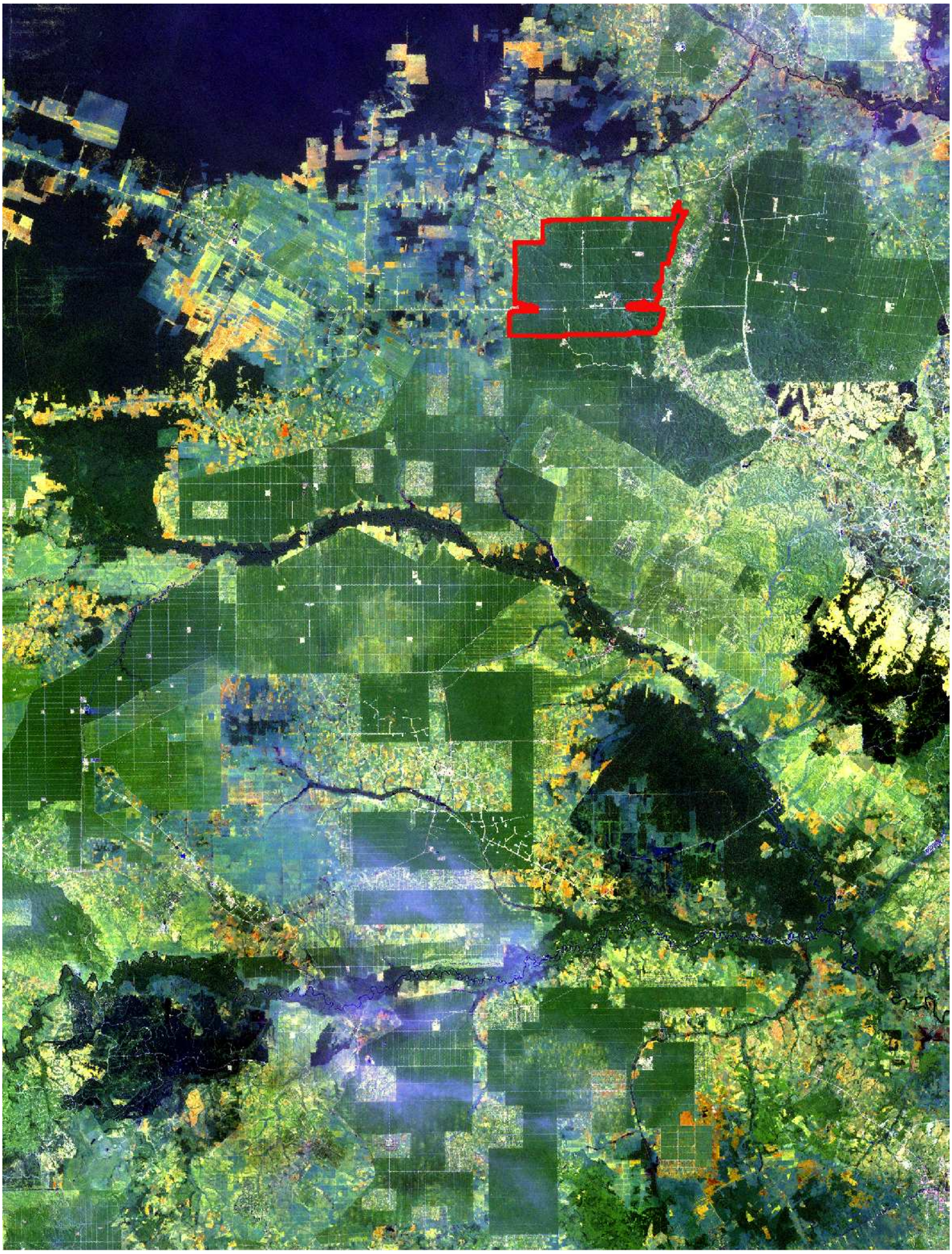


Figure 3: Site of study, in 2000. Libo estate is outlines in red. | Source: Landsat 2000

2.2 The plantation inner structure

The estate is divided in quadrangular blocks, 1 Km long and 300 m wide. Inside each block, 130 rows of 34 palm trees are planted in a triangular pattern to reach the average density of 143 plants per hectare.

Between the rows, one can find either the harvesting path or a windrow of vegetable waste, which was created during land preparation. This windrow is constantly renewed with dead fronds cut while harvesting, that can also be left on each palm's side. On each palm's foot, a 1.6 m to 1.8 m radius circle is kept free of weeds to allow fallen fruits detection.

A 20 years old palm is around 12 to 15 m high. The stem is more or less covered with the decaying bases of formerly cut fronds. Epiphytes can grow on them. When a palm dies it is left lying to rot where it fell.

2.3 Agricultural practices

Inside Libo, fertilization is done either with organic matter coming from the mill's waste or with mineral fertilizers. 4 different treatments are used:

- Mineral fertilization:
- Manual application of N, K and Mg on the outer border of the circles, P in the windrows
- Homogenous mechanic dispersion of N, P, K and Mg
- Organic fertilization:
- Empty fruit bunches (EFB) application along the harvesting paths
- Land Application (LA) of mill effluents in basins dug inside the windrows

Herbicide spraying is periodically done on harvesting paths and circles, using glyphosate, paraquat and dimethyl-metsulfuron Epiphytes and *Imperata cylindrica* plants are treated separately by wiping. As workers are told to treat only when necessary, the amount and periodicity of herbicide application is not directly available.

Chemical control of animal pests seldom occurs: integrated pest management techniques are commonly used with good results.

2.4 Sampling stations definition

The structural unit of the plantation is defined as the space around each palm tree comprised between the fronds piles on each stem's side, the windrow and the harvesting path. This is the smallest habitat variation scale this study takes into account.

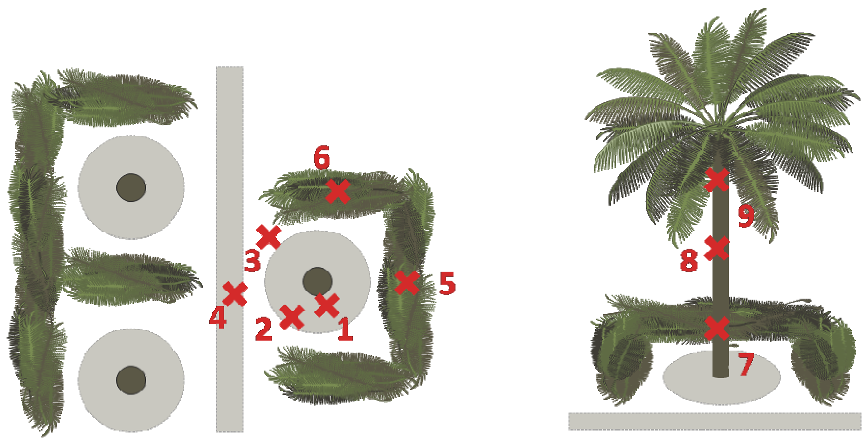


Figure 4: Stations location inside the plantation's structural unit.

1. Inner circle
2. Outer circle
3. Interval
4. Harvesting path
5. Windrow
6. Fronds pile
7. Stem basis (1-2 m)
8. Stem middle (5-6 m)
9. Under crown (9-10 m)

9 sampling stations were defined inside of the structural unit (fig. 4), each station being different from the other according to a few parameters that are supposed to be important for

habitat definition (tab. 1): organic matter abundance in the soil, fertilizers income, herbicide treatments and available light.

In addition of these 9 stations, three types of open areas were also selected for sampling: dead palms, borders (roads around the blocks) and river banks. The “open area” definition relies on the breaking of the plantation pattern of the block: to be considered as an open area, the distance between two palm trees standing on opposite sides of a given road, river or dead palm must exceed the standard distance between palm trees inside the block.

Table 1: Hypotheses on stations properties depending on fertilization management

	Fertilisation management			Additional conditions
Plot name	**EFB**	**Homogenous mineral**	**heterogenous mineral**	
inner circle	OM, herbicide	OM, N, P, K, Mg	OM, herbicide	light depends on proximity effects
outer circle	herbicide	N, P, K, Mg, herbicide	N, K, Mg, herbicide	
interval	(OM, herbicide)	N, P, K, Mg, (OM, herbicide)	N, K, Mg, (OM, herbicide)	
harvesting path	OM, herbicide	N, P, K, Mg, herbicide	herbicide	
windrow	OM	OM, N, P, K, Mg	OM, P	
fronds pile	OM	OM, N, P, K, Mg	OM	
EFB	OM	-	-	
stem basis	(OM), light -	(OM), light -	(OM), light -	OM depends on frond bases or dead palm residuals
stem middle	(OM), light =	(OM), light =	(OM), light =	
under crown	(OM), light +	(OM), light +	(OM), light +	
open areas	(OM), light +	(OM), light +	(OM), light +	

2.5 Sampling area and collection sites choice

As it was not realistic to survey biodiversity on the whole estate, a reduced sampling area has been chosen on the estate’s geographic information system completed with relevant fertilization data for years 2007-2009. 5 blocks (fig. 5) have been selected under the following criteria:

- Topographic diversity, including all particular land structure that can be found in the estate
- Stability in fertilization treatments, which effects are to be assessed.

The survey itself was conducted by collecting plants on clusters of 12 sampling sites corresponding to the 12 stations of the structural unit defined above. In order to avoid auto-correlation in the data, the 12 sites inside each cluster were taken on or around different palm trees randomly chosen inside subsets of 122 palms, the position of which were also randomly defined inside the blocs. The choice of sampling sites has been programmed with R.2.9.1 software.

When sampling was not possible on one site, because the palm was dead or beyond the block’s boundaries, the site was given up and not replaced.

For this study, 147 sites have been sampled on the five selected blocks: 13 inner circles, 11 outer circles, 11 intervals, 14 harvesting paths, 14 windrows, 12 fronds piles, 13 stem bases, 11 stem middles, 12 under crown, 12 river banks, 12 borders and 12 dead palms.

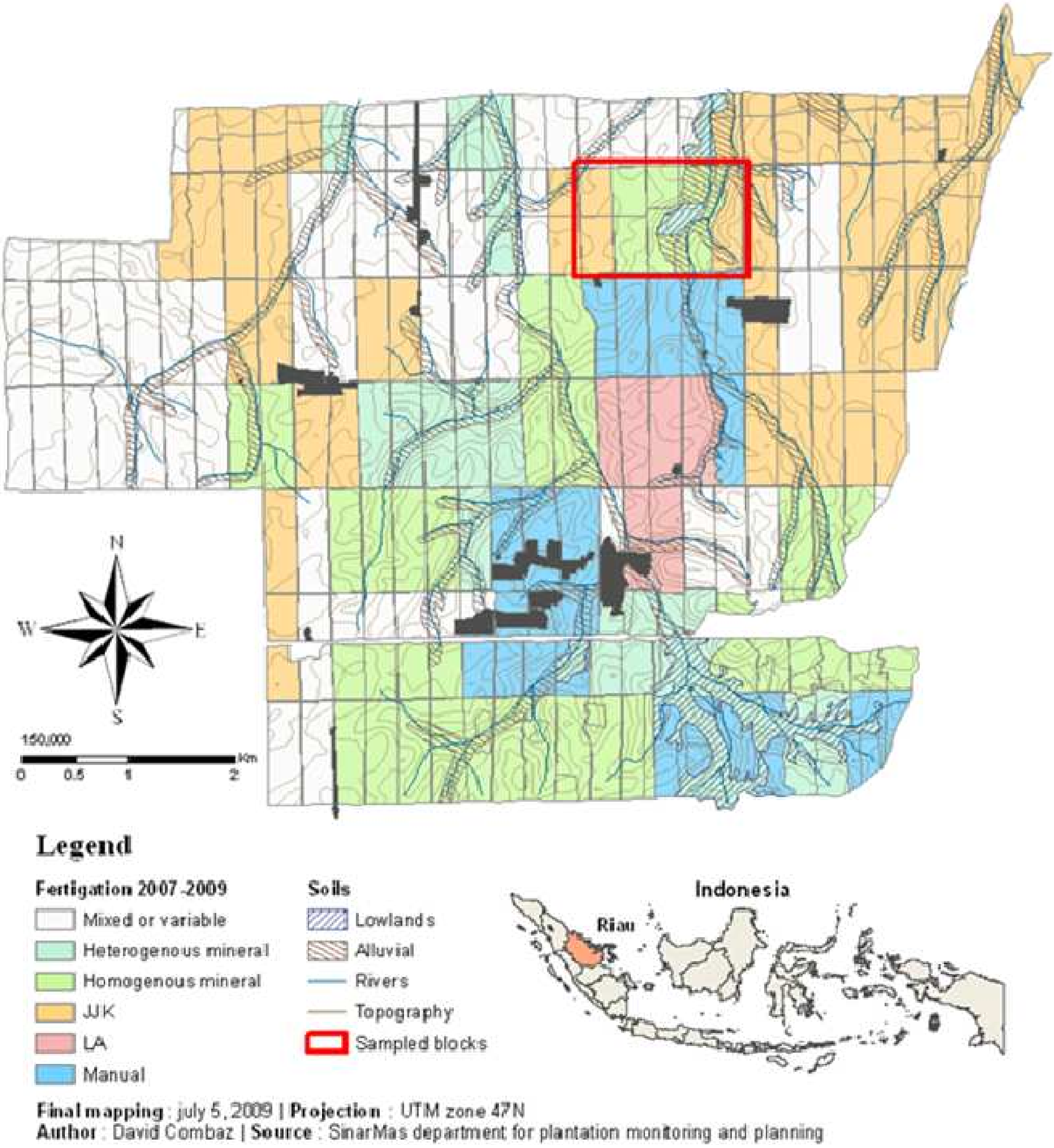


Figure 5: Cartography of higher scale environmental variables in Libo estate, and study area's selection

2.6 Site description

Each sampled site was precisely described in order to allow statistical analysis on environmental variables that may have effects on light availability, seed dispersion, soil properties and herbicide presence (tab. 2). These variables are either quantitative or qualitative. In this last case, precise classes have been used:

- Fronds base abundance on different parts of the stem. Absent, scarce, abundant.
- Topographic situation: *plain* (basic flat ground), *low plain* (flat ground on alluvial inclusions), *lowland* (low plain flooded more than six month a year), *slope top*, *slope side*, *slope basis*, *hollow* (little land depression), *elevation*, *step* (flat break in slope side), *river bank*.

- Fertilization: EFB, homogenous mineral, manual, LA, unknown.
- Dead weeds abundance inside the sampled area: *none*, *scarce*, *abundant*.
- River type: adds a precision to distance to river. River types classes are written under the format "*Major/minor*" (depending on the width) "*open/closed*" (depending on palm repartition around the banks), the distinction between these classes being always the plantation pattern breaking criterion.

Quantitative variables were:

- Planting year
- Dead palms around: relevant for the six palms immediately around the reference tree of sampled plots, or the plot itself in case of open areas.
- Slope in percentage, measured with optic clinometers, along the maximum slope axis, between the palms immediately above and below the reference tree.
- Sampling height: for plots on stem only (others get the 0 value). Measured with a 30 m measuring tape, from the sampling frame center to the ground. Rounding at the closest 10 cm.
- Distance to road and river: For all plots. Measured with a 30 m measuring tape, using relays if necessary, from the sampling frame center to the road (river) proximal limit. Rounding at the closest meter. When two rivers can be found around, both distances are measured.
- Distance to closest palm: always measured from the reference tree's stem to the other palm's stem, except for open areas in which case the origin point is the center of the sampling frame. Rounding at the closest 10 cm.

Table 2: Variables used for collection sites description sorted by ecological parameters affected

<table>
<tr><th>Light</th><th>Seed dispersal</th><th>Soil properties</th><th>Disturbance</th></tr>
<tr><td>Distance to closest palm</td><td></td><td></td><td></td></tr>
<tr><td>Dead palms around</td><td></td><td></td><td></td></tr>
<tr><td>Sampling height</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Distance to border</td><td></td><td></td></tr>
<tr><td colspan="2">Distance to river</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Topographic situation</td><td></td></tr>
<tr><td></td><td colspan="2">Steepness of slope</td><td></td></tr>
<tr><td></td><td></td><td>Fertilization</td><td></td></tr>
<tr><td></td><td></td><td>Frond bases abundance</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Dead weeds abundance</td></tr>
</table>

2.7 Vegetable samples collection and identification

The vegetation samples were taken inside a 80cm squared frame, divided as shown on fig. 6 in doubling surfaces, from 400 cm² to 6400 cm². These dimensions have been chosen in order to fit the station areas. For ground-level samples, the frame was made of wood, and thrown it randomly on the area to sample. For stations on stem, this sampling frame was made using long nails and string.

Inside the frame, individuals of each species were counted in each subdivision, in a cumulative way until the exact number of them present in the total surface was known. Individuals were defined in a genetically way: when it was obvious that two stems came from the same root, stolon or rhizome, they only accounted for one individual.

A cover percentage was also estimated for each species, following the same principle of counting. The minimal precision was fixed at 5 %. A cover percentage could be attributed to a species that didn't belong to the frame, (*i.e.* if their roots were outside), as long as their leaves or fronds entered the frame. When several strata of vegetation were present, cover percentages were attributed for each stratum, before adding them for each species.

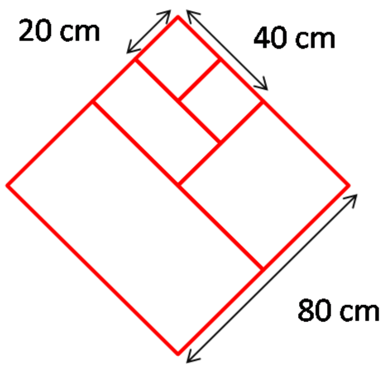


Figure 6: Sampling frame.

For every species found in each site, a representative individual was collected and given a unique reference number to allow traceability. Identification of species was made on these samples using three books devoted to weeds in tropical crops (Barnes & Chan 1990, Soerjani et al. 1987, Merlier & Montegut 1982), and validated by sending an individual of each species to the *Herbarium bogoriense* collection in the Indonesian institute of science. Remaining unknown species were given nicknames.

2.8 Data processing and analyses

All the sampling data and environmental variables on collection sites were recorded under Microsoft Excel 2007 software in a single table then send under .csv format to R.2.9.1 interface for statistical analyses.

Survey quality and efficiency:

The species accumulation curve plotting the total number of species discovered against the number of sites collected (sampling effort) was drawn using the function *specaccum*, (R package *vegan*). A horizontal asymptote would indicate that all the biodiversity of the studied area have been recorded.

As this is not likely to happen, especially under tropical latitudes, "true" species richness estimators Chao, Jackknife 1 an 2 and Boostrap were calculated (function *specpool*, R package *vegan*) (Marcon & Mornea 2006), in order to assess the percentage of biodiversity actually sampled.

The sampling yield of the survey was calculated dividing the empiric species richness by the total sampling effort.

For each station, an area-species curve was drawn by plotting the average number of species discovered inside the sampling frame subdivisions against the corresponding area. These can be read the same way as species accumulation curve: a horizontal asymptote indicates the collection area is large enough to record all the species present on the site.

Sampled biodiversity comparison among stations

For quantitative description of the biodiversity sampled among the stations, three common biodiversity indexes were used:

- The species richness *S* (the number of sampled species)
- Shannon-Wiener index (1948) : $H = -\sum_{i=1}^{x} p_i \cdot ln\, p_i$ with p_i = species *i* frequency
- Simpson index (1949) : $E_s = 1 - \sum_{i=1}^{x} p_i^2$ NB : $E_s \in [0; 1[$
- Note that Shannon-Wiener and Simpson indexes also give information on the evenness of the species distribution in the corresponding area. Higher values are obtained for a large number of equally distributed species. These indexes were calculated on experimental data (without extrapolation), using the *diversity* function in R package *vegan*.

First comparisons of biodiversity composition have been done on higher taxa using both the number of different pteridophytes, dicotyledones and monocotyledones species found on each station, and the corresponding percentage of each taxa's pool of species.

Finer comparison was then done with detrended correspondence analysis (Hill & Gauch 1980, *decorana* function, R package *vegan*) on a table giving the incidence of each species in each collected site. DCA is a variation of correspondence analysis that allows compensating the Gutman's effect – the bending of the scatter diagram of observations along an environmental gradient – and the compression of the projected observations towards the axes higher values.

The station effect on species composition was then assessed by fitting the centroid of each group of collected sites corresponding to a given station into the ordination diagram, using the least squares method (function *envfit* R package *vegan*). When two stations seemed very close, a multiple response permutation procedure (function *mrpp*, R *package* vegan) was driven to test if there was any difference in species composition among these stations. The MRPP test is a non parametric ANOVA-like test that compares dissimilarities (Euclidean distance) between collection sites within and among stations.

In order to test the pertinence of the sampling height criterion for stem stations definition, an additional DCA was made for them, and the frond bases abundance factor was projected on the diagram.

Sampling yield improvement

This part is aimed at finding how to reduce the sampling effort with a minimal loss of information on biodiversity inside the plantation. The principle is to focus the sampling effort on the most diverse areas, and to avoid redundancy in species composition of stations.

For this the results obtained in the studies above were used to suppress stations on which no particular trend in species distribution was found on DCA results, and to merge stations showing the same trends in their species compositions after MRPP test.

A second stations redefinition was proposed on the same general principle, but taking into account an originality index defined here as the number of species that were found only on a given station, divide by the number of corresponding collected sites. When this value is low, it means that most of the species that grow on this station can be discovered on other stations; in this situation, the station is hence suppressed. *A contrario*, stations with high values on this index were not merged with others.

For each station redefinition, 10 sampling campaigns have been simulated by randomly choosing 12 sites of each station in the original sampling database, or less when 12 sites were not available. The quality of these new sampling campaigns has been then evaluated by redrawing the species accumulation curves, and estimating the averages biodiversity coverage and yield.

3 Results

91 species (45 dicotyledones, 24 monocotyledones and 22 pteridophytes) have been found on the collected 147 sites. 27 of them are not identified yet and 6 of them are only identified on genus level.

3.1 Survey quality and efficiency:

According to the species accumulation curve (fig. 7), the number of collected sites is not large enough to have the complete pool of species recorded, despite it showing signs of reaching its asymptote.

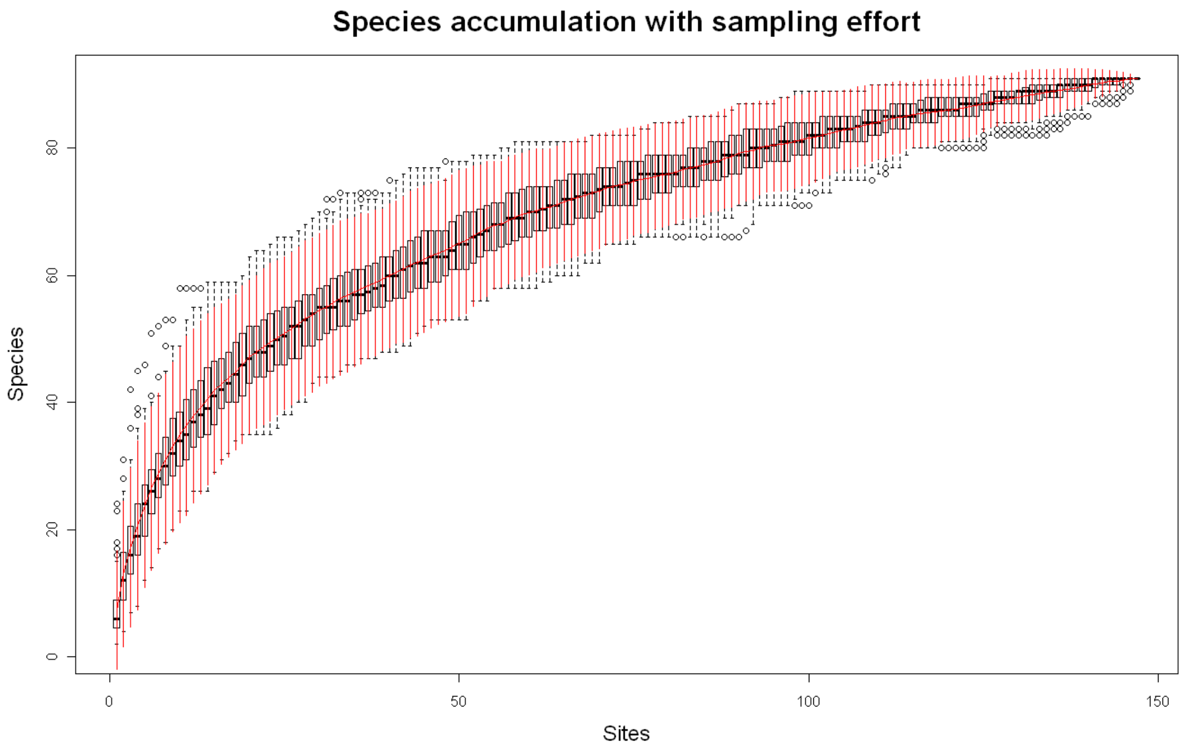


Figure 7: Species accumulation curve the progression of the discovered species richness vs. sampling effort increase.

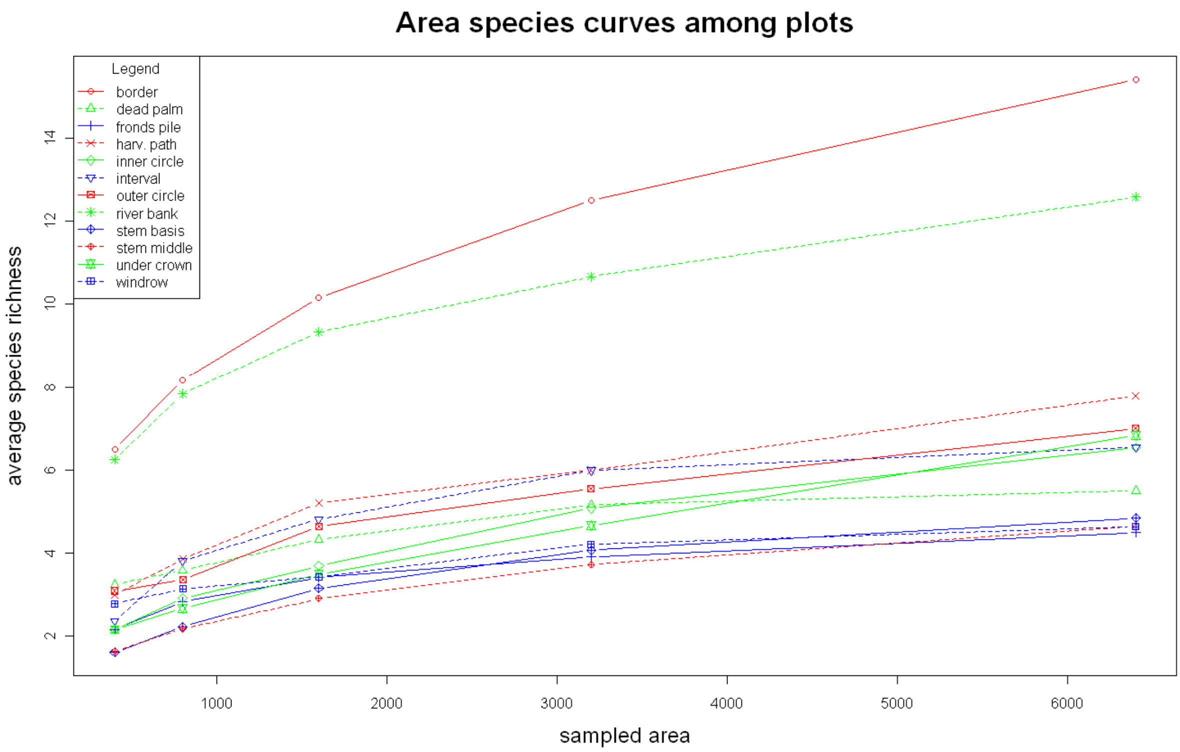


Figure 8: Average area-species curves on the 12 sampling stations.

The species richness of the sampled area is hence underestimated: species richness extrapolation methods Chao, Jackknife 1 & 2 and Bootstrap give several estimations of what the real species richness should be, the range of it being comprised between 95.6 and 120.8 species. This allows us to estimate this survey covered between 75% and 93% of the studied area's flora biodiversity, with a sampling yield of 0.62 new species per site (tab. 3).

Table 3: Recapitulation of sampling campaigns results in species richness (S). Est.min & Est.max are calculated estimators of true species richness, including standard errors, with Chao, Jackknife 1 & 2 and Bootstrap methods. Cov.min &Cov.maw represent the estimated percentages of true species species pool of studied area found with the sampling method used. Yield represent the average number of species found per sampling effort unit.

	Effort	S.Found	Est.min	Est.max	Cov.min	Cov.max	Yield
total	147	91	97.58483	118.8175	0.765881	0.932522	0.619048

Area species curves (fig. 8) show the same kind of profile as the species accumulation curve: even if the horizontal asymptote doesn't seem far to be reached, the sampling frame size is not large enough to have a complete image of any given station's diversity. The curves have different shapes among the stations, the implications of which will be discussed later.

3.2 Biodiversity repartition among stations

Species richness and Shannon and Simpson indexes occur to be generally higher in the plantation's border and river bank stations (fig. 9, 10 and 11), but little difference can be seen among the other plots: Kruskal-Wallis test's p-values are 0.028, 0.917 and 0.603 for S, H and E, when these stations are removed, against 2.2×10^{-8}, 9.3×10^{-5} and 1.2×10^{-3} with the complete data set.

Higher taxa representation

Pteridophytes, Dicoltyledones and Monocotyledones are unevenly represented among stations (fig. 12). The diversity of Pteridophytes seems well represented in stem stations and especially in stem middle (68.2 %) in spite of its low average species richness. On windrow, fronds pile, harvesting path, interval and dead palm stations the representation of Pteridophytes biodiversity is quite stable between 30 and 40%, whereas it drops under 10% in border and circle stations and rise up to 45.5% in river banks. Monocotyledones and Dicotyledones representations show similar profiles: they are low on stem stations, windrows and frond piles, and seem to follow basically the same pattern as species richness, with a strong increase in border and river banks.

Detrended correspondence analyses

The DCA results are represented on fig. 13. The three first axes account respectively for 45.5%, 23.1% and 15.6% of inertia (calculated on eigenvalues after correction of the bias induced by detrending).

Axis 1 opposes species that have been sampled on stems (with positive scores) and others, more characteristic of the herbaceous strata. The higher the positive values, the rarest are the occurrence of these species on ground level (e.g. *Antrophyum reticulatum*, *Vittaria elongata*). At the opposite end of the axis, the lowest values are associated with species often found on open and well lit areas, like *Mimosa pudica* and *Hedyotis corymbosa*. Axis 2 and 3 are less easy to interpret and may reflect other environmental effects on species distribution, which remain to be explored into detail.

Harvesting path, inner and outer circle are projected very close one from results show distinct projections of dead palm and river bank stations on axes 1, 2, and 3 that each other on these three axes. MRPP test on these stations returns a p value of 0.162, which doesn't allow rejecting the null hypothesis of similarity among species distribution.

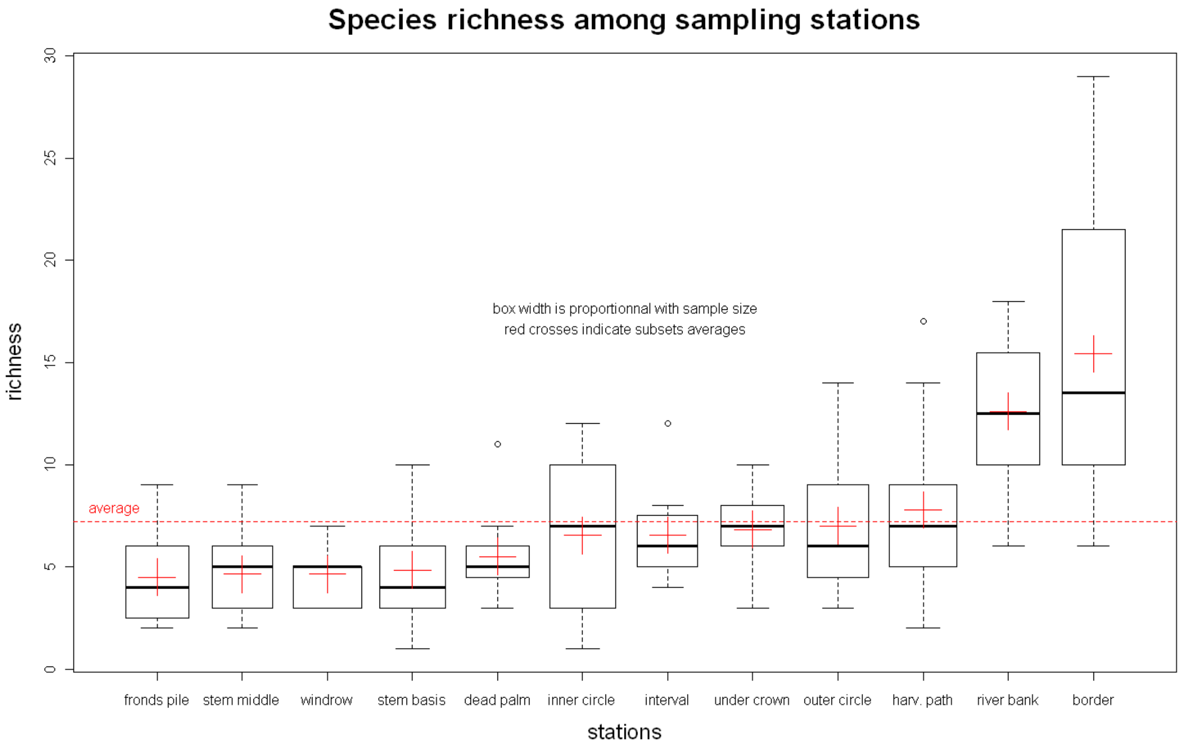


Figure 9: Distribution of experimentally found species richness among collected sites, for each station.

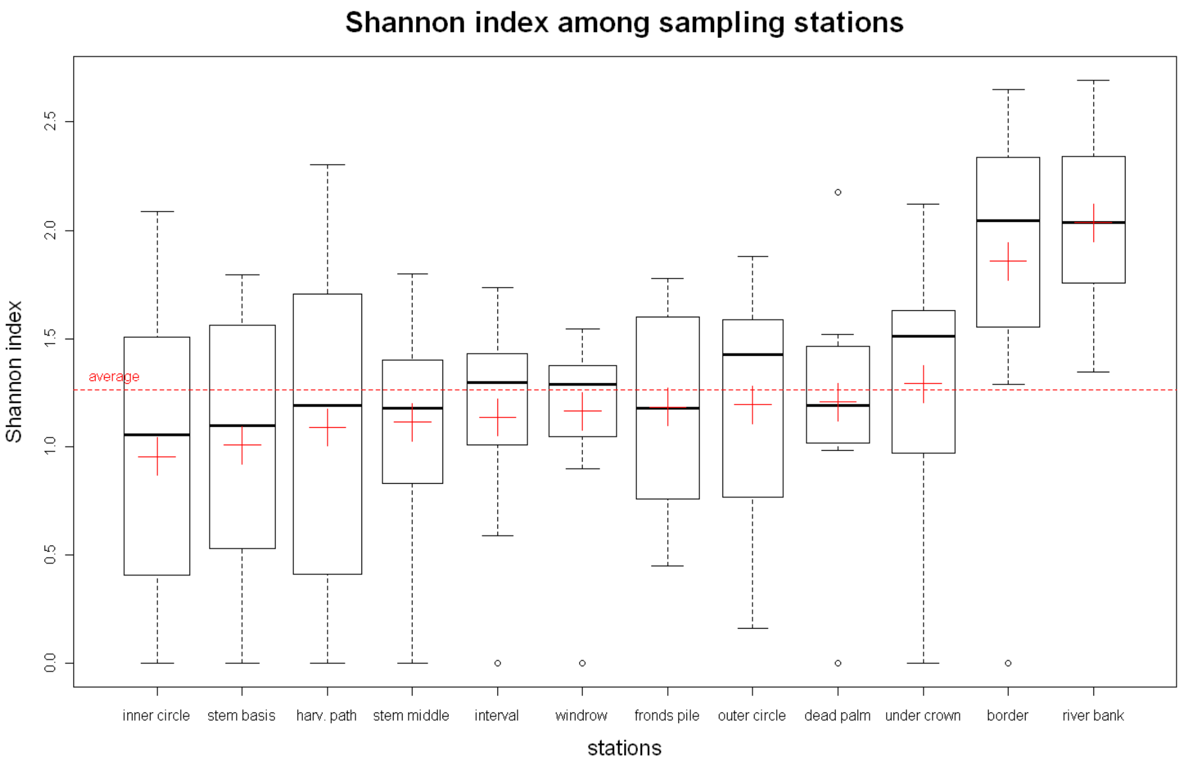


Figure 10: Distribution of experimentally found Shannon indexes among collected sites, for each station.

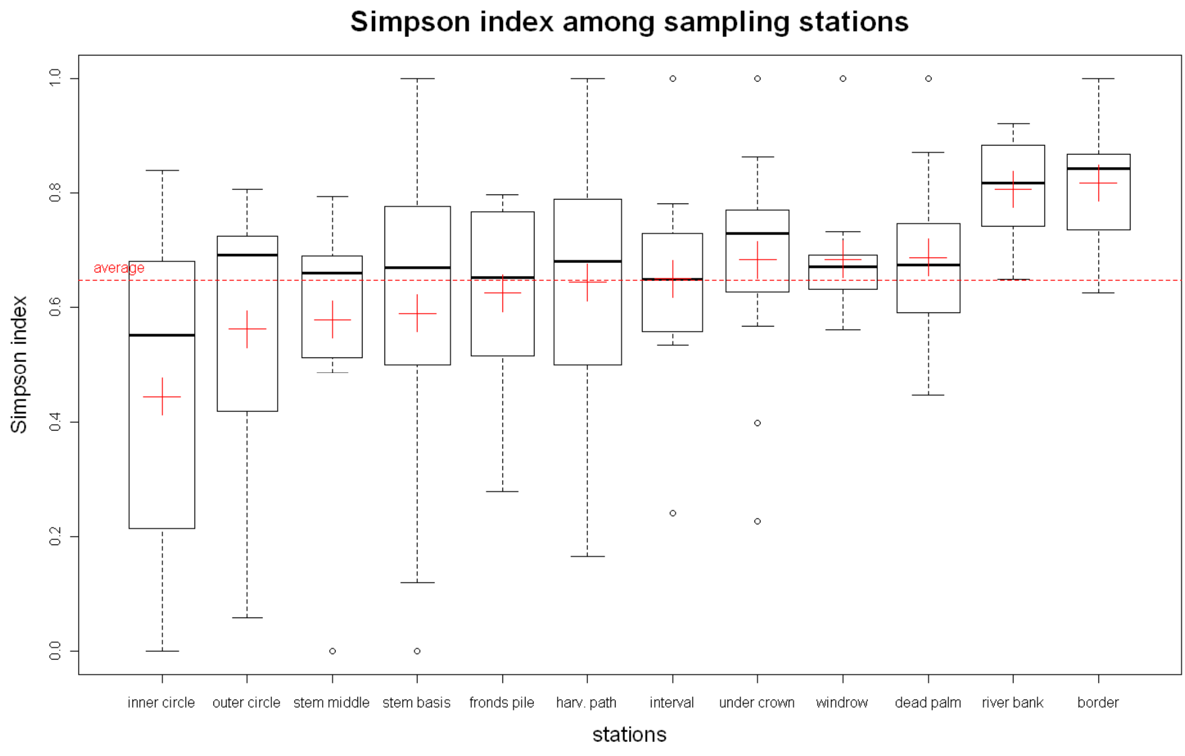


Figure 11: Distribution of experimentally found Simpson indexes among collected sites, for each station.

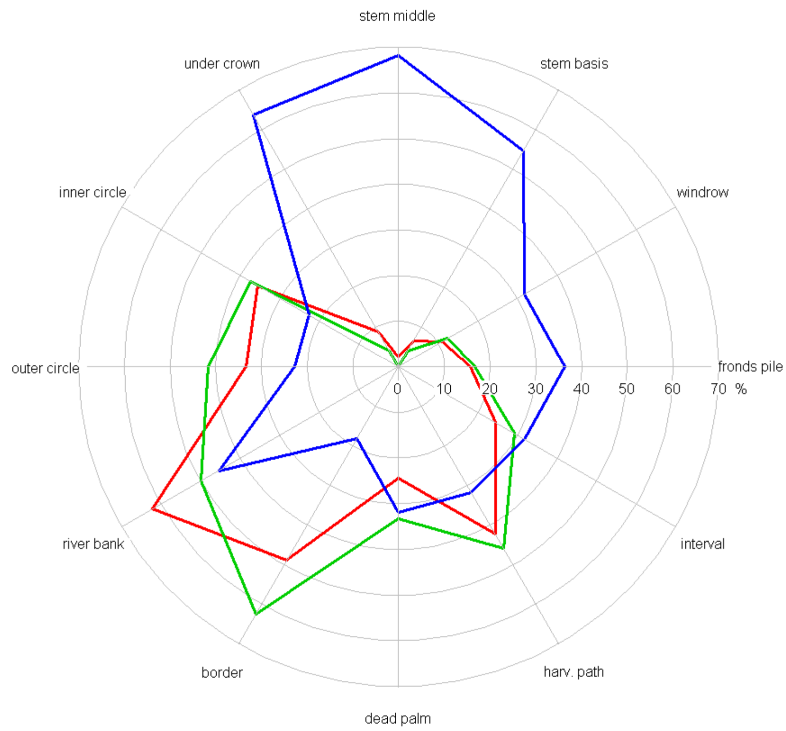


Figure 12: Representation of higher taxonomic groups among the sampling stations, in percentage of each group's total pool of species. Blue = pteridophytes, red = monocotyledones, green = dicotyledones.

Windrow and fronds pile are also very closely projected on axes 1 and 2. MRPP test returns a p value of 0.699, and share therefore the same species. Interval is always projected very close to the origin of the ordination diagram.

River bank, border and dead palm projections are distinct, at least on axes 1 and 3. River bank and dead palm seem close on axis 2, but MRPP test return a feeble p value of 0.001 that leads to rejecting the equivalence hypothesis. Interval is always projected very close to the origin of the axes.

Projections are very close for stem basis and under crown stations, whereas stem middle presents higher values on Axis 1. MRPP test reflects this difference with a p value of 0.003. The projection of frond bases presence on the additional stem focused DCA (fig. 14) shows this last criterion is more important for discriminating the stem stations: sites on which frond bases are absent differ strongly from the others on axis 1 and MRPP test returns a lower p value of 0.001.

3.3 Yield improvement

First station redefinition on DCA results

The new defined stations were:

- “River bank”, “Dead palm” and “Border”, without any modification. 12 sites for each.
- “Piles”, result of the merging of windrows and fronds piles. 26 sites available.
- “Bare ground”, result of the merging of inner and outer circle and harvesting path. 38 sites available.
- “Nude stem” i.e. stem sites without any frond base. 4 sites available.
- “Frond bases” i.e. stem sites with frond bases. 32 sites available.
- “Interval” was suppressed

The 10 sampling campaign simulation were done on 76 sites (51.7% of initial effort), and resulted in an average sampling of 84.1 species (92.4% of all species found) with a standard deviation of 1.57. The “true” species richness estimators were slightly lower than the ones calculated on the full database, but the biodiversity coverage estimators were roughly the same. Yield on these campaigns was an average 1.11 species per site (tab. 4). The corresponding species accumulation curves (fig.15) reflect well this amelioration, with a visible increase of the rate at which species are discovered.

Enhanced station redefinition on DCA results and originality index

The new defined stations were:

- “River bank”, “Dead palm”, “Border” (12 sites for each) and “Harvesting path”, without any modification (14 sites).
- “Circle”, result of the merging of inner and outer circle. 24 sites available.
- “Nude stem” i.e. stem sites without any frond base. 4 sites available.
- “Frond bases” i.e. stem sites with frond bases. 32 sites available.
- “Windrow”, “Fronds pile” and “Interval”, with minimal values for originality index (fig. 16), were suppressed.

This time, on the 76 sampled sites, the 10 simulation resulted in an average of 86.5 species discoveries (95.1% of all species found), with a slightly higher standard deviation of 1.78. Estimation of “true” species richness was closer to the ones calculated with the full database with this station redefinition, but biodiversity coverage estimations were lower. Yield was an average 1.14 species per site (tab. 4). The species accumulation curves (fig 17.) are very similar with the one drawn on the previous stations, but steeper.

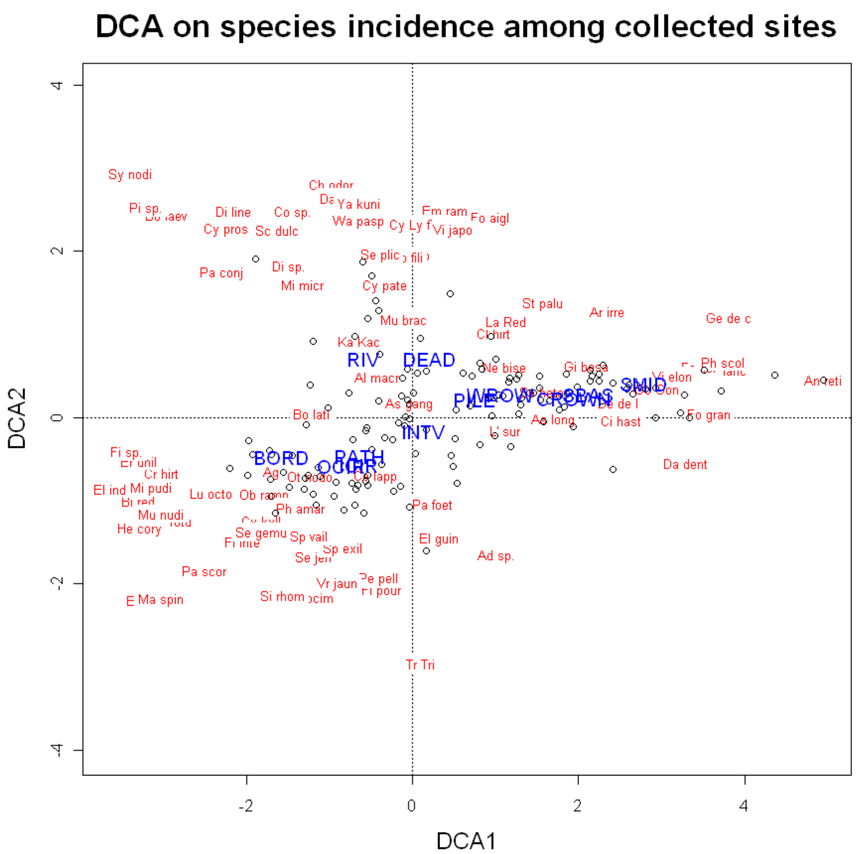


Figure 13: Detrended Correspondence Analysis biplot diagram. Black circles represent collected sites, species are written in red, stations centroids are projected as blue bold text.

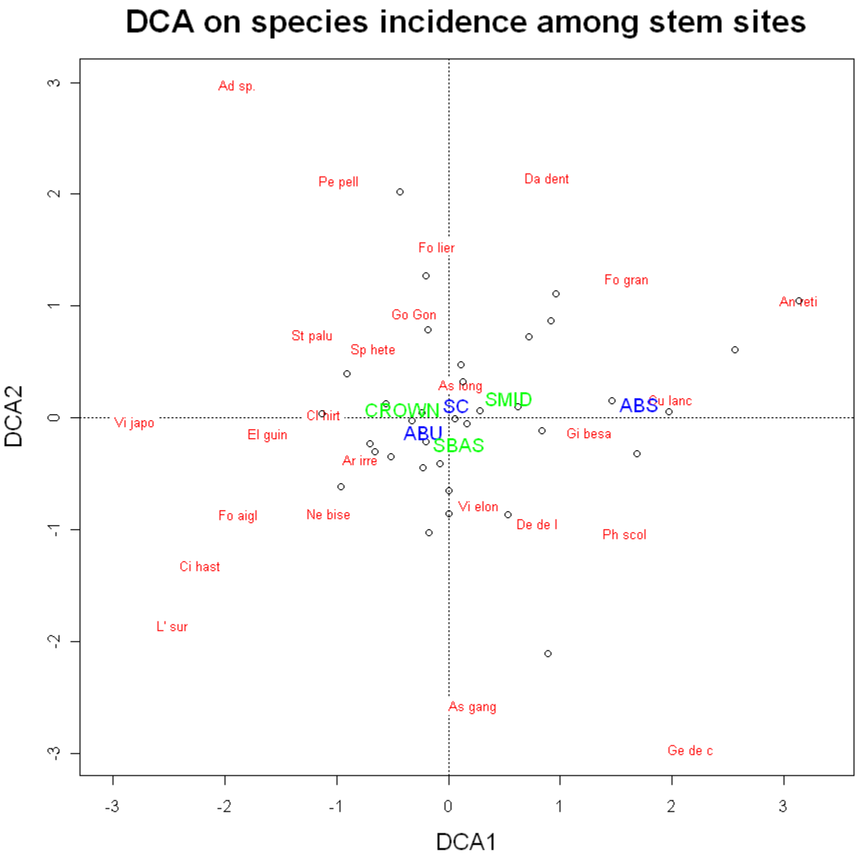


Figure 14: DCA biplot diagram for sites and species among stem stations. Black circles represent collected sites, species are written in red, stations centroids are projected as blue green text, and frond base abundance centroids are projected in blue bold text..

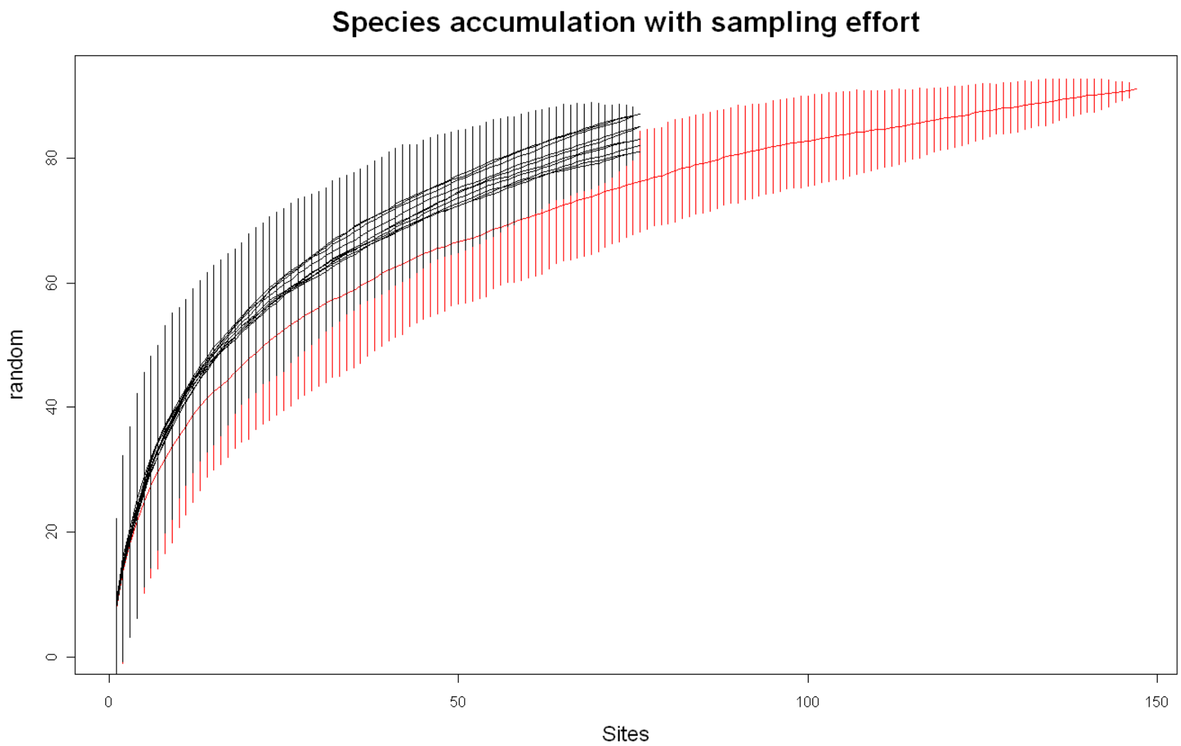


Figure 15: Species accumulation curves comparison among the ten simulated sampling campaigns based on DCA results (black) and the original dataset with the 12 stations (red)

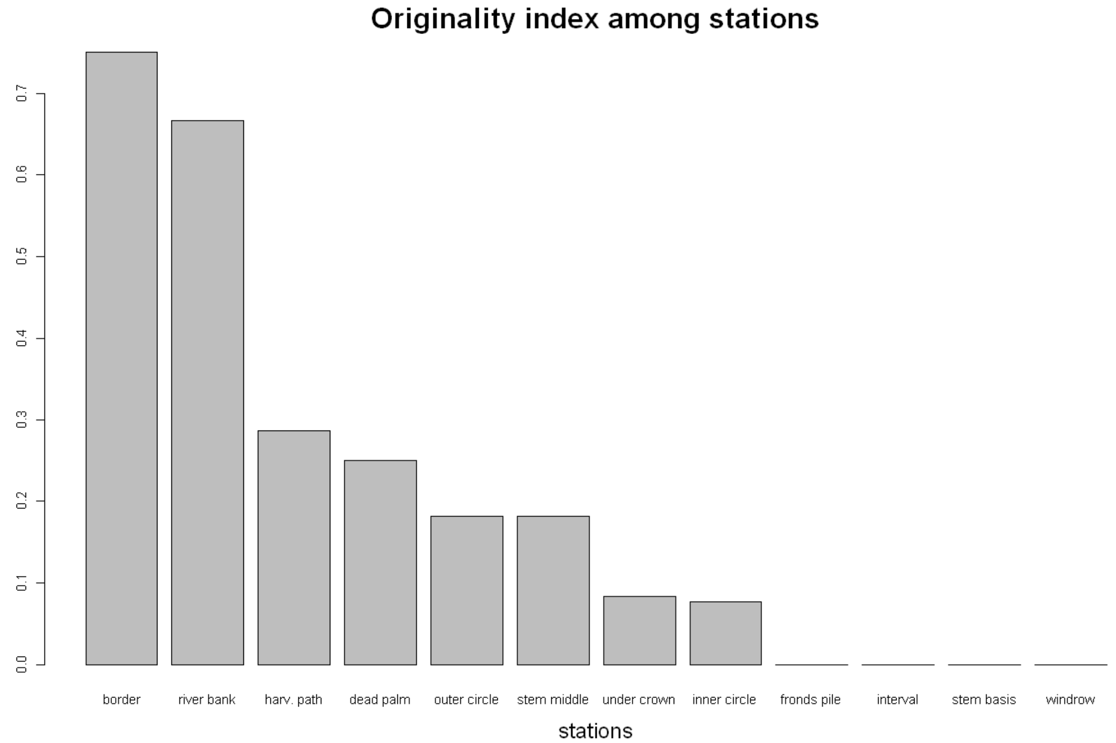


Figure 16: Originality indexes among stations. For each station, the originality index is the number of species that were not found on other stations, divided by the number of sites collected for this station.

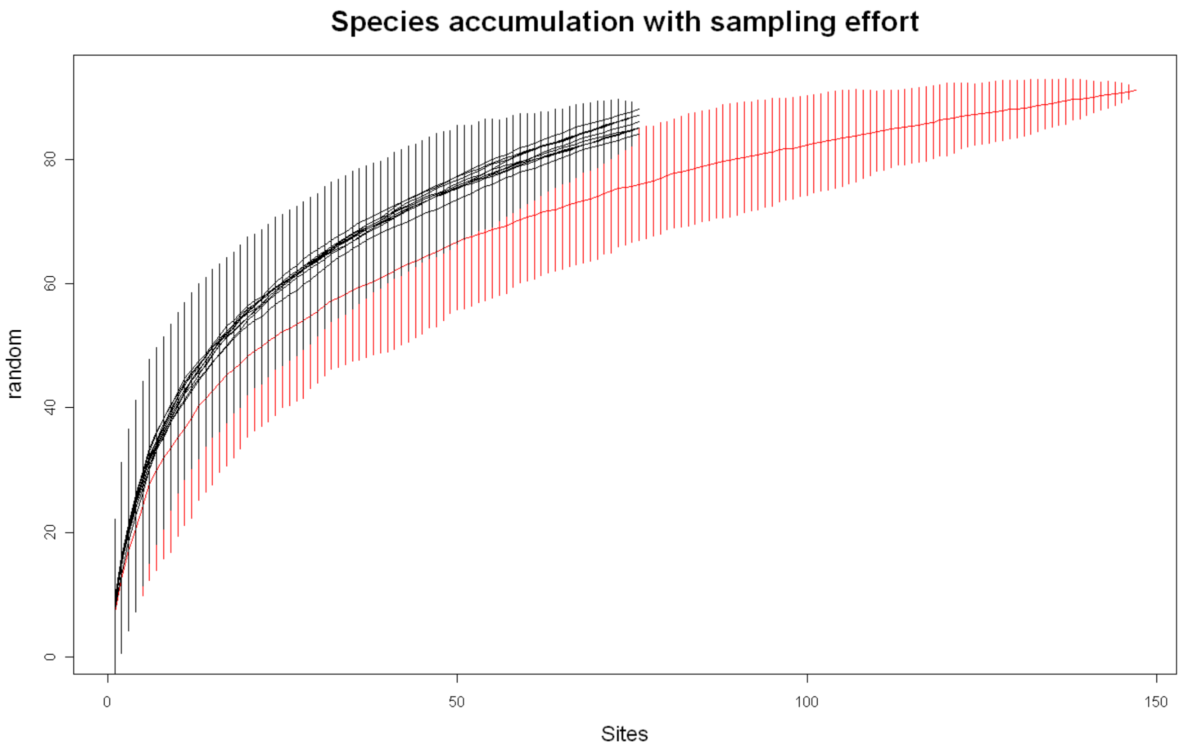


Figure 17: Species accumulation curves comparison among the ten simulated sampling campaigns based on DCA results and originality indexes (black) and the original dataset with the 12 stations (red)

Table 4: Recapitulation of real (Total, red) and simulated (Subsets, black) sampling campaigns. Subsets 1 are based on DCA results alone, whereas Subsets 2 also take originality indexes into account for station redefinition. Values on subsets are averages of the ten simulations. Ratios allow comparison with the complete database.

	Effort	S.Found	Est.min	Est.max	Cov.min	Cov.max	Yield
Total	147	91	97.6	118.8	0.8	0.9	0.6
Subsets 1	76	84.1	90.6	113.8	0.7	0.9	1.11
Ratios 1 (%)	51.7	92.4	92.9	95.8	96.6	99.5	178.8
Subsets 2	76	86.5	93.7	123.0	0.7	0.9	1.14
Ratios 2 (%)	51.7	95.1	96.0	103.5	92.3	99.0	183.9

4 Discussion & Conclusion

4.1 Biodiversity repartition

DCA analyses, focused on the station effects, show several trends in stations-species associations.

Circle, path and border

In this hypothesis, the first group would be composed of species more commonly found in the circle, harvesting path and border stations. These species are mainly monocotyledones and relatively small herbaceous dicotyledones, e.g *Axonopus compressus*, *Centotheca lappacea*, *Ottochloa nodosa* (Poaceae), *Ageratum conyzoides* (Asteraceae), *Phyllanthus amarus*, *Croton hirtus* (Euphorbiaceae), *Peperomia pellucida* (Piperaceae) for the most common of them.

Biodiversity among these stations, in terms of species richness, Simpson index, and in a lesser way Shannon index, grows higher along the sequence: {inner circle; outer circle; harvesting path; border}, with very high levels on borders, that present more frequently species that are seldom observed inside the blocks boundaries (e.g. *Mimosa pudica* (Fabaceae), *Hedyotis corymbosa* (Rubiaceae), *Sida rhombifolia* (Malvaceae).

Despite all the environmental effects have not been tested yet, a few observations can be made to give orientations for further analyses:

The {inner circle; outer circle; harvesting path; border} sequence can be linked with an "opening" gradient: whereas circle is enclosed on three sides by windrow and fronds piles, harvesting path and border present a linear structure that could make easier biodiversity fluxes. This hypothesis could be tested with observation of reproduction/dispersion strategies among species on these sites, with more expected vegetative reproduction on circles.

Border differs from the other stations by two parameters: light abundance and herbicide treatments. Harvesting path may be also be expected to receive more light than circle plots that are always under the of the palm's crown shade. Moreover, in this study circles were not sampled when the reference palm was dead, whereas harvesting paths were. These environmental effects remains to be tested on circle and harvesting path stations with variables "dead palms around", "distance to closest palm", "dead weeds abundance" and "distance to border".

From piles to stems

On the DCA axis 1, the following sequence can be seen, from the lowest positive values to the highest ones: {fronds pile; windrow; under crown; stem basis; stem middle}, for better comprehension, the stem plots can be converted into frond bases (fb.) abundance, and the sequence becomes: {fronds pile; windrow; fb. abundant; fb. scarce; fb. absent}.

Along this sequence, pile plots, i.e. fronds pile and windrow treated as a whole, are linked with widespread shade-tolerant species, mostly big ferns as *Nephrolepis biserrata* (Dryopteridaceae), *Sphaerostephanos heterocarpus* (Thelypteridaceae), *Asplenium longissimum* and *Asplenium tenerum* (Aspleniaceae) and a few dicotyledones like *Clidemia hirta* (Melastomaceae) and the very common *Asystasia gangetica* subsp. *Micrantha* (Acanthaceae).

These species seem particularly well adapted to soils rich in decaying organic matter. When frond bases are present on stem they present the same soil properties as pile stations, and share therefore a part of their biodiversity. But with reduction of frond bases abundance, the habitat suitability for hemi-epiphytes apparently decreases and "true" epiphytes like *Anthrophium reticulatum* and *Vittaria alongata* (Vittariaceae) replace them.

This hypothesis should be confirmed analyzing the ecological characteristic of all the species sharing the higher values on axis 1.

River bank

River bank has shown itself as the most biodiverse station sampled in this study. Moreover it is always projected distinctly from the other stations on DCA, and therefore is associated with singular species associations.

Four environmental effects may be involved: the special soil properties and moist of rivers, on which aquatic plants like *Monochoria* sp. (Pontederiaceae) grow; a relative abundance of decaying organic matter brought by the stream or after floods that could enhance ferns like *Stenochlaena palustris* (Blechnaceae) development, and light availability when the planting pattern is broken that removes the shade selective pressure and therefore allows competition among species.

The ecology of the associated species (low values on axes 1 and 3, high values on axis 2) should be studied for a better comprehension, with control on the river relevant variables (width, open or closed banks, topography, distance to river).

Dead palm

Dead palm biodiversity is more difficult to interpret for it has very low values on axis 1. On axis 2 it is projected close to river bank and on axis 3, close to pile station. This last similarity can be linked with the fact that dead palms and piles are structurally close because of the high amount of decaying organic matter. Ferns like *N. biserrata* and *A. longissimum* and *tenerum* are therefore commonly found on dead palms.

The proximity with river on axis 2 may be attributed with the only shared criterion between these two stations, light abundance, that allow dicotyledones and monocotyledones to settle more easily. Organic matter and light abundance also characterize under crown station, but the absence of monocotyledones – except *Elaeis guineensis* itself – on this last station explains why it is so clearly distinct from dead palm.

Remaining shades and limits

At this stage of the study it is obvious that station effects are not sufficient to explain the repartition of species in distinct communities: the stations projections (except those for stem stations) on ordination diagram remain close to the origin, whereas species projections cover a much wider range.

Environmental effects may have strong importance in explaining the remaining variance, and should hence been tested. Data mining on the database created for this study may help to build hypotheses. Nevertheless, the protocol used in this study doesn't enable concluding definitively for environmental effect. Specific protocols should hence be built to test hypotheses on each variable, with control of other parameters.

The analysis methods used also have drawbacks. Here, all analyses have been conducted on presence/absence data which give the same weight to all species. The rarest species, which have been sampled only on one particularly biodiverse site, may therefore influence the projection of the corresponding station and mask association with more common species. The database on which this study was realized provides cover percentage and individuals counting data, which remain to be explored into details.

Other ordination and environment variable fitting methods should also be tested, for DCA detrending algorithm may imply distortion of the whole dataset on the less significant axes, and mask interesting environmental effects (Bouxin 2008).

4.2 Sampling protocol

Station definition effects on yield

Results speak by themselves: even if the simulated sampling campaigns after station redefinition did not "collect" enough sites to find all the species, the rate at which discoveries progress – the steepness of the curves – are clearly improved compared to the original protocol. The efficiency of the method is obvious: with a 50% reduction of sampling effort the loss of information is lower than 10%.

The two station redefinitions proposed above don't follow the same objectives, and it would be a mistake to adopt the second one only because of its higher yield.

- If the aim is to establish a catalogue of all species inside the plantation (e.g. to find rare species), the second station definition redefinition may be useful, and it may even be enhanced using the originality indexes (fig.) that would suggest for instance to sample frond bases station in the upper parts of the stem in order to avoid redundancy between circle and stem basis stations on species like *A. gangetica* subsp. *micrantha*.

- If the aim is to understand and monitor the biodiversity levels and patterns inside the plantation, the first station redefinition may be more reliable, for it doesn't omit any structural part of the plantation. More fidelity with real patterns could even be reached by splitting again the harvesting path from circles stations.

The river bank, dead palm and border stations must also be taken with precaution, for they represent special situations are not automatically linked with oil palm plantation's structure. As most species richness extrapolation methods rely on rarest species incidence per sampling effort unit (Marcon & Morneau 2006), an excessive representation of these stations among sampling site introduce a bias positive bias may in biodiversity measures. Generally speaking, focusing on high biodiversity stations for better sampling yields is dangerous, because it could lead to an overestimation of the "true" species richness inside the studies sites (Sastre & Lobo 2009).

Shades and precautions

As one of the objectives of this study was to understand biodiversity patterns among structural elements of the plantat.ion, it was important to collect enough species on particular stations such as dead palms and rivers. The resulting positive bias that we may expect to find in the species richness assessment may be estimated with a control sampling campaign (or simulation), with reduced representation of these stations.

A good way to estimate the needs in open area (including rivers) sites may be to assess the percentage of total surface that can be found in river borders, and to take the same ration of total collection sites. Another way, less difficult to follow for it doesn't require precise cartography, would be to sample these sites only when a reference tree is randomly chosen directly on a river bank or border, or when the palm itself is dead.

As this study was made on a single estate, other studies should be made to confirm all the results presented here, before they become suitable for the building of standardized biodiversity survey procedures.

Going further

In this study, the reflection was focused on the stations definition, but the sampling method itself may be improved for a better efficiency. Sampling on squares allows recording a high quantity of information, especially cover percentages.

Nevertheless, the numbering of individuals takes time, and the cover percentage assessment is likely to be biased by the operator. Despite it suitability to reflect the relative importance of species in terms of biomass and in ecosystem contribution, cover percentages are not always useful, and other methods exist which could allow significant time gains.

4.3 Taxonomy: issues and perspectives

This study was centered on environmental effects on plant associations, but the plants collected have not been studied into details. Focus on the species sampled inside the plantation could help understanding the species responses to environmental variations (including station effects) by analyzing their ecological characteristics and life traits such as reproduction and dispersion strategies, needs in light and soil, etc. This information could allow predictive expert models to extrapolate the biodiversity on one site, on a few environmental parameters basis (Amiaud et al. 2008)

Moreover, a better knowledge on these species would be of critical importance to understand the stakes the plantation's biodiversity may represent. In the Southeast Asian context, these stakes are very high. Indonesia's biodiversity is characterized by a high rate of endemism. As oil palm culture has been introduced very recently, local flora may not have had enough time to adapt with the oil palm system. This point has already been underlined on birds and butterflies taxa (Koh 2008).

In this study, many species have been identified with identification tools designed for pest control, and many of these pests presented had a pan tropical distribution (e.g. *A. gangetica* subsp. *micrantha*, *Chromolaena odorata* (Asteraceae), C. *hirta*, *A. compressus, O. nodosa*…). All biological introductions present risks of invasion, with possible replacement of local diversity. A complete knowledge and monitoring on foreign and native species is therefore necessary to be able to assess in which extent the oil palm plantations may behave as invasive species "base camps".

Reciprocally, agricultural systems may represent connectivity elements for native species if relevant management strategies are followed. The key to define these strategies may be found in the ecological analysis of the different high biodiversity elements of the estate (Perfecto & Vandermeer 2008).

All along this study, the identification of species was a problem, especially because of the lack of experience among SMARTRI employees. This problem could be dodged with a strong investment in identification resources and reference collection building, to develop the flora biodiversity skills of SMARTRI scientists. Powerful informatics tools already exist for more or less assisted identification of vegetable taxa, which rely on a non hierarchical identification key linked with a database of plants characteristics. The AMAP Research unit, Montpellier, France, in which the CIRAD participates, has developed some of these informatics solutions that could be adapted for oil palm production systems.

5 Acknowledgements

Special thanks to Jean-Pierre Camilan, Julie Wohlfahrt and Aude Verwilghen for giving me this opportunity, to Bernard Amiaud, Phillipe Girardin, Albert Flori and Patrick Giraudoux for their scientific advice, to Dedi Purnomo, Mr Simon, Jaka and Novrianto who were of precious help during the sampling process and who will pursue these studies, to Arwin and Rudy for their logistic support, to Irina, Julie, Danang, and all SMARTRI staff for their human support.

6 References

Abdullah, S. A. and Æ. A. A. Hezri. 2008. From Forest Landscape to Agricultural Landscape in the Developing Tropical Country of Malaysia: Pattern, Process, and Their Significance on Policy. Environmental Management 42:907–917

Amiaud, B., F. Pervanchon and S. Plantureux. 2008. Un modèle expert pour prédire la diversité spécifique des prairies : Flora-prédict. *Les cahiers d'Orphée*

Bangun, D. 2006. Indonesian palm oil industry. in National Institute of Oilseed Products annual convention, Phoenix, Arizona, U.S.A.

Barnes, D. E. & G. L. Chan. 1990. *Common weeds of Malaysia and their control* Shah Alam, Malaysia.

Bouxin, G. 2008. Analyse statistique des données de végétation. Techniques d'analyse factorielle et d'ordination. Récupéré le 15 juillet 2009 de : http://users.skynet.be/Bouxin.Guy/ASDV/ASDV.htm.

Buckland, H. 2005. The oil for ape scandal - How oil palm is threatening orang-utan survival. Friends of the Earth trust, London.

Caliman J.-P., R. Carcasses, P. Girardin, Pujianto, B. Dubos, and T. Liwang. 2005. Development of agri-environmental indicators for sustainable management of oil palm growing. General concept and the example of nitrogen. MPOB International Palm Oil Congress (PIPOC). 25-29 September 2005. Kuala Lumpur. Malaysia.

Caliman, J.-P., A. Berthaud, B. Duboz and B. Tailliez. 2005. Agronomy, sustainability and good agricultural practices. *Oleagineux, corps gras, lipides* **12(2)**: 134-140.

Clergue, B., B. Amiaud, F. Pervanchon, F. Lassere-Joulin, S. Plantureux. 2005. Biodiversity: function and assessment in agricultural areas. A review. *Agronomy and Sustainable Development* **25**: 1–15

Fitzherbert, E. B., M. J. Struebig, A. Morel, F. Danielsen, C. A. Brühl, P. F. Donald, and B. Phalan. 2008. How will oil palm expansion affect biodiversity? Trends in Ecology and Evolution 23:538-545.

Food and Agriculture Organization of the United Nations. 2006. Global Forest Resources Assessment 2005, FAO.

Girardin, P., J.P. Caliman, and J. Wohflahrt. 2007. INDIGO Palm: A method based on agro-ecological indicators to assess the environmental stability of oil palm plantations. *International Conference of oil palm and environment*, IOPRI. Bali, Indonesia.

Girardin, P., L. Guichard, and C. Bockstaller. 2005. Indicateurs et tableaux de bord : guide pratique pour l'évaluation environnementale. Lavoisier, Cachan.

Greenpeace. 2007. *How the palm oil industry is cooking the climate*. Greenpeace International, Amsterdam.

Hill, M.O. & H.G. Gauch. 1980. Detrended correspondence analysis: an improved ordination technique. *Vegetatio* **42:** 47–58.

Jacquemard, J. C. 1995. Le Palmier à huile. Coll. Le technicien d'agriculture tropicale. Maisonneuve & Larose, Paris.

Koh, L. P. 2008. Can oil palm plantations be made more hospitable for forest butterflies and birds? Journal of Applied Ecology 45:1002–1009

Koh, L.P. and D.S. Wilcove. 2008a Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters 1: 60–64.

Levrel, H. 2007. Quels indicateurs pour la gestion de la biodiversité ? Institut Français de la Biodiversité, Paris.

Marcon, E., and F. Morneau. 2006. *Mesures de la biodiversité.* UMR Écologie des Forêts de Guyane (ECOFOG).

Merlier, H. and J. Montegut. 1982. *Adventices Tropicales*. Ministère des relations extérieures – coopération et développement, Paris.

Nantha, H. S., and C. Tisdell. 2009. The orangutan-oil palm conflict: economic constraints and opportunities for conservation. Biodiversity and Conservation 18:487-502.

Omont, H. 2005. Roundtable on Sustainable Palm Oil – RSPO.The second RSPO meeting in Jakarta in October 2004. *Oleagineux, corps gras, lipides* **12(2)**: 125-128.

Perfecto, I. and Vandermeer, J. 2008. Biodiversity conservation in tropical agroecosystems – A new conservation paradigm. *Annals of the New York academy of science*s **1134**: 173-200

RSPO 2007. *Revised RSPO Principles & Criteria Document*. 2009, march 17 from: http://www.rspo.org/Revised_RSPO_Principles_-_Criteria_Document.aspx

Sastre, P & J. M. Lobo. 2009. Taxonomist survey biases and the unveiling of biodiversity patterns. *Biological conservation* **149**: 462-467

Shannon, C. E. 1948. A Mathematical Theory of Communication. *The Bell system Technical journal* **27**: 379-423, 623-656 *cited in* Marcon, E. (2006). *Mesures de la biodiversité* UMR ECOFOG.

Sheil, D., A. Casson, E. Meijaard, M. van Nordwijk, J. Gaskell, J. Sunderland-Groves, K. Wertz, and M. Kanninen. 2009. The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? Occasional paper no. 51. CIFOR, Bogor, Indonesia.

Simpson, E.H. 1949. Measurement of diversity. *Nature* **163**: 688 *cited in* Marcon, E. (2006). *Mesures de la biodiversité* UMR ECOFOG.

Soerjani, M., A.J.G.H. Kostermans and G. Tjitrosoempomo. 1987. *Weeds of rice in Indonesia*. Balai Pustaka, Jakarta.

Thoenes, P. 2006. Biofuel & Commodity Market - Palm Oil focus. FAO, Commodities and Trade Division.

Turner, E. C., J. L. Snaddlon, T. M. Fayle, and W. A. Foster. 2008. Oil Palm Research in Context: Identifying the Need for Biodiversity Assessment. *PLoS ONE* **3.**

Wohlfahrt, J., J.-P. Caliman., P. Girardin, and A. Wahyu. 2006. Development of an agro-ecological indicator (I-PHY Palm) to assess the sustainability of pesticides utilization in oil palm plantations. IOPRI International Palm Oil Conference. 20-24 June 2006. Bali. Indonesia

WWF International. 2003. (1st ed. 1996). *Oil palm and soy: the expanding threat to forests*.WWF Forest conversion initiative. Zurich.

www.rspo.org (s.d.). *History of RSPO*. Downloaded 2009, march 17 from: http://www.rspo.org/History_of_RSPO.aspx

www.rspo.org (s.d.). *Member profile*. Downloaded 2009, march 17 from: http://www.rspo.org/members_list.aspx?catid=37&ddlID=39&membercat=13

7 Annexe: list of species

Species	Higher taxonomic group	Family
Asystasia gangetica subsp. micrantha	*Dicotyledones*	*Acanthaceae*
Alternanthera sessilis	*Dicotyledones*	*Amaranthaceae*
Cyathula prostrata	*Dicotyledones*	*Amaranthaceae*
Vitis japonica	*Dicotyledones*	*Ampelidaceae*
Ageratum conyzoides	*Dicotyledones*	*Asteraceae*
Chromolaena odorata	*Dicotyledones*	*Asteraceae*
Mikania micrantha	*Dicotyledones*	*Asteraceae*
Sparghanophorus vaillantii	*Dicotyledones*	*Asteraceae*
Synedrella nodiflora	*Dicotyledones*	*Asteraceae*
Cleome aspera	*Dicotyledones*	*Capparidaceae*
Cleome rutidosperma	*Dicotyledones*	*Capparidaceae*
Commelina sp.	*Dicotyledones*	*Commelinaceae*
Croton hirtus	*Dicotyledones*	*Euphorbiaceae*
Euphorbia hirta	*Dicotyledones*	*Euphorbiaceae*
Phyllanthus amarus	*Dicotyledones*	*Euphorbiaceae*
Mimosa pudica	*Dicotyledones*	*Fabaceae*
Mucuna brachteata	*Dicotyledones*	*Fabaceae*
Sida rhombifolia	*Dicotyledones*	*Malvaceae*
Clidemia hirta	*Dicotyledones*	*Melastomataceae*
Melastoma affine	*Dicotyledones*	*Melastomataceae*
Ludwigia octovalvis	*Dicotyledones*	*Onagraceae*

Passiflora foetida	*Dicotyledones*	*Passifloraceae*
Peperomia pellucida	*Dicotyledones*	*Piperaceae*
Borreria laevis	*Dicotyledones*	*Rubiaceae*
Borreria latifolia	*Dicotyledones*	*Rubiaceae*
Hedyotis corymbosa	*Dicotyledones*	*Rubiaceae*
Hemidioidia ocimifolia	*Dicotyledones*	*Rubiaceae*
Spermacoce exilis	*Dicotyledones*	*Rubiaceae*
Scoparia dulcis	*Dicotyledones*	*Scrophulariaceae*
Fleurya interrupta	*Dicotyledones*	*Urticaceae*
Cissus hastata	*Dicotyledones*	*Vitaceae*
Big red sword	*Dicotyledones*	NA
Elliptique rampante	*Dicotyledones*	NA
Empire rampant	*Dicotyledones*	NA
Kacangan	*Dicotyledones*	*NA*
Lady Red	*Dicotyledones*	*NA*
L'arbre sur l'herbe	*Dicotyledones*	*NA*
Likur (-enatapibukan)	*Dicotyledones*	*NA*
Maria spinosa	*Dicotyledones*	NA
Obtuse rampante	*Dicotyledones*	NA
Seed gemuk	*Dicotyledones*	NA
Seed jeril	*Dicotyledones*	NA
Trinerveuse	*Dicotyledones*	NA
Vrille jaune	*Dicotyledones*	NA
Yang kuning	*Dicotyledones*	NA
Alocasia macrorrhiza	*Monocotyledones*	*Araceae*
Elaeis guineensis	*Monocotyledones*	*Arecaceae*
Murdannia nudiflora	*Monocotyledones*	*Commelinaceae*
Cyperus grand trigone	*Monocotyledones*	*Cyperaceae*
Cyperus hexagonal	*Monocotyledones*	*Cyperaceae*
Cyperus kyllingia	*Monocotyledones*	*Cyperaceae*
Cyperus rotundus	*Monocotyledones*	*Cyperaceae*
Fimbristylis sp.	*Monocotyledones*	*Cyperaceae*
Daniella nemerosa	*Monocotyledones*	*Liliaceae*
Axonopus compressus	*Monocotyledones*	*Poaceae*
Bracharia mutica	*Monocotyledones*	*Poaceae*
Centotheca lappacea	*Monocotyledones*	*Poaceae*
Cyrtococcum patens	*Monocotyledones*	*Poaceae*
Digitaria sp.	*Monocotyledones*	*Poaceae*
Eleusine indica	*Monocotyledones*	*Poaceae*
Eragrostis uniloides	*Monocotyledones*	*Poaceae*
Ottochloa nodosa	*Monocotyledones*	*Poaceae*
Paspalum conjugatum	*Monocotyledones*	*Poaceae*
Paspalum scorbitulatum	*Monocotyledones*	*Poaceae*
Rumput gajah	*Monocotyledones*	*Poaceae*
Setaria plicata	*Monocotyledones*	*Poaceae*
Waving paspalike	*Monocotyledones*	*Poaceae*

Monochoria sp.	*Monocotyledones*	*Pontederiaceae*
Fine pourpre	*Monocotyledones*	*Poaceae*
Asplenium longissimum/tenerum	*Pteridophyta*	*Aspleniaceae*
Stenochlaena palustris	*Pteridophyta*	*Blechnaceae*
Davallia denticulata	*Pteridophyta*	*Davalliaceae*
Arcypteris irregularis	*Pteridophyta*	*Dryopteridaceae*
Nephrolepis biserrata	*Pteridophyta*	*Dryopteridaceae*
Dicranopteris linearis	*Pteridophyta*	*Gleicheniaceae*
Adiantum sp.	*Pteridophyta*	*Polypodiaceae*
Goniophlebium/Polypodium	*Pteridophyta*	*Polypodiaceae*
Phymatosorus scolopendria	*Pteridophyta*	*Polypodiaceae*
Pityrogramma sp.	*Pteridophyta*	*Pteridaceae*
Lygodium flexuosum	*Pteridophyta*	*Schizaeaceae*
Sphaerostephanos heterocarpus	*Pteridophyta*	*Thelypteridaceae*
Antrophyum reticulatum	*Pteridophyta*	*Vittariaceae*
Vittaria elongata	*Pteridophyta*	*Vittariaceae*
Cuir lanceolé	*Pteridophyta*	NA
Dent de lait	*Pteridophyta*	NA
Fougère aiglon	*Pteridophyta*	NA
Fougère filiforme	*Pteridophyta*	NA
Fougère grand ficus	*Pteridophyta*	NA
Fougère lierre	*Pteridophyta*	NA
Geante de cuir	*Pteridophyta*	NA
Gigi besar	*Pteridophyta*	NA

NB: Non italic written species are unidentified and considered as morphologic species or "morphospecies".