POTENTIALITY OF EUCALYPTUS PLANTATIONS IN THE DISTRICT OF ANJOZOROBE IN TERM SUSTAINABLE WOODENERGY PRODUCTION

RAKOTONIASY Jean Raymond
Student in Doctoral School in Natural Resources Management and Development, University of Antananarivo, Madagascar

ABSTRACT

The city of Antananarivo is supplied with fuelwood mainly from peasant forest eucalyptus plantations. Anjozorobe district is among the top three districts contributing their share in the capital wood fuel supply. This study aims to assess the potential of peasant eucalyptus plantations in Anjozorobe district for a sustainable supply of fuelwood. The methods adopted are mapping and analysis of forest inventory data. The results show an exploitable area of 14 378 ha in any district in 2018. An increase in eucalyptus plantations of 374 ha per year has been observed in 12 years, an increase of 7% per year. In total, the surface gains are estimated at 4 488 ha in 12 years. For coppices, 3675 individuals were observed during the inventory. The mean diameter of the coppice stands was estimated to be 4.69 ± 0.18 cm. Over 95% of the individuals were individuals in the diameter class between 0 to 10 cm. The trend of the number of stems per diameter class shows a regular decrease in the number of stems when moving from one diameter class to the next. This shows a good state of natural regeneration of the eucalyptus coppice plantations.). This also explains at the same time an intensive exploitation of the stands with a shortening of the duration of the cutting rotation. In the face of the current population growth and urbanization, recovery measures are essential.

Keyword : *energy wood, stand, diameter, plantation*

Introduction

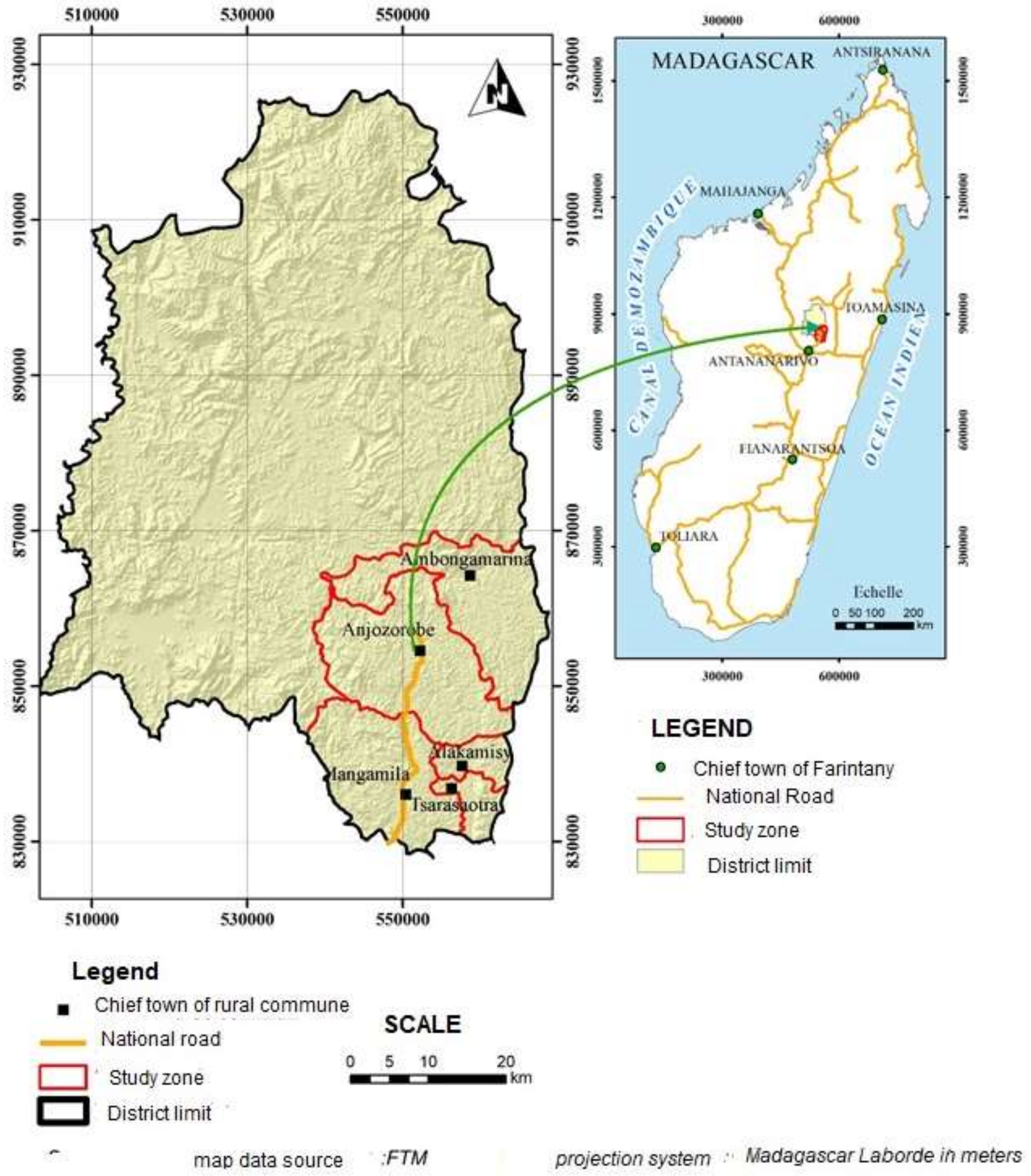
Access to energy is an essential component of economic, social and political development. It is therefore an absolute priority for sustainable development (Valensisi, 2018). Wood plays a fundamental role in access to domestic energy in developing countries. In view of population growth, the population dependent on solid fuels, especially fuelwood, has grown steadily over the past three decades (Madon, 2017). But the excessive exploitation of wood energy to meet growing demand from rural and urban areas is one of the causes of deforestation. Indeed, deforestation in Madagascar continues to increase (ONE et al, 2015). Some 200,000 hectares disappear each year due to: (i) overexploitation for fuelwood, fuelwood, timber and construction wood needs; (ii) land clearing for the use of food and cash crops; and (iii) bush fires, accidental or not (Bernard et al, 2015). Forest plantations play an important role in reducing pressure on natural forests.
The city of Antananarivo is supplied with fuelwood mainly from peasant forest eucalyptus plantations (Bertrand et al, 2010). Anjozorobe district is among the top three districts contributing their share in the capital wood fuel supply. For all these reasons, we carried out a study of eucalyptus reforestation in the district of Anjozorobe in order to estimate the potential of peasant plantations for a sustainable supply of fuelwood. The objective of the study is to assess the spatiotemporal evolution as well as the structural characteristics of eucalyptus stands.

1. Materials and methods

1.1. Presentation of the study area

The district of Anjozorobe is located in central Madagascar 90 km north of the capital along the RN3 national road. It is located between the following geographic coordinates: Latitude: 506.564 South, Longitude: 830.927 East. It covers 368 400 hectares; its area is 3684 km2. Specifically, our area of intervention is located in five municipalities, namely the rural municipalities of Mangamila, Tsarasaotra, Alakamisy, Ambongamarina and Anjozorobe.

The climate is tropical in altitude. The annual average temperature is 18.3 ° C, with a maximum in December (20.9 ° C) and a minimum in July (14.1 ° C). The region receives an average of 1237 mm of rain annually, spread over 119 days. The soil is ferralitic with red yellow to dark brown horizons. The soil is acidic (ph between 5.15 to 6.19), generally rich in Nitrogen with a sandy loam texture and lumpy structure.



Map 1: Location of the study area

1.2. Methods

a) *Cartographic*

The purpose of the analysis of the mapping data consisted in (1) delimiting the forest plantations in order to determine the exploitable surface of the plantations for the year 2018, (2) to assess the spatiotemporal evolution of the plantations between 2007, 2011, 2015 and 2018. The various analyzes come from the use of SPOT 5 and LANDSAT 5 satellite images. The multi-date satellite images used are provided by USGS (years 2005, 2007, 2011, 2015, 2018 and 2016). They have the spatial resolution of 30 m for Landsat 5, 10 m for Spot 5 (table 1)

Table 01: Description of the characteristics of satellite images

Satellite	Bands	Resolution	Date of acquisition
Landsat 5	7	30 m	22-04-2007
Landsat 5	7	30 m	26-10-2011
Sentinel-2	13	10 m	29-09-2015
Sentinel-2	13	10 m	04-08-2018 09-08-2018
SPOT 5		10m	03-06-2005

For the evaluation of the spatiotemporal evolution of the plantations between 2007, 2011, 2015 and 2018, all the maps showed good precision and excellent kappa indices. The maps thus obtained can therefore be used for all subsequent analyzes.

Table 02: Result of image classification: 2007, 2011, 2015, 2018

	2007	2011	2015	2018
Indice de Kappa	0,8945	0,9027	0,916	0,9045
Overall Precision	91,67	92,5	93,33	92,5

b) *Data collection*

Fieldwork was carried out in August and September 2018. The teams were provided with equipment such as a GPS, a 30-meter or 50-meter metallic tape measure, a 5-meter long measuring tape, a 80 meters with nodes every 20 meters and office supplies for data recording.
The inventory data collection method was ensured by sampling because of the large scale in relation to the time and means available of the area of the plantations in the district. The sampling unit was 20-meter x 20 meter square plots with a single compartment.
The calculation of the sampling intensity (the number of sampling plots to be carried out in a forest stand) was estimated via a pre-inventory undertaken at the level of five (5) communes using the following formula (Riba, 2019)

$$n = \frac{t^2CV^2}{E^2 + \frac{4CV^2}{N}} \quad (1)$$

n = number of sample plots, t = Student's t (statistical estimator).
In forest inventories, t = 2 for a confidence level set at 95%,
CV = Coefficient of variation, E = maximum admissible relative error (depends on the management objective),
N = total number of plots in the population (sample area).

34 plots spread over the five communes were established, making a sample size of 1.36 hectares. This number was found to be representative considering the coefficient of variation of the basal area at 20% and a maximum permissible error of 15% even though the sampling rate seems low, ie 0.014%. The choice of the inventory plot was made randomly stratified. First, the population was stratified by study sites and then into two strata (coppice and high forest) by site according to the nature of the stand. Five of the most wood-fueled rural communes in Anjozorobe district were considered as study sites.

Table 03: Distribution of plots and surface area of sites

N°	Study sites	Nb coppice plot	coppice area (ha)	Nb high forest plot	area high forest (ha))	Area total (ha)
1	Tsarasaotra	3	0,12	1	0,04	0,16
2	Mangamila	10	0,4	2	0,08	0,48
3	Anjozorobe	5	0,2	4	0,16	0,36
4	Alakamisy	3	0,12	1	0,04	0,16
5	Ambongamarina	3	0,12	2	0,08	0,20
	Total	**24**	**0,96**	**10**	**0,40**	**1,36**

Structural surveys were carried out in the plots by measuring their diameter at 1.30 m from the ground, their maximum height and the height of their barrels. This method allows to characterize the distribution according to the classes of diameters, to evaluate the specific diversity, the density of the stand, as well as the earth surface and the biovolume

c) Analysis of forest inventory data

Vegetation structure was determined by parameters such as density, basal area, average diameter, height and distribution of individuals by diameter classes. Density is the number of stems counted per hectare. Basal area is the sum of the cross-sections at 1.30 m from the ground of the individuals in the stand. It is related to the hectare and expressed in m²/ha.

The importance value of an IVI species (Curtis & Macintosh, 1950) is a quantitative index that identifies ecologically important species in a plant community (Adomou et al., 2009). It ranges from 0 (no dominance) to 300 (mono-dominance).

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The relative dominance of a species is the ratio between is basal area on all plots and the total basal area of all species. The relative frequency of a species is the ratio between its specific frequency and the total of the specific frequencies of all species (Adjonou et al, 2016).

Ces paramètres ont été calculés avec les formules énumérées ci-dessous :

$$D = N/S \qquad (2)$$

D : Density; N : total number of tree stems / plot ; S : plot area in ha.

$$G = \pi/4 \sum_{i=0}^{n} di^2 \qquad (3)$$

G= basal area of each tree (m^2/ha), di= diameter of each

$$V = 0{,}53 \times gi \times hi \qquad (4)$$

V : volume of the tree , 0,53 : shape coefficient of the tree
gi : basal area or basal surface of tree, **hi** : total height of the tree

$$IVI = Fr\% + D\% + Do\% \qquad (5)$$

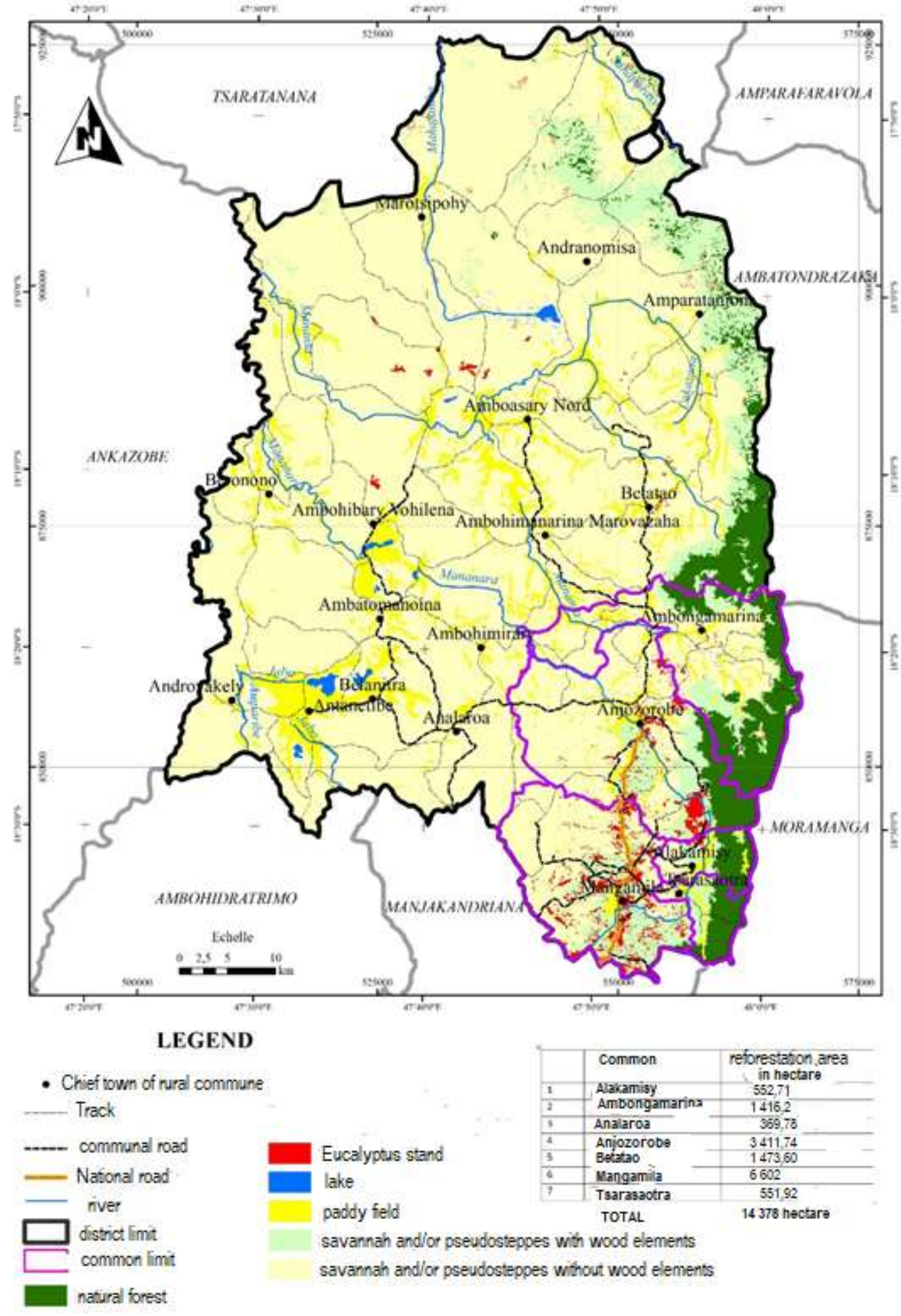
Fr : relative frequency, D : relative density and Do : relative dominance.

d) Statistical analysis

The analysis of variance (ANOVA) allowed a comparison of the means of the diameters at 1.30 meters from the ground and the stand heights in the different sites (communes), with a significance level of 5%.
The Multiple Correspondence Analysis (M.C.A.) allowed to study the links that could exist between the variables diameter classes and the different planting sites as well as the stand varieties (coppice or high forest). XLSTAT and SPSS were used for the different statistical analyses.

2. Results

2.1. Mapping of Eucalyptus Plantations in Anjozorobe District

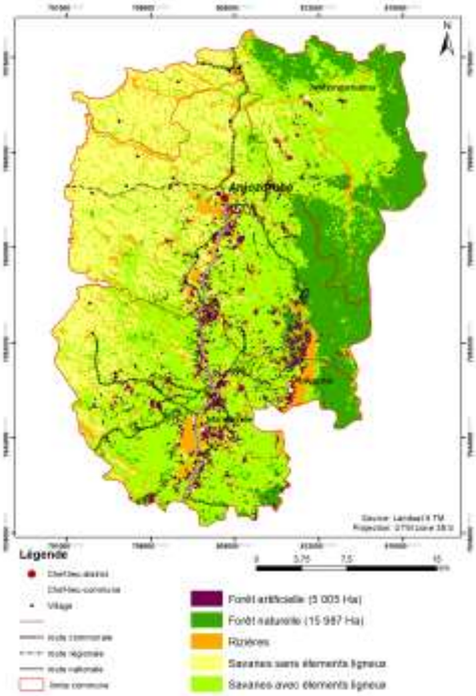


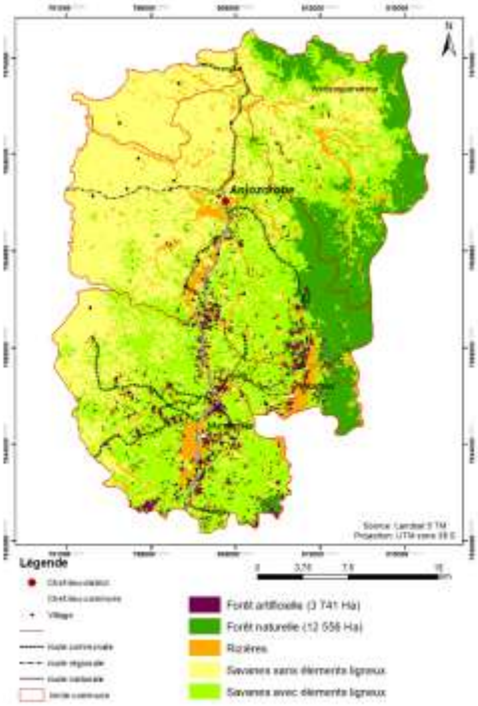
	Common	reforestation area in hectare
1	Alakamisy	552,71
2	Ambongamarina	1 416,2
3	Analaroa	369,78
4	Anjozorobe	3 411,74
5	Betatao	1 473,60
6	Mangamila	6 602
7	Tsarasaotra	551,92
	TOTAL	14 378 hectare

Map 2: Mapping of eucalyptus plantations in Anjozorobe District in 2018

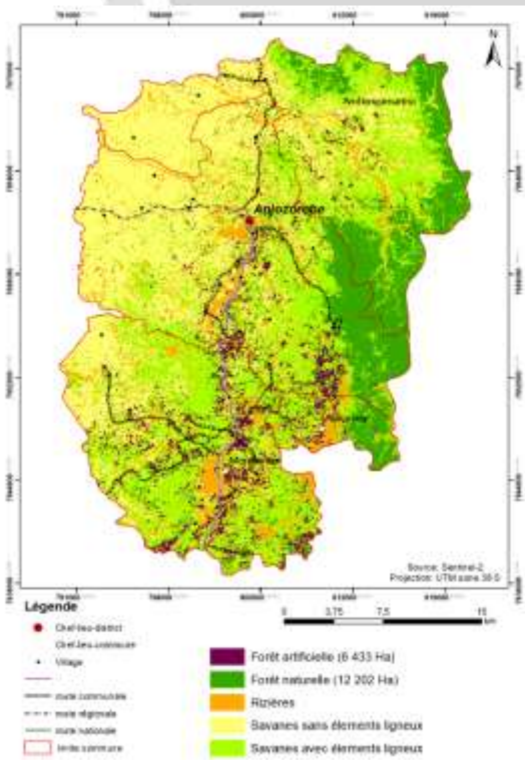
The result of eucalyptus plantation mapping showed a usable area of 14 378 ha in any district in 2018. This surface is distributed in different communes, namely: Mangamila (6602 ha), Anjozorobe (3411.7 ha), Betatao (1473.6 ha), Ambongamarina (1416.2 ha), Alakamisy (552.7 ha), Tsarasaotra (551.9 ha) and Analaroa (369.8 ha). Eucalyptus stands are concentrated in the southeastern part of the district (Map 2). An extrapolation of the study carried out by RANDRIANJAFY shows that 95% of the eucalyptus plantation area on the Anjozorobe-Manjakandriana-Tsiazompaniry axis is coppice, only 5% is coppice (Randrianjafy, 1999), i.e. 13 659.100 ha of coppice in any one district.

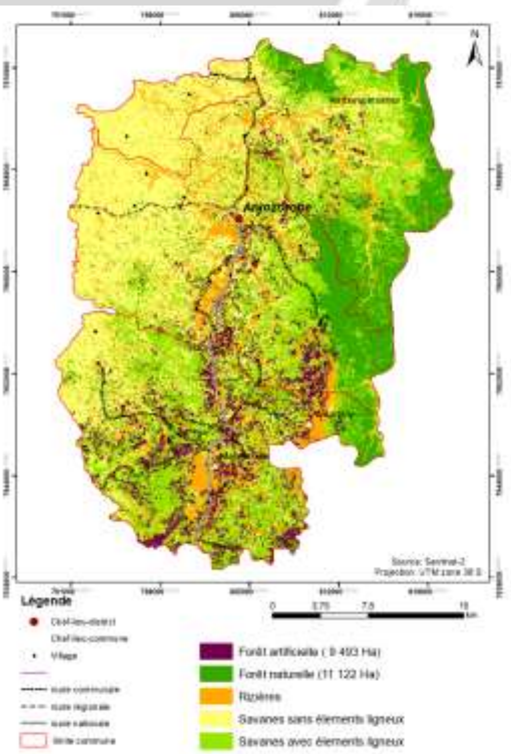
2.2. Spatial and temporal evolution of plantation areas between 2007, 2011, 2015 and 2018





Map 3 : Mapping of the 2007 study area **Map 4 : Mapping of the 2011 study area**





Map 5: Mapping of the 2015 study area **Map 6 : Mapping of the 2018 study area**

The determination of the spatiotemporal evolution of the surfaces of the plantations was carried out in the five rural communes where the inventory was carried out, namely Ambongamarina, Anjozorobe, Mangamila, Tsarasaotra and Alakamisy. In 2007, the surface area of eucalyptus plantations in these five wood energy producing communes was estimated at 5004.99 hectares. In 2018, this area was estimated at 9,493.62 hectares, a gain of 4,488 hectares. An increase of 374 ha per year has been observed in 12 years, i.e. an increase of 7% per year. Total area gains are estimated at 4,488 ha in 12 years. As regards natural forests, the study reveals losses in area of about 4865 hectares in 12 years, i.e. a loss of about 400 hectares per year.

Table 04: Spatial and temporal evolution of plantations in the five communes

Years	2007	2011	2015	2018
Area (ha)	5 004,99	3 740,67	6 432,99	9 493,62
Surface gain or loss (ha)	0	-1264,32	2 692,32	3 060,63
Total area gains and losses in 12 years (ha)				4 488,63

2.3. Structural characteristics of plantations

In general, there are only two species of eucalyptus in artificial plantations: Eucalyptus robusta and Eucalyptus rostrata. 34 plots of 20 m * 20 m were inventoried in coppice and high forest plantations (26 coppice, 8 high forest). The high forests belong either to the State or to private property.

2.3.1. Overall structure of Eucalyptus stands (coppice and high forest)

A number of dendrometric criteria such as abundance, dominance, content and distribution according to diameter classes were noted in order to characterize the stands.

a) Stand abundance, dominance and capacity

4285 individuals were inventoried in eucalyptus plantations. Diameter classes at 1.30 m from the ground were used as a basis for characterization instead of species because the object of the inventory consisted only of eucalyptus plantations.

In terms of abundance, 2773 individuals or 2038 individuals per hectare were composed of individuals with diameters between 0 and 5 cm. More than 95% of the individuals were composed of individuals in the diameter class between 0 to 10 cm.

In terms of dominance, individuals in the 5 to 10 cm diameter class predominated with a basal area of about 3.26 m² per hectare, followed by individuals in the 0 to 5 cm diameter class with a basal area of about 1.69 m² per hectare. In general, high diameter individuals have a low dominance.

In terms of capacity, 5-10 cm diameter class individuals prevailed (42.37 m3 per hectare) followed by 0-5 cm diameter class individuals. In general, individuals of small diameter classes predominated in terms of volume.

The maximum diameter was around 97 cm, and the maximum height was 20 meters.

b) Overall stand density (coppice and high forest)

The diameter class with the highest density was the class below 5 cm (64.71%) with an estimated density per hectare of 2,038.97. Individuals with diameters less than 10 cm presented almost all the stands (more than 90%). Individuals in large diameter classes were very poorly represented.

The pattern of the number of stems per diameter class shows a steady decrease in the number of stems when moving from one diameter class to the next. There are many more small woods than medium woods, and more medium woods than large woods. The distribution of individuals by diameter class shows a histogram with a classic inverted J shape.

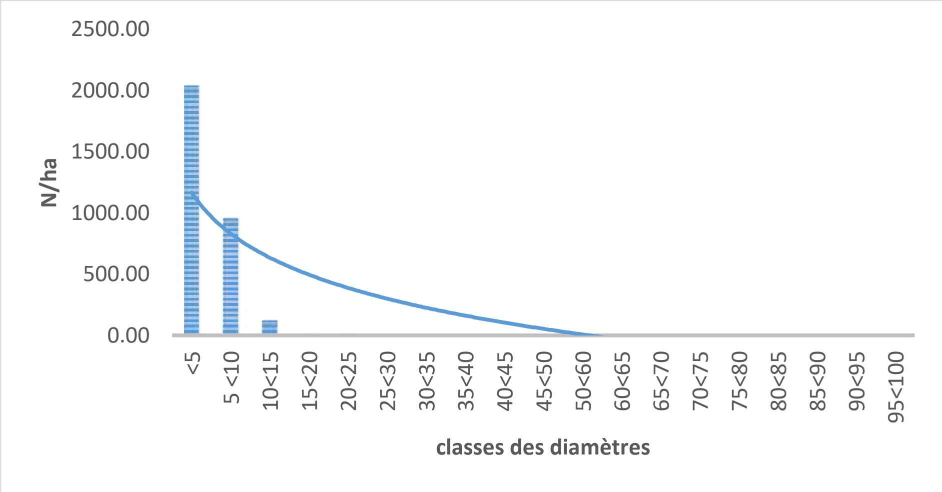


Figure 01 : Global distribution of individuals by diameter class

2.3.2. Structural Characteristics of Coppices

This study only concerns coppice stands because the production of wood energy is carried out only with coppice stands. Since the forest stands are intended for the production of COS wood, they were not included in this study.

a) Linking study that could exist between diameter classes, stand categories and different sites.

A Multiple Correspondence Analysis (MCA) allowed to study the links that could exist between the diameter class variables at 1.30 metres from the ground of the woodland and the different planting sites at the level of the communes as well as the varieties of the stand (coppice or high forest).

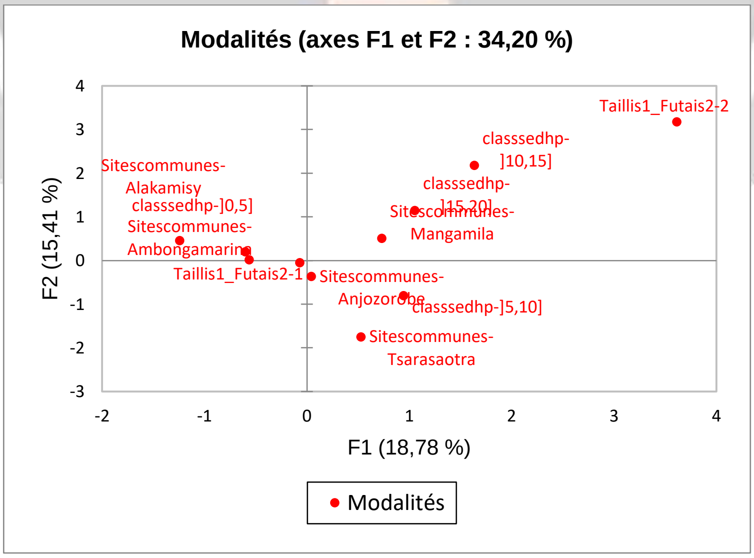


Figure 02: Relationship between diameters and communal sites

On the F1 axis, there is a clear discrimination between the low diameter class (left) and the medium and high diameter classes (right). The sites in the commune of Alakamisy and the commune of Ambongamarina are close to the low diameter class, while the sites in the commune of Mangamila, Anjozorobe and Tsarasaotra are predominant factors in the medium and large diameter classes.

Looking at the graph on the F2 axis, it is noted that there is a discrimination of the large diameter classes: 10.15] cm and]15.20] cm (top) with the medium diameter class]5.10] cm (bottom). Modalities close to high diameter classes are the sites in the commune of Mangamila, while modalities close to medium diameter classes are the sites of Anjozorobe and Tsarasaotra.

b) Average coppice diameters

For coppices, 3675 individuals were observed during the inventory. The comparison of mean diameters by commune was carried out as part of the analysis of variance (ANOVA). The Fisher's F test was used. The stand at the Alakamisy site showed the smallest mean diameter: 2.30±0.16 cm). The highest value was observed in the Mangamila stand (5.89) and in Tsarasaotra (5.69 ± 0.164). The mean diameter of coppice stands was estimated at 4.69±0.18 cm. (F=332.9; p<0.0001)

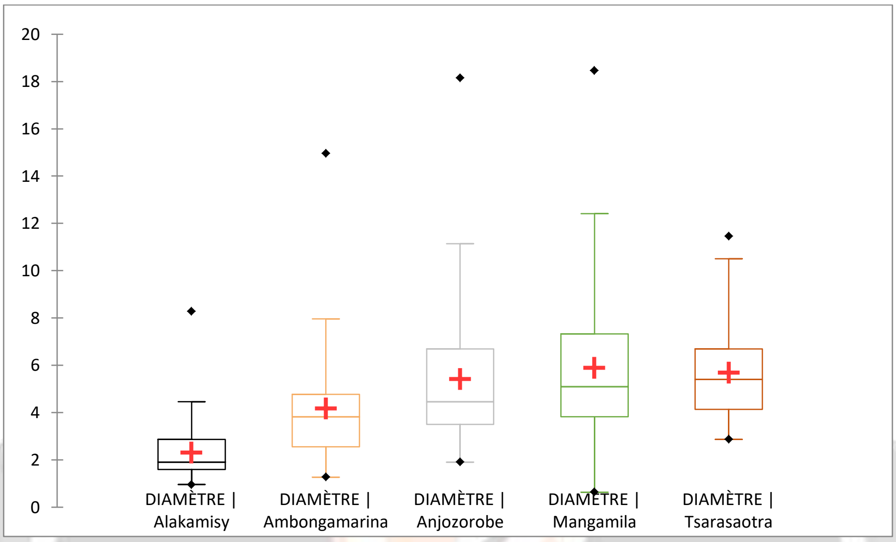


Figure 03: Average diameter of coppice stands by site

c) Distribution of diameter classes

For coppice, the distribution of diameter classes across the study sites produced a classic inverted "J" curve (Figure 04). Most individuals were in the 0-5 cm class: 97.3% at Alakamisy, 76.8% at Ambongamarina, 58.4% at Anjozorobe, 50.9% at Mangamila, and 39.3% at Tsarasaotra sites. In the last two sites (Mangamila and Tsarasaotra), all diameter classes of 0-5 cm and 5-10 cm had a frequency of 89.1% and 95.1, respectively. (Figure 04).

d) Distribution of coppice total height classes

The distribution of total height classes across all sites showed that the total height class below 10 meters accounted for more than 80% of the individuals. For each site, the same total height classes predominated. At the Alakamisy site, almost all individuals inventoried were classified in the total height class between 0 and 5 meters. The distribution of total height classes in the study sites produced a classic inverted J curve (Figure 05).

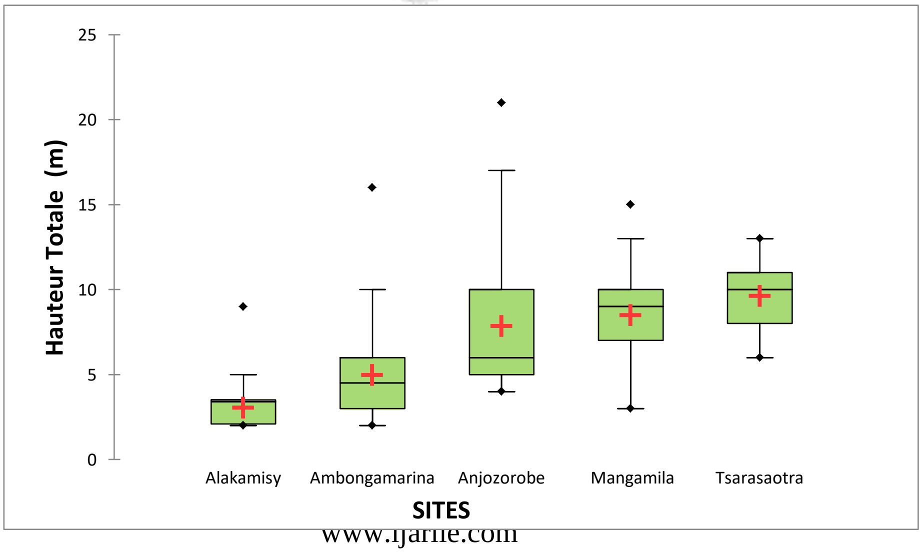


Figure 05: Box plot of the means of the total heights of stands by site

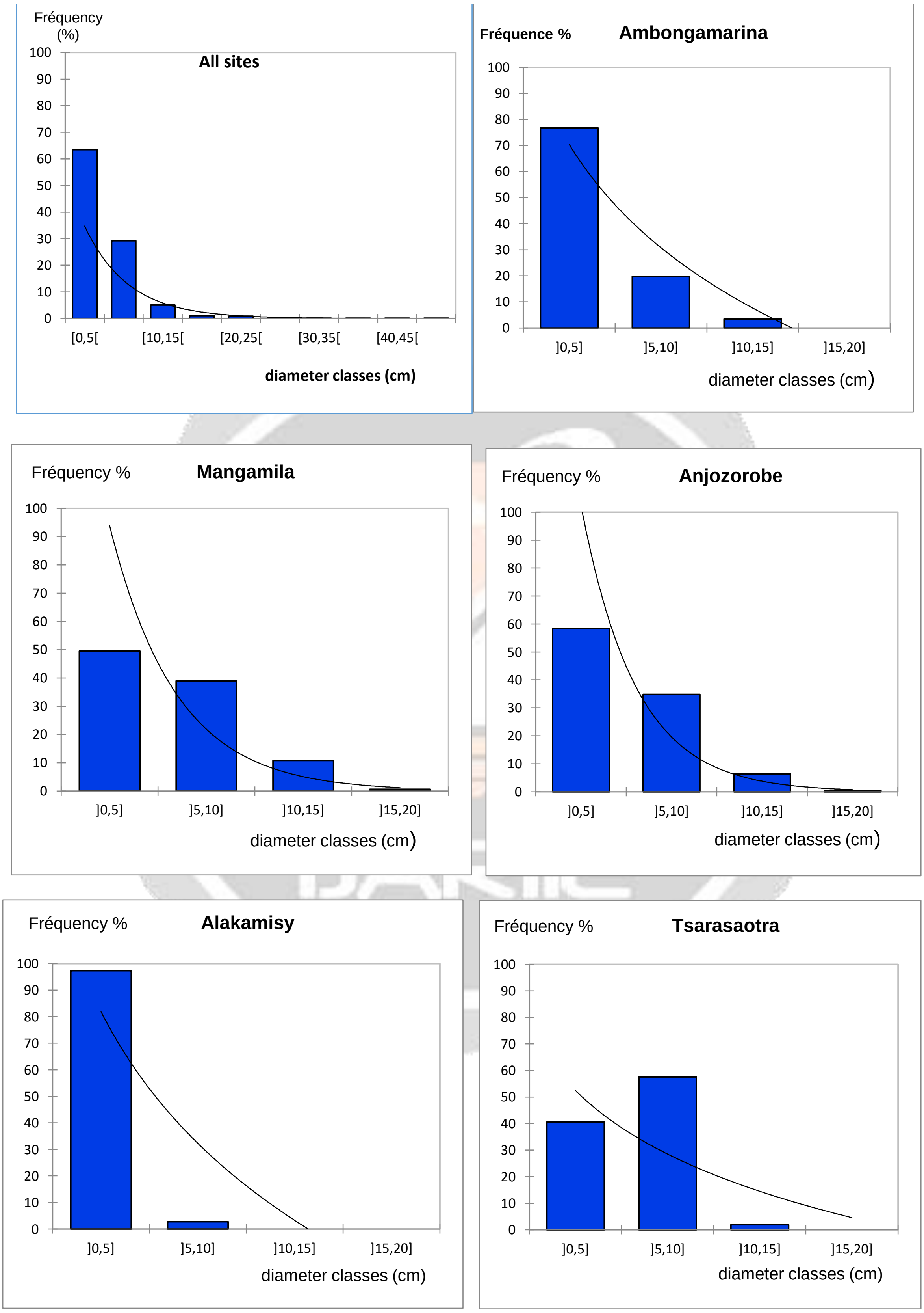


Figure 04 : Distribution of coppice diameter classes by site

The average total stand height at all sites was estimated at 6,730 metres with a standard deviation of 3,336. The minimum total stand height was 2.0 metres, the maximum height was 21.0 metres (Figure 05).

Comparison of the mean total heights of the study sites according to the ANOVA with the Tukey pair comparison test showed a significant difference in the means between the different sites with a significance level alpha of 0.05 (p<0.0001) The highest mean heights were observed at Tsarasaotra (9.609 ± 0.206) and Mangamila (8.493 ± 0.128), the lowest was at Alakamisy (9.609 ± 0.206) and the highest at Mangamila (8.493 ± 0.128).

e) Density, basal area of coppice stands by sites

In terms of density, Alakamisy (N=6,433 ind/ha) and Ambongamarina (N=4,808 ind/ha) had the highest density. The lowest density was observed at the Anjozorobe site. In terms of basal area, the Mangamila site represented the best basal area (4.38 m²/ha). Ambongamarina, Anjozorobe, and Tsarasaotra showed almost the same basal area of 1m²/ha. (Table 05).

Table 05: Density, basal area of coppice by sites

N°	Study site	Number of coppice plot	coppiced area (ha)	N (individu)	N (individu/ha)	Average Gi (m²/ha)	G (m²/ha)
1	Alakamisy	3	0,12	772	6 433	0,000482	0,3726314
2	Ambongamarina	3	0,12	577	4 808	0,001702	0,9818433
3	Anjozorobe	5	0,2	485	2 425	0,002781	1,3488503
4	Mangamila	10	0,4	1360	3 400	0,003224	4,3845204
5	Tsarasaotra	3	0,12	481	4 008	0,002679	1,2885091
	Total	**26**	**1,04**	**3675**	**3 534**		

f) Value of importance relative to coppice stand diameter classes at all sites.

Eucalyptus coppice plantations in the study area were characterized by a predominance of individuals in diameter classes between 0 to 5 cm and individuals in diameter classes between 5 to 10 cm (Table 06).

Table 06: IVI of coppice stand diameter classes at all sites

Diameter classes	N (individu)	Average Diamètre (cm)	Relative Fréquency (%)	Relative Density (%)	Relative Dominance (%)	IVI
[0,5[	2346	3,17	63,84	63,84	2,09	129,76
[5,10[	1112	6,76	30,26	30,26	9,52	70,04
[10,15[	207	11,76	5,63	5,63	28,76	40,02
[15,20[	10,00	16,93	0,27	0,27	59,63	60,18
Total	**3675**	**9,66**	**100**	**100**	**100**	**300**

3. Discussion

Two main conclusions can be deduced from these results: first, the area of the plantations is increasing; second, the structures of the plantations are characterized by a predominance of small-diameter individuals;

3.1. Discussion of the methodology

Concerning the cartography, the image processing with Landsat 5, Sentinel 2 and Spot 5 was done with a better resolution and excellent kappa indices. Nevertheless, classification biases could occur throughout the study. There is also the fact that a series of Landsat was evoked as part of a group of medium resolution satellites (Antoine L. et al, 2015). This lack of resolution performance could lead to information bias as some pixels on the map may have been misclassified. However, with the very good accuracy and resolution as well as the excellent Kappa index, the mapping results seem to be plausible. It should be noted that no information corresponding to the mapping of plantations in any district of Anjozorobe was found in the available documents. This investigation could then serve as a basis for further study in this direction.

Concerning the size of the sample for the forest inventory, compared to the sampling carried out within the framework of the study of the potential for wood energy production of the ASA project, (2018), this sampling remains plausible. In this study, a forest inventory by sampling was conducted in order to know the wood resources available for wood energy production in the city of Antananarivo in the ten (10) intervention districts over a total area of 1,854,039 ha. To do so, 86 clusters each consisting of five (5) 30 m*30 m square plots were established. The sampling rate appears low, i.e. 0.002% on average. On the other hand, the present study established 34 plots of 20 m*20 m in a total plantation area of 14,378 ha in any district in 2018, i.e. a sampling rate of 0.014%.

3.2. Discussion of results

a) *Concerning the surface area of the plantations*

The exact area of forest plantations located in the region is a matter of debate. In 2014, based on published data (FAO, 2010; Randrianjafy, 1999), it can be estimated that 235,000 hectares have been reforested with eucalyptus, 140,000 of which are around Antananarivo. In the Analamanga region, several bibliographic sources provide values between 64,176 and 120,000 hectares (ASA, 2018; Randrianjafy, 1999). In this study, the area of plantations was estimated at 14,378 ha in any one district in 2018 and 9493.62 ha in the five communes where the inventory was carried out. These results seem to be the most plausible because only within the framework of the ARINA project, an energy-oriented reforestation of 2,593 ha was carried out and supervised between 2015 and 2019 in the communes of Ambongamarina and Betatao (ASA, 2018) and according to the Haririsoa study (2016), only the area of Mangamila was estimated at 7,973 ha in 2015. The credibility of Haririsoa's result is observed through direct observation because the commune of Mangamila is among the rural communes with more surface area of eucalyptus plantations compared to other communes in any district of Anjozorobe. These plantations are certainly the fruits of earlier reforestation.

b) *Concerning the dynamics of the plantations*

In the case of this study, an increase of 374 ha per year was observed in 12 years, an increase of 7% per year. These results are similar to those of Haririsoa in 2016, which revealed an increase of 1 to 3% in the area of plantations in the rural commune of Mangamila between 2003 and 2015. On the other hand, a decrease in the plantation area was observed between 2007 and 2011. This situation is in line with the result of Rakotomavo (2018) which spread out a high production of charcoal during the post-crisis political period of 2009 according to which the proliferation of corruption and illegal exploitation of plantations was completely uncontrollable by the authorities.

This dynamic of plantations comes from the characteristic of coppicing, which is a forest stand made up of stump sprouts. The benefits of the natural regeneration of coppice encourage farmers to develop this crop. Moreover, the exploitation of a plot of eucalyptus does not require much investment. On the other hand, a plantation can produce for nearly a century by being exploited every 3 or 4 years. There is also the motivation of the farmers to reforest in the hope of being able to conquer the plot they occupy. Eucalyptus plantations have always appeared to be both a particularly economical way of developing the land, and thus of gaining access to it, and an investment likely to yield a secure income at regular intervals of a few years (Bertrand, 1999). Moreover, the downward trend in timber prices, the growth of the rural population, and the need to maintain their subsistence income is pushing farmers to expand their plantations.

At the international level, an expansion of the areas occupied by forest plantations is in fact increasing on all continents, the largest areas being observed in the United States of America, China and Brazil. In Africa, the area occupied by plantations has increased to nearly 5 million hectares: they occupy 3.7 million hectares in Oceania and 2.0 million hectares in Europe (Tchichelle, 2016). While between 1990 and 2015, the percentage of global forest cover decreased from 31.85% to 30.85%, that of planted forests increased from 4.06% to 6.95% (Bouvet et al, 2019).

c) *Concerning the structural characteristics of the stands*

The curves of the diameter distributions show that the majority of the plantations have diameters less than 10 cm. This is explained by the good state of natural regeneration of eucalyptus coppice plantations (Rajemison, 2010; Agbodjogbe, 2011). This analysis is confirmed by the general pattern of the histogram of diameter classes is in the shape of an inverted 'J', which is typical of a forest with good regeneration capacity (Nusbaumer, 2003). According to Bouko et al (2007), such a diameter distribution would reflect a state of equilibrium in an environment, which implies good natural regeneration (Puig, 2001). This situation shows a good experience of farmers as well as a good local ecological condition in terms of reforestation. Indeed, reforestation is very active, especially in Mangamila. The population reforests every year at the beginning of the rainy season. The surface area of plantations increases by 1 to 3% each year and reaches up to 180 ha per year for Mangamila (Haririsoa, 2016). This also explains at the same time an intensive exploitation but also a form of transition to thickets. After a first cut generally made between 7 and 8 years after planting, the cuts are in fact made every 4 or 5 years or even every 3 years. The owners thus privilege the search for the most regular and frequent income possible.

4. Conclusion

In this study, our initial hypothesis that "the potential of plantations in Anjozorobe District in terms of wood energy productivity is declining" is refuted. Nevertheless, the shortening of the cutting rotation reduces the productivity of the plantations. Moreover, the population growth and urbanization that is currently taking place will further lead to over-exploitation of peri-urban forest resources for charcoal production. This available potential could be overtaken by the growing demand for wood energy in the medium term. Recovery measures are essential in order to play down the situation.

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