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From shifting rice cultivation (*tavy*) to agroforestry systems: a century of changing land use on the East Coast of Madagascar

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Abstract While agroforestry is promoted in many regions worldwide, limited attention is paid to farmer-led transitions toward agroforestry. Agroforestry systems (AFS) are ubiquitous and structure the landscapes along the east coast of Madagascar. These systems are managed by smallholders and produce a variety of products, some for export (mainly clove products, vanilla, and lychees), others for self-consumption or for sale locally (including fruit, tubers, timber and fuelwood). We compared information in historical documents with data collected in household surveys in 2016 in one village to identify the socio-technical and economic determinants that guided farmers' strategies over a century and led to the current production systems and landscapes. The agricultural policy implemented by the French colonial power, required farmers to produce industrial crops for export. Reluctantly at first, farmers gradually abandoned shifting rice cultivation (*tavy*) to grow cash crops, mainly coffee, paving the way for an economy based on trade and monetization. Later, farmers replaced coffee by clove trees, gradually transforming shifting cultivation into AFS with cloves. Simultaneously, they extended paddy rice cultivation and diversified their AFS in response to economic and climatic disturbances and to more gradual changes, thereby demonstrating their continual responsiveness. Similar dynamics can be observed in many contexts where the colonial powers forced farmers to produce cash crops to supply industries in the metropolitan area, obliging them to diversify their production and cropping systems. Our results provide valuable insights into the multiple drivers of these transitions toward agroforestry and into the complexity of the processes involved.

Keywords Land use evolution · Agroforestry · Farming practices · Land use mapping · Agrobiodiversity · Madagascar

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Introduction

After Indonesia, Madagascar is the second biggest producer and the primary exporter of cloves and clove oil in the world, the world leader on the vanilla market and the fourth world producer of lychees (Chalmin and Jégourel 2019; Altendorf 2018). From an economic point of view, *Sygygium aromaticum*, *Vanilla planifolia*, *Litchi chinensis* produce the three main agricultural products exported from Madagascar (Gouzien et al. 2016). These crops are cultivated in different types of cropping systems and, in particular, in diverse agroforestry systems (AFS) managed by smallholder farmers located on the east coast of Madagascar.

Today, in the Analanjirofo region (Fig. 1), the center of clove production (Danthu et al. 2014) AFS are simultaneous associations of trees, of which the main one is the clove tree, of crops and more rarely of animals. Given the longevity of clove trees, up to 100 years (Maistre 1964), and the duration of their exploitation period, clove trees are cultivated in cropping systems that evolve with the socio-economic context and climatic events (e.g. cyclone). They are either monoculture (5–10% in our surveys), parklands or complex multi-layered, multi-species AFS. Parklands are similar to simple AFS with annual food

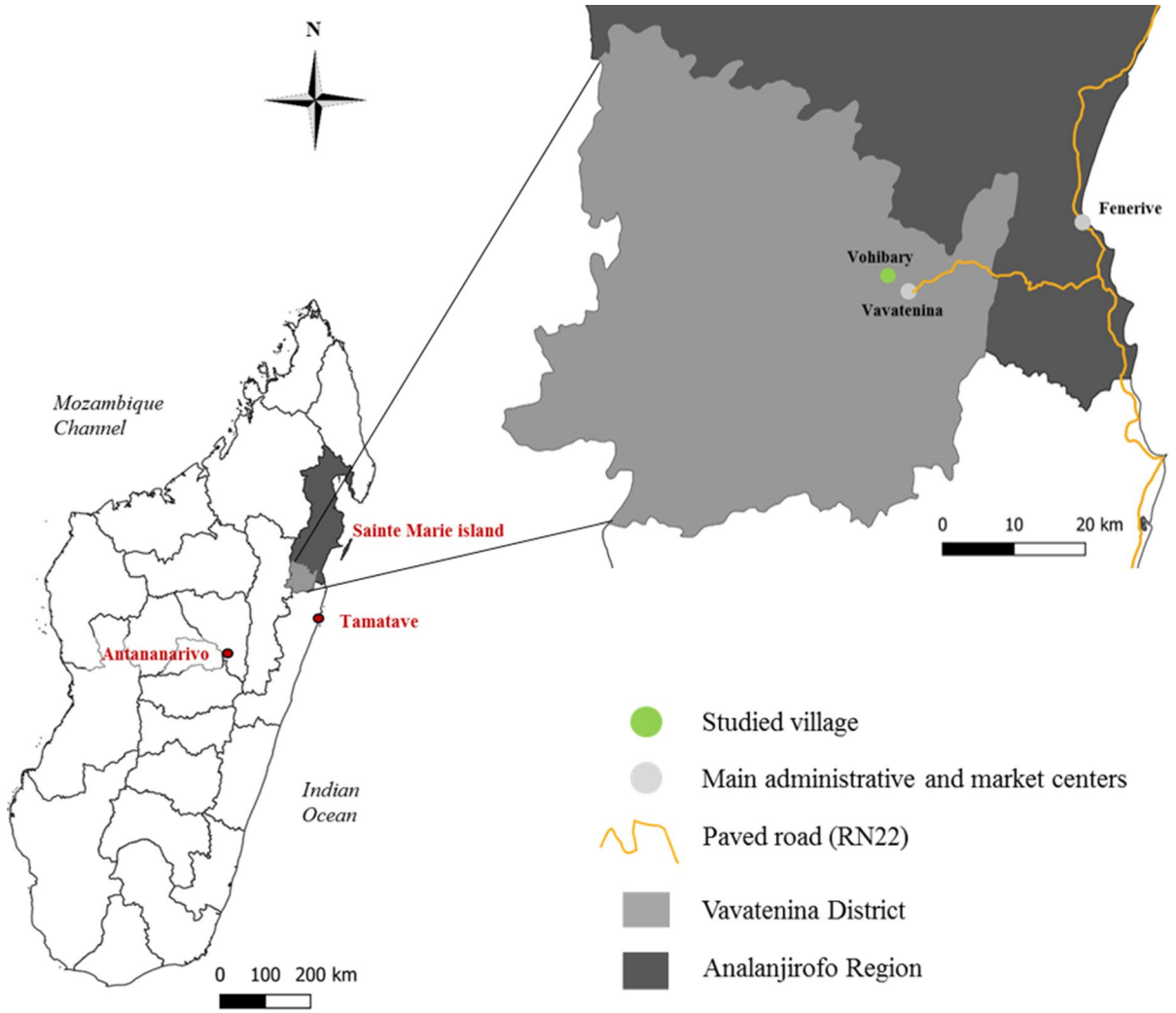

Fig. 1 The study area: the village of Vohibary, district of Vavatenina, Region of Analanjirofo, Madagascar

crops (e.g. rainfed rice, cassava, tubers, sugar cane), intercropped with clove trees growing in pastures (60–70%). Complex AFS (20–35%) combine large fruit trees (lychee, mango, breadfruit, jackfruit etc.), smaller trees (coffee, citrus), herbaceous plants or lianas (vanilla, pepper) and sometimes include remaining native forest trees (Michels et al. 2011; Arimalala et al. 2019; Michel et al. 2021). The main food crop is rice, produced in paddy fields in all available lowland areas (Le Bourdiec 1978).

Studies by Arimalala et al. (2019), Cocoual and Danthu (2018) highlight the fact that the diversity of current production systems derived from the strategies applied by the farmers in the first half of the twentieth century. These strategies depended largely on the agricultural policy implemented by the French colonial power that promoted industrial crops for export, grown in large-scale colonial plantations but also cultivated by smallholders (Galliéni 1908). Arimalala et al. (2019) also showed that farmers started growing cloves, but did not apply the cultivation practices recommended by European agricultural technicians (monoculture and low planting density), thereby creating original cropping systems (AFS and high planting density) whose imprints are still visible today. These studies showed that the landscapes and farming systems on the east coast of Madagascar result from interactions between multiple drivers and from changes that took place over more than a century. This complex history sheds light on the agro-ecological contexts and farmers' current practices.

We focused on a clearly identified zone, one village and its surrounding landscape, with the aim of updating and analyzing the historical, socio-technical and economic factors that determined changes in the farmers' strategies, production systems, and landscapes. For this purpose, we used as a baseline a monograph by an agronomist (Gérard Dandoy), published in 1973, that described the landscape of Vohibary, a small village in the Vavatenina district in 1966 (Fig. 1). In particular, the monograph includes a land use map we compared with an updated map drawn 50 years later, based on a set of field surveys conducted in 2016. This diachronic analysis was completed by a corpus of scientific and technical references published over more than a century.

First, we compared the diagnoses and maps made in 1966 and 2016 to identify the land use changes in the agricultural landscape of Vohibary. Second, we examined a set of technical and historical documents to explain these changes. Supplementary data were collected in surveys of the farmers, visits to AFS, and the testimonies of village elders.

Material and methods

Study area

The study area focused on the village of Vohibary, located 5 km from Vavatenina, the main town of Vavatenina district, and its agricultural landscape (Figs. 1 and 2). Vohibary landscape covers an area of 210 ha whose limits are natural ridges or rivers. The natural landscape is shaped by low hills (*tanety*) whose altitude does not exceed 413 m with steep slopes and deep ravines excavated by tropical rainfall. Flat land is limited and lowland rice accounts for a total area of about 13 ha. Cyclones occur regularly (Donque 1975), the last major cyclones were Honorine in March 1986, Bonita in January 1996.

Today, the village is composed of two hamlets, Vohibary (the original village) and Antanambo. The population mainly belongs to the Betsimisaraka ethnic group. Table 1 lists some characteristics of the village in 1966 reported by Dandoy (published in 1973) and updated in 2016.

Land use mapping and diachronic analysis of the study area

The study area was mapped using very high spatial resolution arial photographs acquired by drone in June 2016 (Figs. 2A and B). To ensure complete coverage of the areas overflown, the aircraft's flight paths, and automatic release frequencies were adjusted to obtain a 60% longitudinal overlap and a 30% lateral overlap. The geometric distortion (fish-eye effect) caused by the type of camera on board the drone, as well as variations in the topography and in the pitch and tilt of the drone during each flight were corrected using projective transformation functions. The projections were based on several anchor points collected with a GPS or obtained from previously georeferenced and ortho-rectified satellite products. The aerial photos obtained were combined in a mosaic with a spatial resolution of 0.63 m. A total of 74% of the study area was covered. The remaining 26%, corresponding

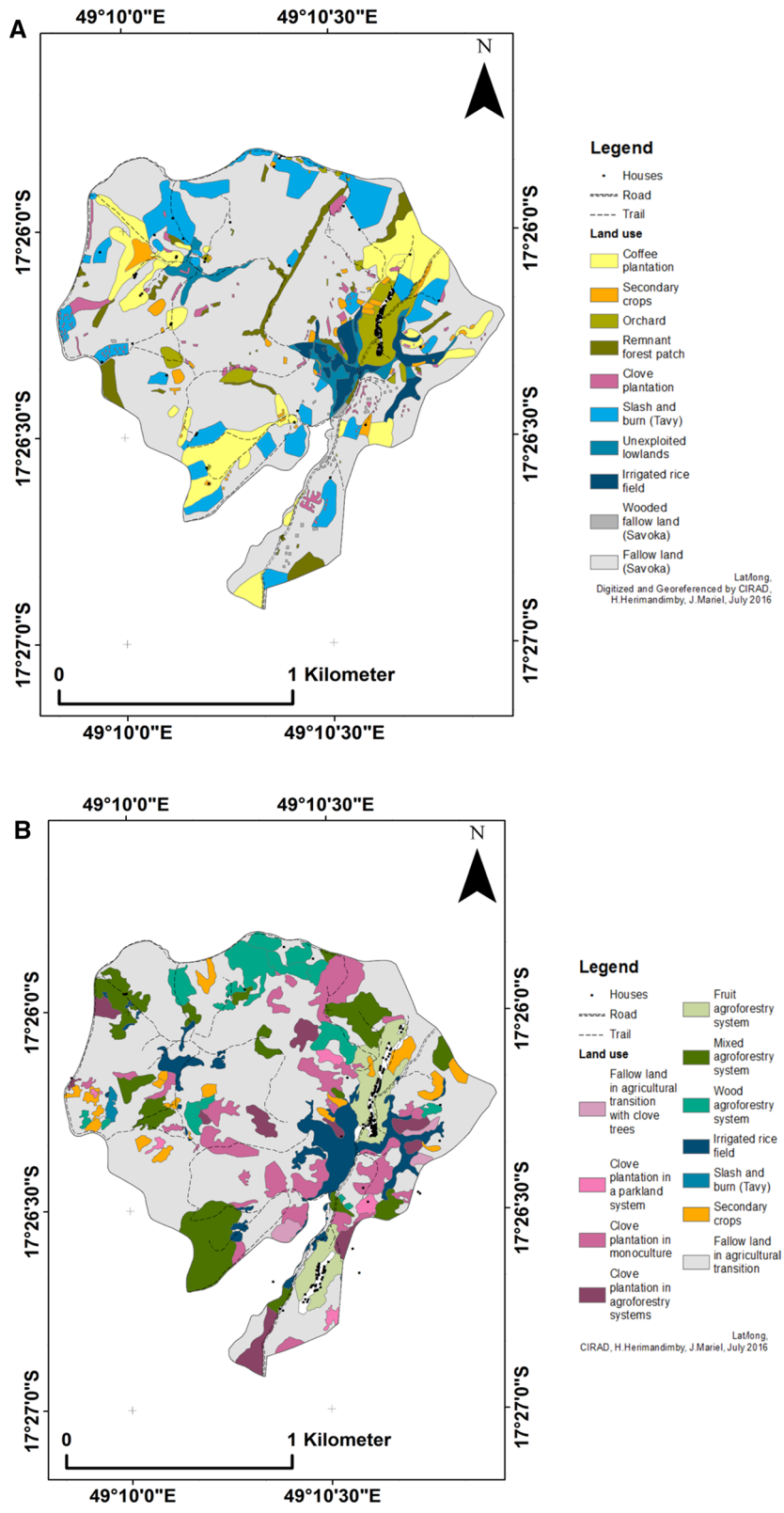

Fig. 2 Land use map of the agricultural landscape of Vohibary: **A** in 1966 after Dandoy (1973); **B** in 2016 (map based on aerial photographs combined with field surveys) (map digitized and georeferenced by H. Herimandimby and J. Mariel, July 2016)

Table 1 Some characteristics of the village of Vohibary in 1966 (after Dandoy 1973) and in the 2016 surveys

	1966	2016
	One hamlet (Vohibary)	Two hamlets (Vohibary and Antanambo)
Population	186 inhabitants	About 120 households in the two hamlets (600 inhabitants)
	2.76 children/household	About 3 children/household
Accessibility	No road, one hour on foot from Vavatenina (5 km)	2.5 km of paved road (in bad condition) then 2.5 km of track (accessible to off-road vehicles)
Average size of farms	5 ha, including 1.6 ha cultivated land	Between 2 and 3 ha/farm, no more available land
Market/marketing methods	In the village: self-consumption, local sales, barter: vegetable, edible leaves, fruits	In the village: self-consumption, local sales, barter: rice vegetable, edible leaves, fruits
	Sale of fruit, edible leaves, banana, cassava and other products at the Vavatenina market with the goods carried on the back/head; purchase of staple products (rice, salt, sugar, oil, soap, petroleum)	Sales in Vavatenina with the goods carried on the back/head
	Sale of cloves, clove oil and coffee prepared in Vavatenina (barter with Chinese traders)	Traders come to the hamlets to collect the cloves
		Sale of lychees to middlemen (who work for exporters) and set up where the track meets the paved road (2.5 km from the village)

to valley bottoms mainly occupied by dense AFS, were mapped from satellite imagery available on the Google Earth virtual globe. Photo interpretation of the mosaic was based on in situ observations to confirm each type of land use zoning. Using the Dandoy map, particularly the main trails and paths that have barely changed since 1966, we were able to geo-reference and digitize the information, and thus to compare it with our 2016 land cover map.

Most of our historical information came from old documents, journal articles and reference works written by botanists, agronomists or geographers who had resided in Madagascar since the 1900s. Most were written in French. They are listed in the bibliography.

Surveys in Vohibary to document agroforestry practices, product uses, and local perceptions of change

In 2016, the structure and composition of 12 AFS belonging to agricultural households in Vohibary were characterized. They were selected according to the local definition of an AFS, i.e.a cultivated land with several herbaceous and perennial species in association, other than rainfed rice, and necessarily with edible species. The characterization of the studied AFS was based on farmers' reports and *in-situ* observations of the number of plants of each species present in the AFS and their age class (i.e. productive or juvenile). The different types of AFS were distinguished according to these criteria, and the AFS identified helped us classify the land uses mapped by drone in 2016.

We conducted surveys of the households who owned the AFS to collect data to (i) describe the different uses for self-consumption and ways of sale of agroforestry products, (ii) estimate self-consumption of fruit and wood originating from AFS, and (iii) explore the practices used to establish an AFS.

Semi-structured interviews with the village chief and the customary authorities (*tangalamena*) helped understand the changes that have occurred in and around Vavatenina. This information was used as inputs for our diachronic mapping analysis of the Vohibary landscape and to identify the key facts that have remained in the collective memory.

Results

Description of Vohibary landscape in 1966

In 1966, the area under shifting cultivation (*tavy*) accounted for 10.8% of Vohibary total land area,

while fallow (*savoka*) accounted for 66.6% (Fig. 2A, Table 2). Three quarters of the territory was thus deeply imprinted by *tavy* (defined below) at that time. *Tavy* is rooted in the Betsimisaraka ethnic culture (Perrier de la Bâthie, 1921; Kiener 1963; Dez 1966; Le Bourdiec 1978).

Tavy is defined as the cultivation of upland rice, or other crops (maize, beans, groundnuts, cassava) without plowing, after slash-and-burn of natural forest, or secondary forest (*savoka*) (Kiéner 1963; Aubert et al. 2003). *Tavy* consists of successive stages: coarse deforestation of a forest plot by cutting down trees, burning the wood and shrubs and herbaceous vegetation, then sowing rice as the first annual crop, with superficial weeding, and harvesting (generally with low yields). After two to three years under rice, or other annual species, the plot is set aside for a period varying from seven to 10 years to allow soil fertility to regenerate. After clearing and burning, holes were made in the ground with a stick (no plowing) and combinations of seeds of maize, sesame, or lentils were sown (Dandoy 1973) (Fig. 3A and B). According to Torquebiau (2000), *Tavy* corresponds to an ancestral form of sequential agroforestry in which not cultivated trees and crops are not to be found simultaneously on the same piece of land, but follow each other in time. This point distinguishes it significantly from the clove tree AFS.

Savoka is the name given to the fallow vegetation that grows following *tavy*, after cropping is abandoned. The savoka that replaces the forest is a dense thicket, rich in *Afromomum angustifolium, Psiadia altissima, Neyraudia madagascariensis* or *Clitoria lasciva*, that is gradually replaced by a secondary forest with reduced biodiversity and the dominance of species such as bamboo, *Ravenala madagascariensis* or *Harungana mdagascariensis* (Perrier de la Bâthie 1921; Dandoy 1973). But with an increase in the number of *tavy* cycles, the savoka vegetation becomes poorer and soil fertility decreases.

At the time of Dandoy's study (1973), some strips of mature forest were still present but accounted for only 3.4% of the area studied. The main perennial crop cultivated was coffee, which accounted for 11.4% of the total area (Fig. 3C), followed by clove trees but accounted for a much smaller area (1.8%) while only half the lowlands had been converted into paddy rice fields (Fig. 3D).

Changes between 1966 and 2016

The comparison of land use in 1966 and 2016 revealed a set of changes in cropped and uncultivated areas (Fig. 2A, B, Table 2). First, this comparison highlights the almost complete disappearance of *tavy*, which dropped from 23.1 ha to 0.6 ha. The

Table 2 Comparison of land use in the Vohibary region, in 1966 (from Dandoy 1973) and in 2016: changes in the cultivated surface area in each cropping system

1966			2016		
Land use	ha	%	Land use	ha	%
Surface area occupied by cultivated plants, mainly perennial species					
Orchard	6.8	3.2	Cloves as monoculture	19.7	9.3
Clove plantations	3.8	1.8	Cloves in complex AFS	7.4	3.5
Coffee plantations	24.4	11.4	AFS with fruit trees	9.8	4.6
			AFS with wood trees	12.5	5.9
			Mixed AFS	22.1	10.4
Surface area occupied by annual crops					
Secondary crops	3.6	1.7	Secondary crops	6.3	3.0
Slash and burn (*Tavy)*	23.1	10.8	Slash and burn (*Tavy)*	0.6	0.3
Irrigated rice field	6.2	2.9	Irrigated rice field	13.2	6.2
Unexploited lowlands	4.9	2.3		-	-
Surface area not cultivated or at the start of cultivation					
Wooded fallow (*savoka*)	0.5	0.3	*Savoka* at the start or in the process of cultivation (clove plantations)	117.8	55.8
Fallow land (*savoka)*	132.8	62.2		-	-
Remnants forest patch	7.3	3.4		-	-

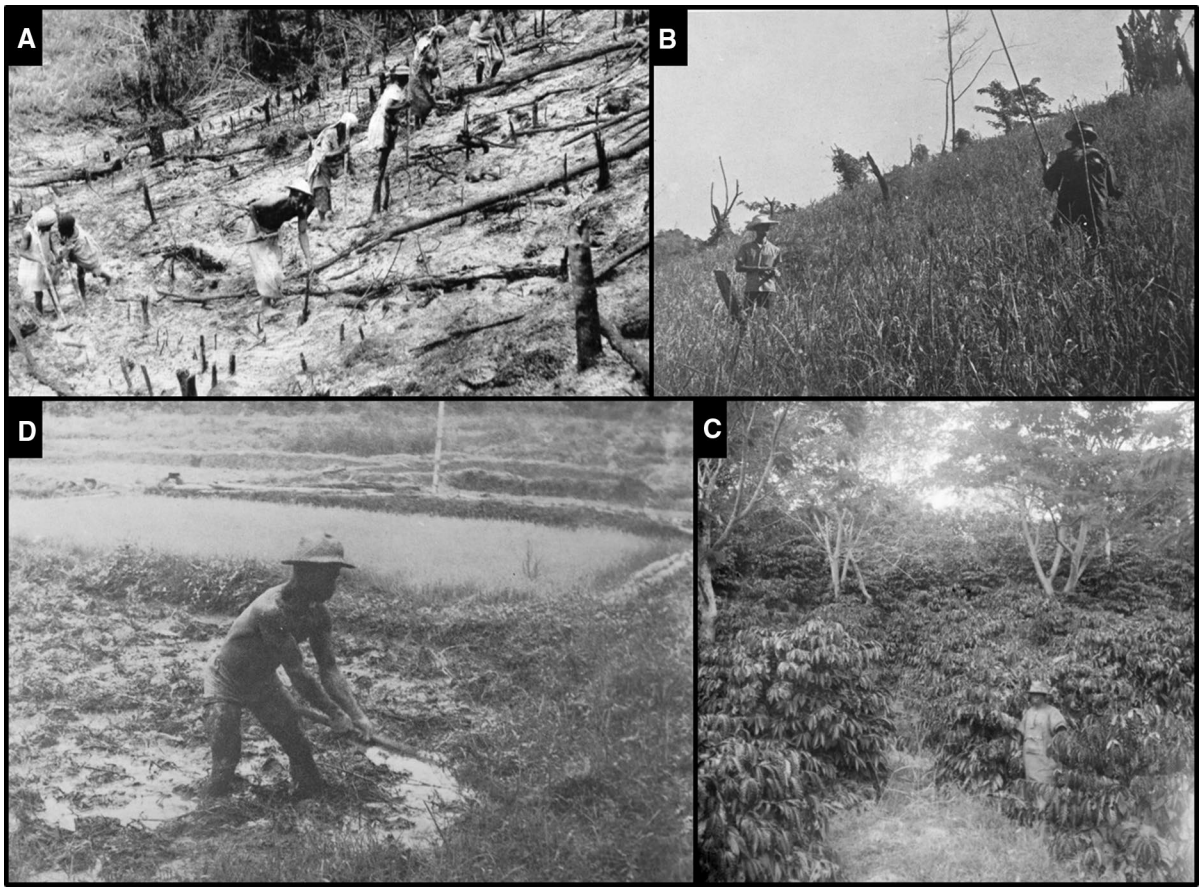

Fig. 3 **A** Sowing rain-fed rice in *a tavy* in the 1960s (Kiéner 1963). **B** *Tavy* ready for harvest at Vohibary in 1966 (Dandoy 1973). **C** Coffee plantation under *Albizzia lebbeck* on the Malagasy east coast in the 1930s (photo Ledreux) (Ledreux © CIRAD). **D** Installation of a rice field in the 1960s in Vohibary (Dandoy 1973)

land under *tavy* was mainly transformed into plots of perennial species and annual food crops (secondary crops). Another major change was the disappearance of mono-cropping of coffee trees. These areas were replaced by diversified AFS, generally dominated by clove trees, associated with other fruit trees, vanilla, timber species and some remaining coffee trees. There was an almost 88% increase in the area under clove trees, all types of systems combined (Fig. 4). There was a 75% increase in secondary crops in the total area occupied by annual crops, compared to the 1966 map in which *tavy* dominated annual cropping systems. In 1966 and today, annual crops are mainly cassava, sweet potato and some sugar cane (for the production of a local alcohol called *betsa betsa*). Lastly, the comparison of land use maps showed a 110% increase in land under paddy rice, now cultivated in lowlands not yet exploited in 1966 plus on some of the lower hillside slopes (*tanety*) where water is available.

The comparison of the two land use maps also revealed changes in uncultivated areas. The vestiges of mature forest remaining in 1966 had completely disappeared in 2016. Part of the fallow vegetation (*savoka*) was converted into clove plantations (as monoculture, in AFS and in parklands). Field observations notably revealed diversification of part of the old wooded fallow (*savoka*) in wood-based AFS (Fig. 5A).

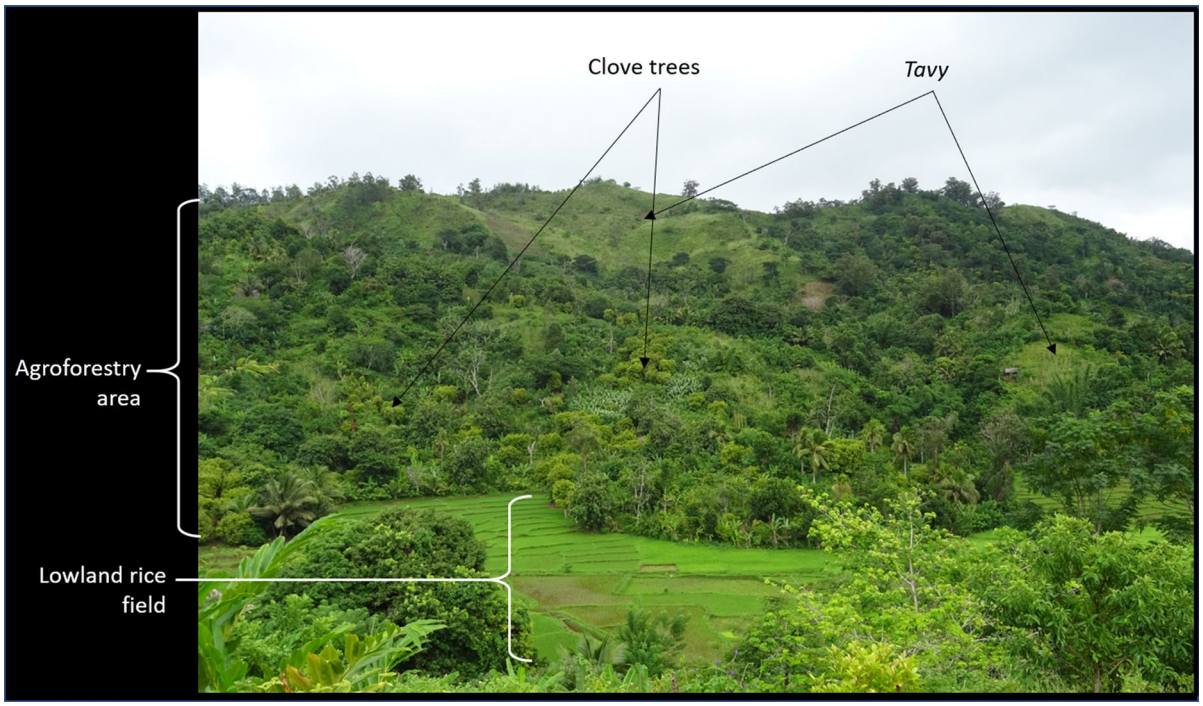

Fig. 4 Several types of agroforestry systems with *tavy* field plots covering *tanety* landscape (Photo Mariel)

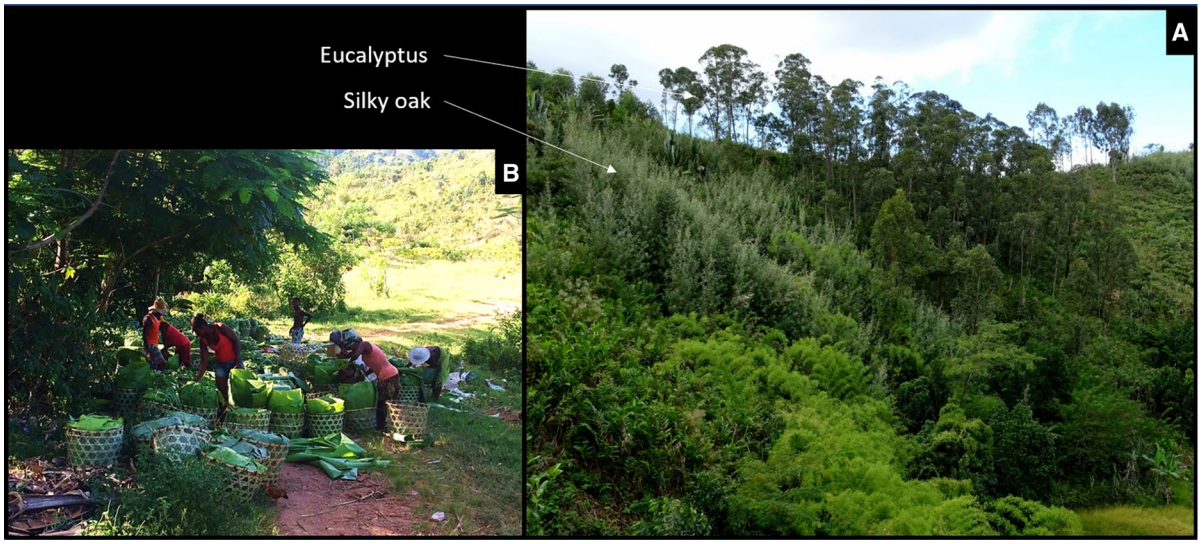

Fig. 5 **A** Agroforestry system with timber species (Photo Mariel). **B** Packaging of lychees before delivery to the middleman, Vohibary, November 2019 (Photo Mariel)

Discussion

A shift from subsistence agriculture to the monetarization of crop productions: drivers and consequences of the changes related to rice production

Rice is a key staple food for Malagasy people. The Betsimisaraka ethnic group cultivated rice to be self-sufficient in two different ways: traditionally on *tanety* by practicing shifting cultivation (*tavy* rice) but also in the lowland in irrigated systems (paddy rice). Our diachronic analysis of land uses in Vohibary landscape highlighted two major changes in local rice production. First, the abandonment of the traditional practice of *tavy* and second, the expansion of irrigated rice in the lowlands. We now review the drivers of these changes and their consequences for farmers' food production strategies and income, and for the landscape.

The end of the traditional tavy practice: drivers and consequences

Rainfed rice on *tavy* was the first form of agriculture practiced by farmers in Madagascar, as far back as the testimonies go (described by botanists such as Perrier de la Bâthie (1921, 1922/1923). *Tavy* aimed at ensuring farmers' rice self-sufficiency and later became nearly complete self-sufficiency. Dandoy (1973) estimated that the average yield was approximately one ton of paddy per hectare, but other authors reported much lower yields. Kiener (1963) estimated paddy yield at between 500 kg and one ton in the first year of the *tavy* supplemented with a little cassava in the second year, but yield could drop to 250 kilos in the case of drought (Rabearimanana 1985). *Tavy* rarely enabled household self-sufficiency, and farmers often gathered supplementary forest products (Le Bourdiec 1978). Dandoy (1973) also reported the physiological and nutritional hardship of families subsisting on *tavy* alone.

The "*Code des 305 articles*" enacted in 1881 by Queen Ranavalona II, punished anyone who destroyed the forest to create fields in which to grow rice, corn or any other crop by five years of jail (Thébault 1960). The ban was kept in successive French legislation, but, in practice, was never implemented, due to lack of the necessary resources and the vast territory to be controlled (Lavauden 1934). *Tavy* deeply imprinted the landscape: the gradual retreat of natural forest produced a hilly *tanety* landscape, mainly covered with fallow vegetation (*savoka*) and pastureland, sometimes containing some strips of remnant forest towards their summits, or even more rarely, completely wooded as described by Perrier de la Bâthie in 1922/1923. In the Vavatenina region, natural forest probably disappeared long ago, as in 1899, Zimmermann estimated that opposite Tamatave, the retreat of the forest from the waterfront was 70 to 75 km. Vohibary is located in this coastal strip, its distance to the coast is about 25 km. The farmers of Vohibary kept on practicing *tavy*, and developed clove tree plantations, but the contribution of the clove tree to deforestation seems minor, the plantations being carried out in the *savoka* which, in 1966, represented 70% of the landscape of Vohibary (Dandoy 1973). Nevertheless, it is possible that a few forest fragments have been cleared to be transformed into clove plantations, as Petit observed in 1965 in the village of Ankofa (Antongil Bay), leading to the disappearance of the remaining vestiges of forest. But this remains a marginal event.

The successive vegetation states that follow several *tavy*-fallow cycles are now well described and involve an irreversible shift from a tree stand to shrubs and subsequently to herbaceous vegetation (Kiéner 1963; Styger et al. 2007; Aubert et al. 2003). This shift is visible on the two maps in Fig. 2. In 1966, 3.4% of Vohibary land, particularly on the ridges, was still covered with forest, the last remaining traces of the original forest cover. In 2016, these last shreds of forest had disappeared, replaced by more or less diversified perennial plantations and forest plots inherited from fallow (*savoka*) vegetation, but also plots planted with useful species.

Due to population growth and the resulting pressure on land use, *tavy* rice production became unsustainable. The balance between the productivity of the plots, the length of the fallow periods, the loss of soil fertility and the growing number of mouths to feed was upset in Vohibary, where the population has increased almost four-fold.

Lowland rice production for self-sufficiency: an unrealistic goal

Paddy rice (irrigated rice) has long been grown in the lowlands alongside *tavy* rice as they are complementary (Le Bourdiec 1978). In 1966, the survey conducted by Dandoy (1973) showed that rice cultivation areas were divided between t*avy* (23.1 ha), irrigated lowland fields (6.2 ha) and unexploited lowlands (4.9 ha). In 2016,

rice production was concentrated in irrigated lowland fields (Table 2), and to a lesser extent in clove parkland, in which the main accompanying crop is rainfed rice (1.9 ha). Farmers have therefore changed their rice cultivation system from *tavy* to irrigated rice farming.

Rabearimanana (1988) explained the determinants of this change in the highlands, but some elements also apply to the east coast. A major driver of these changes was population growth, together with the increasing appetite for rice at the expense other food products, maize, cassava, yams, sweet potatoes, for cultural reasons. This driver was also combined with the distribution of the work force which had to be spread more over cash crops (coffee, cloves, etc.) than on *tavy* rice production. Lowland rice cultivation was strongly encouraged by the French government. In 1965, Chabrolin, the Head of the Rice department at the Institute for Tropical Agronomic Research and Food Crops, still wrote "*Tavy rice farming should only be tolerated on soils where there is no risk of erosion) […] which might seem to encourage it. On the contrary, irrigated rice cultivation should be expanded and perfected as much as possible*".

However, this type of rice cultivation required ground leveling, water capture, construction of canals and bunds, drainage systems, and time-consuming cultivation practices including soil preparation, plowing, nursery, transplanting, and weeding (Fig. 3D). Irrigated rice is thus very labor-intensive and required an average of 157 working days per year and per hectare. But since it enabled two crops a year, yields were more than twice that of *tavy* rice*:* 2200 kg/ha versus 1000. In fact, the return to labor was multiplied by four: 14.1 kg of paddy rice per working day versus 3.9 for *tavy* rice (Dandoy 1973).

However, the intensification of lowland rice cultivation was not able to feed the increased population of Vohibary. As early as 1947, Tourneur observed that Malagasy farmers were planting food crops in the inter-rows in their AFS to ensure their own food security, and this is still the case today. In 1966, assuming intensive cultivation of the entire lowland and two annual harvests, Dandoy (1973) estimated that paddy production would cover only 2/3 of the village's needs. In the interviews conducted in 2016, local and customary authorities unanimously pointed to the increasing lack of sufficient land to cultivate enough rice for each household and only two of the nine farmers surveyed were self-sufficient in rice.

The use of AFS crops and the monetization of agricultural production have therefore become essential to meet the food needs and in particular, the volume of rice needed by farming households.

The diversification of crop and production systems: the origins of the current agroforestry landscape

The abandonment of *tavy*-based agriculture was accompanied by the introduction and appropriation of cash crops by smallholder farmers, particularly coffee, which was more profitable than other cash crops. However, according to Rabearimanana (1988), along the coast, *tavy*-based agriculture was abandoned late, i.e., between the 1940s and 1960s. We now review the factors that contributed to the diversification of crops and productions systems and hence to shaping the agroforestry landscape today. We describe the agroforestry practices we documented in 2016 and their evolution in response to environmental and socio-economic factors.

The exchange economy via cash crops on the colonizer's initiative: the beginning of the monetarization of agriculture

The first cash crops for export took place on the island of Sainte-Marie (French since 1814) at the beginning of the nineteenth century (Decary 1937). On the big island, the shift from self-sufficiency to diversified agriculture based on perennial crops began with French colonization in response to the concern of the colonizer and the desire of General Galliéni, the first governor of Madagascar (1896 to 1905), to achieve the successful agricultural development of the island and contribute to its economic independence. The governor wanted to improve existing crops and introduce new crops to support the economic development of the Malagasy population, but also with the ambition to feed the export chains and consequently enrich the colonizing power (Galliéni 1908; Scales 2014).

The colonizer's first approach was to try to increase local production by "*using the forest and the bush for their spontaneous products*" (Célérier 1932). Between 1896 and 1905, the main products exported were gold, natural rubber, beef from zebu, skins, raffia, wax, wood, pulses. These products were soon followed by the first introduced crops, vanilla and

cloves, but in much smaller quantities (Galliéni 1908; Célérier 1932; Danthu et al. 2016).

Rapidly, the colonial power imposed the development of recently introduced industrial crops that had already been tested in Madagascar by obliging small-scale farmers to create plantations. One of the means was the implementation of heavy taxes on agricultural production, whose objective was to stimulate cultivation and harvesting for export (Jacob 1987). Thanks to its warm and humid climate, the eastern side of the island has become the privileged zone for productions intended for export (Salomon 1982). This was particularly the case in the province of Fénérive-Est, in which cash crops were introduced in 1898: *These areas are fertile, if we judge by the vigor and the good appearance of the plantations […] that surround the villages; however no tropical crops: coffee, cocoa, vanilla, cloves,* etc. *have been attempted yet* (JODM, October 6, 1898, after Cocoual and Danthu 2018). The first crop promoted by the administration in the Vavatenina area was coffee, particularly after the First World War, and later, around 1930, clove trees (Dandoy 1973).

Coffee, the first industrial crop Malagasy farmers were forced to grow

Under pressure from the colonial power, smallholder farmers were obliged to grow coffee. This colonial decision to promote the cultivation of coffee was based on the fact that, at that time, French coffee consumption depended to a great extent on imports of coffee from Brazil. The first *Robusta* coffee plants were distributed by the Ivoloina test garden in 1906 (François and Ledreux 1929). More than 80% of coffee was produced on the east coast and partly on small Betsimisaraka peasant plots to supplement insufficient production by colonial plantations (Chevalier 1946; Fremigacci 1986; Rabearimanana 1987). Dandoy (1973) reported that the introduction of coffee met strong resistance from farmers who were told to use their best soils (alluvial land, low slopes, thalwegs) and who were not accustomed to managing tree crops other than by picking. As a result, cultivation practices were generally minimal, which "*contributes to giving the plantations the appearance of an abandoned crop*" (Dandoy 1973).

However, the farmers' reluctance to grow cash crops was offset by economic pressure in favor of these crops: the need to find an alternative to *tavy* that was increasingly unable to cover food self-sufficiency, and the possibility of raising money from farming, if only to pay the colonial tax. This context explains why, in the Vohibary territory in 1966, 11.4% of the area was devoted to coffee while *tavy* was declining, but had not yet been completely abandoned.

However, already in 1966, Malagasy coffee dynamics had begun to weaken. It should be noted that coffee was subject to a succession of crises between 1930 and 1960 that affected coffee producers' confidence in obtaining a sustainable income from coffee. The first crisis was linked to determination of the colonial planter and of the administration to maintain high export prices, which made Malagasy coffee less competitive. The second crisis was a consequence of the blockade of Malagasy exports during the Second World War. The third crisis was linked to global coffee overproduction at the beginning of the 1960s and of new coffee producing countries entering the world market. The fall in producer prices continued from the 1960s to the mid-1980s and at the same time, the ratio of the price of coffee to that of paddy, a vital criterion for Malagasy producers who have to buy the rice they do not produce themselves, was halved (Blanc-Pamard and Ruf 1992). The sector declined and the farmers no longer renewed their coffee trees.

The comparison of the two maps illustrates these dynamics: coffee plots in the Vohibary region completely disappeared between 1966 and today. However, a small population of coffee trees, often residual and not very productive, is still present today particularly in AFS (we counted between 10 and 50 trees in the plots we visited). Few of the farmers in Vohibary actively renewed their plantation, most only kept trees left over from the coffee plantations established in the colonial period. The yield of these coffee trees supplied a small local marketing chain and was also grown for self-consumption, as Malagasy inhabitants had gradually become coffee consumers themselves. But the small quantities of green coffee beans sold (between 5 and 50 kg), the low prices plus the poor quality of the products on the market confirmed farmers' disinterest in coffee.

Cloves replace coffee: the farmers' decision preceded that of the colonizer

To offset the shrinking coffee sector, the colonial authorities tried to promote alternative crops: pepper, vanilla, oil palm, cocoa, tea and especially cloves (Dumont 1959).

The smallholder farmers on the east coast started cultivating clove trees very early on, the first clove trees were introduced in Sainte-Marie in the 1820s. Compared to coffee, clove trees have the advantage of growing in all types of soils, even the poorest, and hence also in fallows (*savoka*) and laterite soils which, before this crop was introduced, had remained unused (François 1927). The clove tree is not very sensitive to disease, its maintenance is not very difficult, it reproduces easily by natural sowing, and the cloves are simply collected and dried. In addition, cloves are used to make a second product with high added value: clove oil obtained by distilling clove tree leaves in stills. This oil production expanded very early on the east coast, the first distillations of clove leaves were carried out in 1911 in Sainte-Marie (François 1927; Ledreux 1928, 1932). Clove trees have only three disadvantages: low wind resistance in an area subject to regular cyclones (Ledreux 1928, 1932; François 1927; Donque 1975), sensitivity to a leafminer, *Andretra* (Frappa 1954) and irregular interannual yields (Danthu et al. 2014). This context explains why, very rapidly and before being asked to do so by the administration, small-scale farmers planted clove trees in their plots without respecting the agronomic recommendations given by extension technicians (Arimalala et al. 2019).

Dandoy (1973) reported that from the 1930s on, Vohibary farmers planted clove trees generally by scattering seeds in the fallows or secondary forest regrowth (*savoka* and wooded *savoka* after a *tavy* cycle). The trees produced buds and during the rice shortage period, some farmers trimmed their trees to produce clove oil they distilled by hiring a distiller in a neighboring village. Less demanding than the coffee tree, easier to maintain, clove trees appeared to be suited to the natural conditions of the Vohibary landscape and its inhabitants. In 1966, there were 2700 clove trees, of which 1,900 were less than seven years old, accounting for 1.8% of the land. The 2016 map confirmed the trend: more than 14.5% of the region was cropped with clove trees. Interviews with farmers indicated an average of 223 ± 79 productive and juvenile trees per household, distributed in several plots, grown either in monoculture, parkland, or complex AFS, where the average was around 55 trees versus 93 ± 62 in 1966. The similar proportion of juvenile plants in 1966 (Dandoy, 1973) and 2016 confirms the intention of farmers to maintain and increase their plantations by renewing old and non-productive trees. Indeed, to cite a young farmer we interviewed "*Here, if you don't have clove trees, people don't take you seriously*".

Our 2016 surveys highlighted different trajectories leading to the different clove-based systems mapped in Vohibary territory. For example, a young farmer who inherited a fallow plot (*savoka)* planted clove trees and took advantage of the shade provided by the *savoka* species to protect young clove trees in the first years. Later, the *savoka* species were cleared and replaced by perennial crops, such as fruit and woody trees, but also food crops, notably cassava. Another option consisted of clearing, then burning, followed by cultivating annual species for two or three years, mainly rainfed rice, cassava, and sweet potatoes, and simultaneously planting cloves, often associated with other species. The frequent cyclones in Vavatenina (Donque 1975) also influence the planting of perennial crops and in particular clove trees. Surveys and field observations suggest that planting dynamics have not been constant. In particular, we observed a high proportion of young clove trees in the Vohibary landscape, which, according to producers, were probably less than 20 years old. Unlike the older plantations (planted before 1930), which are generally monoculture or, more rarely, parkland, this wave of recent plantations has mainly been part of setting up complex AFS. Farmers reported that perennial crops were widely abandoned around Vavatenina following the two violent cyclones, Honorine in 1986 and Bonita in 1996, that destroyed a significant proportion of the clove plantations covering the *tanety*. Men migrated temporarily to other regions, especially to the north, to find other sources of income, and planting perennial crops only started again around 2000.

The diversification of cropping systems and products to cope with environmental (deforestation) and socio-economic changes

The species at the origin of diversification and their uses

Dandoy (1973) reported that households of the Betsimisaraka ethnic group usually had a real home garden that included different fruit trees, coffee trees and cloves. He also reported that diversification was essential to compensate for the shortage of rice during the lean period that can last up to three months from January to March. Cassava, taro, yam, or plantain were consumed by the villagers who were mainly food self-sufficient. Local fruits were an important food supplement: pineapple, lychees, apple-cinnamon, avocado, bananas, jackfruit and citrus including tangerines, oranges, grapefruit, and an orange-tangerine hybrid. Breadfruit was and is still widely consumed during the 3-month lean period when it replaces rice. Dandoy (1973) did not mention having observed this species in 1966, even though it seems to have been abundant in the region (François 1927). Although rich in carbohydrates and therefore a good source of energy, breadfruit is very poor in other nutrients, and farmers interviewed did not considered it as food of good nutritional quality.

Overall, the diet was not nutritionally balanced as it lacked protein and lipids. Poultry failed to provide the necessary amount of protein and the rare local zebus (nine zebus were counted in the village in 1966) were reserved for animal traction in the rice fields. Since the 2000s, there has been a considerable increase in livestock rearing as a means of diversification. Breeding small livestock appears to be playing an increasingly important role, particularly pigs, which provide households who have little land with a source of income. Breadfruit and jackfruit are widely used to feed pigs.

The context changed after the 1990s thanks to the opening of an export market for lychees, departing from the port of Tamatave (Jahiel et al. 2014). The main production area for lychees for export extends along the east coast and includes the district of Vavatenina. The sector is supplied by a multitude of small producers, who sometimes only have a few trees scattered through their plots rather than real “lychee orchards”. In Vohibary, the trees are often planted at the edge of monoculture clove plots, in homestead orchards or in home-gardens and AFS. The 12 AFS we surveyed had between two and 20 productive lychees per plot and only two contained no lychee trees. Farmers sold their production to middlemen who work for exporters and visit even the most remote villages when possible (Fig. 5B). Nevertheless, isolation and access—or lack of access—to markets influence the production and marketing of lychees. Due to difficult transport, fruit collection vehicles only come to the Vavatenina district for supplies at the end of the season (end of December) and the quantities collected are adjusted according to the quantities collected from other districts (Jahiel et al. 2014). This harvest policy means isolated farmers cannot be sure they will sell a fixed and significant quantity of lychees every year, and lychees thus remain above all a self-consumed product. All the households we surveyed consumed lychees in quantities per person can be very high: on average 68 kg and up to more than 100 kg over the entire production period from mid-November to the end December.

Vanilla is less widely cultivated by farmers than on the north coast of Madagascar due to its demanding and often poorly known technical itinerary in our study area, where the necessary skills are limited, and inter-annual production fluctuates. Very low to very high price variability, from US$35–500/kg has been recorded over the past 15 years. At the district level, vanilla was already cropped in 1966 but to a very limited extent. According to Dandoy, in 1966, "*Vanilla is a marginal crop in the process of being abandoned*". However, in 2016, among the 12 AFS we visited, three produced vanilla, and the villagers reported that more and more farmers were planting vanilla in their AFS. Its recent very high sales price is a strong incentive to replant vanilla.

Pepper is the least frequently planted cash crop. It was only present in two AFS, with an average of ten plants in each. The majority of the plants were introduced recently, and pepper is not considered as a major source of cash for farmers as prices remain low and the value chain in the district is poor.

Also, according to Dandoy (1973), sugar cane was reported to be almost abandoned, yet in 2016 it was still present although often only in a small patch cultivated in an AFS or another *tanety* for alcohol production. It is doubtful whether sugar cane will continue to be cultivated in the future because the uses that

Betsimisaraka made of it, particularly for the production of *betsa betsa*, a fermented drink shared during the ceremonies of commemoration of the dead, are progressively disappearing.

Some farmers diversify their AFS with other cash crops, cola (*Cola acuminata*), ravintsara (*Cinnamosma madagascariensis*), pink berries (*Schinus terebinthifolius*), or honey. However, this concerns only a minority of those we interviewed, and production remains negligible due to the absence of a market in the district.

The agroforestry systems: the new source of wood

The disappearance of forest, already very advanced in 1966, was complete in 2016. However, it should be noted that the supply of wood for construction or fuel for both family consumption and for distilling clove oil did not appear to be problematic in 1966 (Dandoy 1973). Today, wood resources mainly originate from AFS.

Wood as a source of energy has several origins: cultivated species including old fruit trees that are no longer productive or dedicated "firewood" species such as eucalyptus (*Eucalyptus robusta, Eucalyptus camaldulensis*). These species were introduced in Madagascar very early, during the nineteenth century (Verhaegen et al. 2011), as they provide the best quality wood. Firewood can also be collected in areas where *Grevillea banksii* thrives, an easily dispersed species that was introduced in Madagascar and is today considered as a weed (Tassin et al. 2009).

The total volume of wood consumed in a year varies with the number of people in the household, the presence of animals and the number of distillations for the production of clove oil. The quantity of wood used for cooking was difficult for the respondents to assess, which explains the significant differences reported: from 2 and 10 m^3/person/year. This is an average and does not include farmers who reported high consumption due to a particular activity, such as distilling other products or activities involving cooking (selling cakes in particular). Indeed, farmers who give cooked products (tubers) to their pigs, also consume more wood. The volume of wood used for cooking by all farms was much higher than that used for distilling.

Regarding timber, the species used depend on the type of building required and some of these species are native. For the construction of a traditional home, the most frequently used species was and is still Bamboo, which confirms its importance in Betsimisaraka regions (Decary 1962). Another common species is ravenale (*Ravenala madagascarensis*) which is used for roofing huts, among other things (Rakotoarivelo et al. 2014). Other species can be used to make round poles, the main species being *tsipatika* (*Streblus dimepate*), *ampaly* (*Streblus mauritianus)* and *hintsina (Intsia bijuga*). Eucalyptus and pine, introduced species, provide the best quality wood, and are preferentially used for the construction of concrete houses.

The development of cash crops-based agroforestry: a way of reforest degraded land or a driver to more forest conversion?

The transition from the shifting cultivation to cash crops-based agroforestry is closely dependent on the environmental and socio-economic local conditions. This explains why the agriculture of many other Malagasy regions, that do not benefit from the same climatic and ecological conditions and marketing infrastructure as the northeast coast, remains a subsistence agriculture based on the production of irrigated and rainfed rice, cassava, maize, and small-scale livestock (Dabat et al. 2008). In the northwest of Madagascar, the conversion of primary forests and fallow seems mainly driven by the farmers' need to acquire new lands for food production and the saturation of the lowlands to the production of irrigated rice (Ramboatinana et al. 2018). The same study reports that the first slash and burn of forests and fallows made by farmers is intended for food crops, mainly rice, and not for cash crops (vanilla and coffee). However, the decision to convert to cash crop systems remains possible only if households have sufficient land available and the market price of produce increases. In another district of Analanjirofo region, Andriatsitohaina et al. (2020) show through their land-use decision modeling approach that the farmer's objective to cultivate more cash crops lead to maintain and further develop mixed agroforestry systems. Apart from factors related to household strategies, the study reveals that institutional decisions, as the establishment of a protected area, also influence farmers' land use decisions. These studies confirm that the priority for households remains the cultivation of food crops and it is this objective that leads to deforestation rather

than the cultivation of cash crops. These studies and our findings seem rather converge towards the idea that the development of cash cash-based systems by smallholders' farmers could contribute to restore degraded land through agroforestry practices.

The gradual change from a shifting cultivation for food production to cash crop-based agroforestry has also been reported in Indonesia (Aumeeruddy and Sansonnens 1994; Hariyadi and Ticktin 2012). Although these studies do not explicitly describe the drivers of this shift, they show how agroforestry with cash crops has become a way for farmers to continue supporting a growing agricultural population while land is shrinking due, in these cases, to the establishment of a conservation park to preserve biodiversity by stopping extensive agriculture. In Madagascar, as the establishment of protected area is often driven by decisions at the government level, i.e. ignoring the socio-ecological context, the development of cash crops in agroforestry is not perceived by farmers as an opportunity to adapt to the lack of lands and others environmental and economic changes.

Conclusion

The observed changes in cropping systems and local land use in the Vohibary landscape are evidence for the continuous adaptability of farmers to political, economic or environmental changes. The changes we describe in the small agricultural landscape of Vohibary apply across the whole Analanjirofo region. They are part of a historical trend whose determinants have been the global political and economic context, the population growth, and the degradation of environmental conditions. Local variations in farmers' strategies had three main drivers. Firstly, the introduction of cash crops contributed to the monetization of farming systems either for sale on the local market or for export. Secondly, cropping systems were intensified in response to the 3% annual increase in population, which resulted in the generational fragmentation of land plus increased pressure on land, and the introduction of cash crops, which monopolized a significant proportion of the labor force and resulted in the abandonment of traditional *tavy* rice cultivation. Thirdly, crops were diversified to supplement insufficient rice production and to ensure a regular income, which resulted in diversification of production for export (vanilla, lychees, cloves and/or clove oil) or for the local market (fruit, possible surplus rice, tubers). Complementing the works of Arimalala et al. (2019) and Michel et al. (2021), our study shows that cropping systems in general, and AFS in particular, not only change in space and over time but also in their function, as also described by Nair (1985) and Torquebiau (2000).

The specificity of Vohibary, and more generally of the east coast of Madagascar, is that changes in farming systems were imposed by a strong administrative power whose objective was to supply export sectors by developing industrial crops. It established the means to do so by building the necessary infrastructures (port of Tamatave, Pangalanes canal) to ensure the transportation and export of agricultural products from the East Coast to the metropolis (Salomon 1982). The situation of the Malagasy East Coast is however not unusual and applies to other colonial contexts at the beginning of the twentieth century, particularly to colonies belonging to Great Britain and France. They forced the development of what were then referred to as "colonial crops" in indigenous farming systems in order to feed supply chains destined for metropolitan areas (Volper 2011). The agricultural dynamics described here concern coffee and cloves in Madagascar, but it applies, *mutatis mutandis*, to cloves in Zanzibar (Conte 2019), to cocoa in Africa (Rice and Greenberg 2000; Schroth and Harvey 2007; Jagoret and al. 2011) and to rubber in Southeast Asia (Penot 2001), but also to Malagasy vanilla, Senegalese peanuts, Malian cotton, oil palm and bananas (Volper 2011), whose history sometimes remains to be written to trace the long-term trajectories of cropping systems and to clarify farmers' current strategies.

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