ASSESSMENT OF THE STATIONARY ABUNDANCE OF ZANTHOXYLUM ZANTHOXYLOIDES (LAM.) ZEPERNICK & TIMLER FOLLOWING THE CLIMATE GRADIENT OF BENIN (WEST AFRICA)

ABSTRACT

*Z. zanthoxyloïdes is a multipurpose plant. Therefore, it is under heavy user pressure in Benin. This study assessed the availability of this species and the ecological characterization of natural habitats that currently supports it. The inventory of **Z. Z.** zanthoxyloïdes was carried out in 120 square 50 m x 50 m plots on mega-transets in the Lama, Wari-Maro and N'Dali classified forests and fallows that surround them. Individuals of Z. zanthoxyloïdes were counted and breast height diameters (DBH) greater than 5 cm were measured with pi tape. The stationary abundance of the species between the three classified forests was compared with variance analyzes. The rarefaction index has also been calculated between habitats. The results show that adult and juvenile densities are significantly different between natural forest and surrounding fallow (p <0.0001). The distributions of the diameter classes showed a good fit with the Weibull distribution (p> 0.05). The density of adultZ. zanthoxyloïdes trees is higher in the Lama Classified Forest than in the other two. The study reported that fallows currently contain more young individuals than natural forests. The vulnerability of the species is therefore confirmed as previously reported by the Benin Red List. Thus, actions to assist its natural regeneration would be a necessary contribution to keep the species for present and future generations.*

Key words: *Z. zanthoxyloïdes*, abundance, density, fallow, protected areas, Benin.

Comment [1]: Write it in a correct way

Comment [2]: WhyOnly greater than 5cm?

Comment [3]: This word is mostly used for animals instead of plants, please use appropriate words. And also you said that measure only greater than 5cm, what about the smallest ones?

Comment [B4]: Wwhat are the mechanism that you used to classify adults juveniles? Age? Height or what?

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INTRODUCTION

In several developing countries, non-timber forest products (NTFPs) have long been underutilized. It was from 1995 that the need to domesticate them to increase the well-being of local populations became a major concern (Leakey *et al.*, 2005). Indeed, the information available on non-timber forest resources is most often qualitative and does not bring out the quantitative data necessary to demonstrate economic opportunities or for social development

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and environmental management (Codjia *et al.*, 2003). Among these NTFPs is Z. zanthoxyloids, which is a multi-purpose species. It is a plant on Benin's red list in the category of vulnerable species (Adomou *et al.*, 2011). Its roots are heavily marketed in Benin and even exported (Quiroz*et al.*, 2014). To this end, it deserves special attention for the implementation of conservation and domestication strategies in a context of climate change. A lot of work has been carried out to contribute to the enhancement of the species in the sub-region. However, most studies on this plant have only focused on its pharmaceutical value. Admittedly, some authors, in this case Adomou (2011), Guendéhou (2012) and Yaoitcha (2016) have addressed its ethnobotanical and ecological aspects, but it should be noted that the aspects of abundance and population structure have not been elucidated. This study addressed both aspects in order to have the scientific data to help make conservation decisions to ensure its sustainable use in Benin. Knowledge of the species' population structure is essential because it makes it possible to measure anthropogenic pressures on population dynamics (Sinsin et al., 2004) and is a crucial step in defining a conservation and sustainable management strategy for a species (GlèlèKakaï & Sinsin, 2009; Assogbadoet al., 2010; Sinsin, 2004; Bonouet al., 2009). Those related to Z. zanthoxyloides populations in Benin in general are not yet documented. In terms of the abundance of the species, its knowledge is useful in explaining how it is influenced by environmental conditions and anthropogenic pressures (Jacob et al. 2010). Thus, abundance is one of the very first pieces of information in the evaluation of the potential and availability of species (Avocevou-Ayisso, 2011). The present study, which will document the abundance of Z. Z. zanthoxyloids in the different climatic zones, will allow us to better appreciate the occurrence, the level of availability and the pressure and these data will make it possible to make suggestions for conservation action and sustainable exploitation. In doing so, the species will be conserved for current and future generations.

MATERIAL AND METHODS

A- Material

The material for this study is composed of biological material and field tools.

1) Biological material

It is Z. zanthoxyloides, which belongs to the Rutaceae family. It is a shrub 6 to 7 m high. The twigs are very armed with very curved and sharp prickles, claw-shaped, small or up to 1 meter long. The

Comment [B7]: Your background focus on NTFPs, is your study relate to it ? Please considère it or clear it!

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rachis and sometimes the midrib bear large curved spines. The leaves **(photo 1)** are alternate, compound and imparipinnate with a petiole of 2 to 5 cm of rachis more or less cylindrical or flattened. The stems are in the form of cylindrical fragments 3 to 5 cm in diameter **(photo 2)**.

Comment [B10]: I think thos is not a materials, but descriptions of the species', please correct or remove it.

Photo1. Leafy branch of *Z. zanthoxyloïdes*

Photo2. Stem of *Z. zanthoxyloïdes*

2) Field Tools

The material used in this study consists of a penta decameter for the delimitation of the squares; fluorescent strip to materialize the boundaries of the squares; cutting for the opening of the sills and the making of the corner stakes; pruning shears for taking samples; pi tape for measuring tree diameters, GPS (*Global Positionning System*) for the georeferencing of the feet of *Z. zanthoxyloïdes* and a map of Benin's protected areas.

Comment [B11]: Add references that use those materials for similar study.

3) Study environment

The study area consists of the Classified Forests of the Lama, Wari – Maro and N'Dali (**Figure 1**) below.

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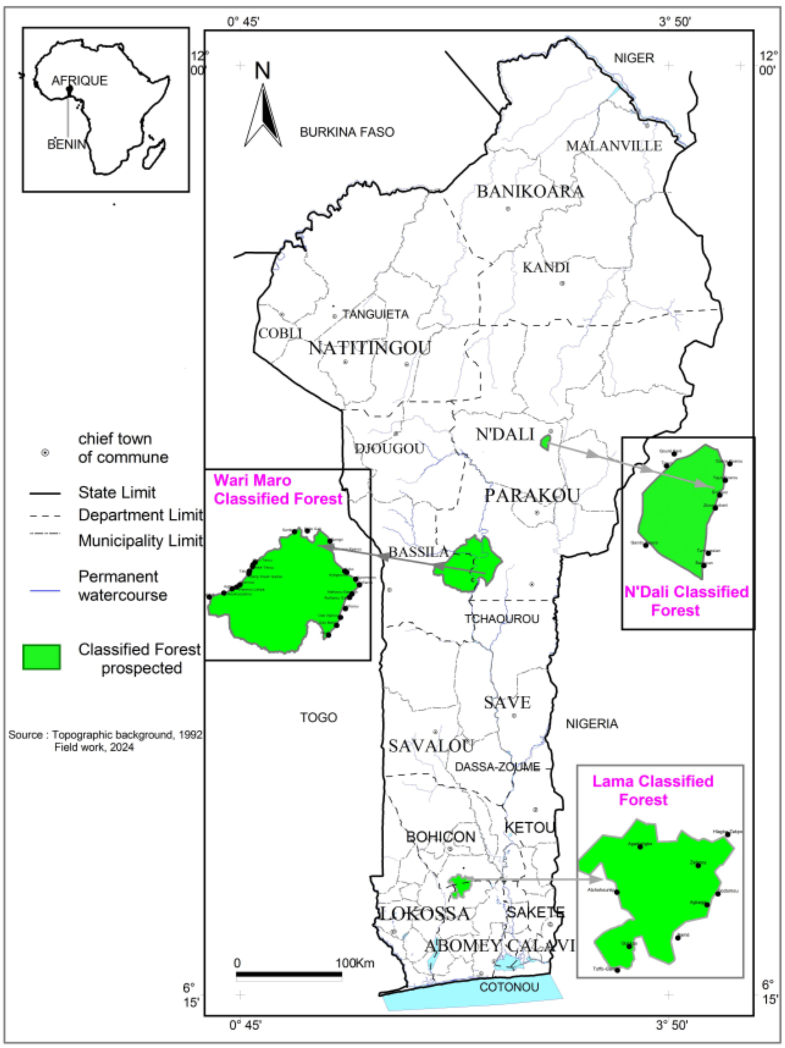

Figure 1 : Map of Benin's protected areas with the three classified forests

B-Sampling and data collection

The choice of its habitats was made in a reasoned way, taking into account the forests classified in each climatic zone. The Lama Classified Forest in the Guinean zone, the Wari-Maro Forest in the Sudano-Guinean transition zone and the N'Dali Classified Forest in the Sudanian zone.

Comment [B13]: Why you select this forest areas ? Please write the selection of the criteria as well as the sampling method please !

The sub-equatorial zone has four seasons and extends from the coast to the latitude of Dan north of Abomey. It experiences 250 days of rain divided into two parts: the first, the longest from March to the end of July and the second from September to mid-November. The two rainy seasons are separated by 2 dry seasons.

Comment [B14]: Add citations

The Sudano-Guinean zone has 2 seasons, one rainy and one dry, and is located in the center of the country with 200 days of rain concentrated in the period from April to October. It extends from the latitude of Dan to that of Savè. The third zone is Sudanian-type with 145 days of rain. It extends from the latitude of Parakou to the entire north of the country. It also has two seasons, one rainy and one dry.

At the level of each habitat, the prospecting effort was determined through the number of plots to be installed by means of the formula of (Dagnelie, 1998) :

$$N = \frac{U^2{}_{1-\alpha/2}(\mathrm{CV}^2)}{\mathrm{d}^2}$$

N, Sample size was determined by vegetation, $U^2{}_{1-\alpha/2}$=1.96 ; CV = coefficient of variation. The coefficient of variation was therefore calculated by Classified Forest and d is the margin of error (d=10 pour cent). Thus, the number of places is as shown in Table 1 below.

These plots were also installed randomly by following mega-transects oriented from south to north. These are the 50 m x 50 m (2500 m2) plots indicated for structural analysis in dense forest (Salako et al. 2013). It is more convenient to use square or rectangular plots in tropical formations (Van Laar&Akça, 2007). In each plot, all Z. zanthoxyloid individuals were counted and the diametric measurement was made at the level of individuals with a dbh ≥10 cm. Table 1 shows the distribution of plots by forest and climate zone.

Table 1: Distribution of plots by Classified Forest and by climatic zone

Climatic Zones	Natural Formations	Fallow	Total
Guinean zone (Classified Lama Forest)	60	19	79
Sudano-Guinean zone (Classified Forest of Wari - Maro)	20	7	27
Sudanian Zone (N'Dalie Classified Forest)	10	4	14
Total	**90**	**30**	**120**

C-Data processing

The collected data were entered into the Excel spreadsheet and several ecological and dendrometric parameters were calculated:

- **Scarcity index (***species rarity weight richness index***)**

The rare status of the species was determined by the rarefaction index calculated according to the following equation: Ri = (1- ni/N) with Ri: rarefaction index of species i, ni: number of places where species i is found and N: total number of places in the formation.

Taking into account this relationship, if the scarcity index is less than 80%, the species is considered preferential, very frequent and abundant in the areas studied. Although the rarefaction index is more than 80%, the species is rare. A 100% rarefaction index means that the presence of the species has not been observed anywhere in the areas studied. Thus, the latter is highly threatened with extinction in the region.

Comment [B15]: Add citations that were used this methods

- Stand density

N is the average number of mature trees (dbh ≥ 10 cm) per hectare. It is given by the formula:

$$N = \frac{n}{s}$$

n is the total number of trees per plot and s is the area of the plot in ha. In the case of the density of Z. zanthoxyloides plants, the area considered is equal to 1 ha.

Comment [B16]: Citations

- Structural characterization of Z. zanthoxyloides

Individuals of Z. zanthoxyloid were grouped into classes with a diameter of 5 cm. Thus, the densities of trees by diameter classes were determined. The densities of adults (dbh ≥ 15) and juveniles (10≤ dbh<15) are compared between the three Forests Classified within natural formations and fallow with the nonparametric Mann Whitney test because the data do not follow a normal distribution. This statistical analysis was performed with the R software. The diameter distribution classes were fitted to the theoretical 3-parameter Weibull distribution (a, b and c) using the density function (f) expressed as a function of the diameter (x) according to the formula :

$$f(x) = \frac{c}{b}\left(\frac{a-b}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

where: b= scale or size parameter; a=position parameter; c= shape parameter. The threshold of the parameter a was considered with a=10cm to adjust the class size of the species. The analysis was done in R using the packages (Mass, Survival and Fitdistrplus) to test the observed distribution compared to that of Weibull.

RESULTS

Abundance of Z. zanthoxyloides

Table 2: Densities and Indices of Z. zanthoxyloid scarcity by climatic zone and by forest studied.

Climate Zone	Densities (pieds/ha)	Rarefaction Indices
Guinean (Classified Lama Forest)	1,2	RI<80%
Sudano-Guinean (Wari-Maro Classified Forest)	0,24	RI>80%

Sudanian (N'Dali Classified Forest)	**0,1**	**RI>80%**

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The density of Z. zanthoxyloides subjects decreases from the Guinean zone (FC de la Lama) to the Sudanian zone (FC de N'dali) and the scarcity index also shows that the species is abundant in the Guinean zone and increasingly rare as we evolve towards the Sudanian zone. This result is similar to that of (Romain Glèlè Kakaï et al, 2011) who worked on the ecological adaptation of Vitellaria paradoxa following the climatic gradient in Benin.

Within the Llama FC where the species is abundant, it appears that juveniles are found more in fallow than adults (P-value< 0.0001) while adults have been at the same time more represented in natural formations than in fallow (P-value< 0.0001).

Comment [B18]: Where is the table that shous this results, please insert tha table in your manuscript for all P-value results. Your results so shallow

The diameter structures of Z. zanthoxyloids in the two different plant formations of the Central Core of the Classified Lama Forest are shown in **Figure 2.**

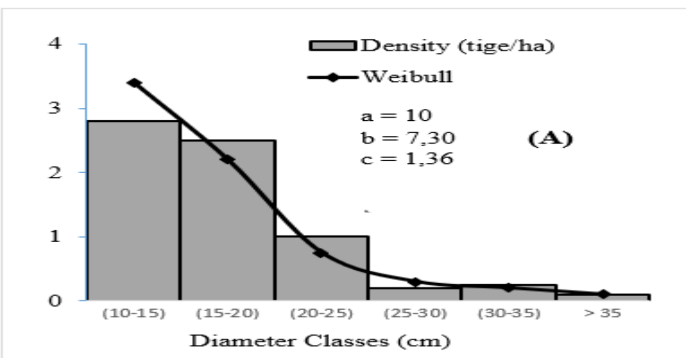

Figure 2 : Structure in diameter of Z. zanthoxyloides in the classified forest of the Lama (A)

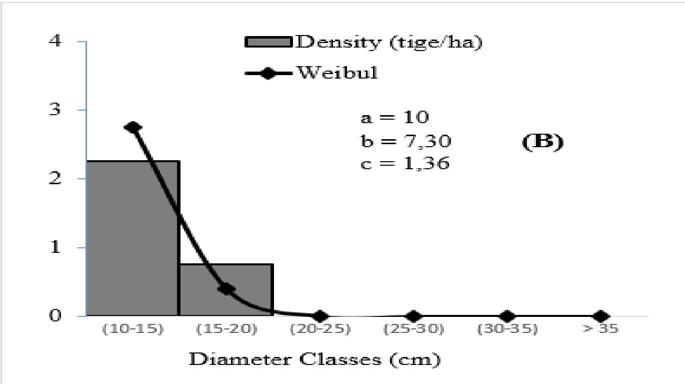

Figure 3 : Structure in diameter of Z. zanthoxyloides in the surrounding fallow land (B)

In both habitats, the Weibull shape parameter (c) is between 1 and 3.6. Thus, the distribution by diameter class of the individuals generally indicates a non-Gaussian appearance everywhere and presents a left asymmetry (1<*c* < 3,6) Characteristic of stands with a relative predominance of young or small diameter individuals. Regardless of the type of habitat, individuals between 10 and 15 cm in diameter are the most abundant. There are nearly 3 plants per hectare in the natural formation and more than 2 plants per hectare in fallows. At fallow land, the diameter of this plant hardly exceeds 20 cm, while it reaches 35 cm in the forest.

Moreover, in the other forests (Wari-Maro and N'dali), no Zanthoxylum zanthoxyloides plants have been found. However, the investigations made it possible to find two isolated plants in a fallow land located in the district of Manigri, a locality not far from the classified forest of Wari-Maro.

DISCUSSION

Abundance of Z. zanthoxyloides

The results of this study showed that the density of Z. zanthoxyloidesse becomes rarer as the distance from the coast increases. This result is similar to that of Yaoitcha (2015), who showed that the species is less abundant in the most arid climates. A recent study had already mentioned that this species is threatened with extinction already at the height of Glazoué-Savè-Ouèssè, in the Sudano-Guinean zone (Ehinnou-Koutchika*et al.*, 2014).

It is therefore not surprising to report the information we have had in this study on this species in the two climatic zones of Central and Northern Benin. The scarcity of adult plants in fallow land in the prospected areas could be explained by the anthropogenic pressure exerted on the species. Indeed, apart from its medicinal values (Queiroz et al., 2006), the species is used for other purposes such as carbonization, wood energy, sculpture, etc. (Pote *et al.*, 2006;Furukawa *et al.*, 2011). Bossokpi (2003) had reported that Z. zanthoxyloides is a species of pre-forest savannahs and coastal thickets; Adesina (2005) also reported in southwestern Nigeria that the species is more abundant in savannah and dry forest, so it would not have been otherwise at our study sites if adult plants were not regularly collected. The proof of this is that juvenile and young plants are fairly well represented in fallows, a sign that natural regeneration is occurring relatively well.

In fallow land, direct access to light allows seedlings to establish and develop. Fallow land and open plant formations therefore have a high conservation potential if specific management actions are carried out on this young population of the species (Houéhanoue*t al.*, 2013).

Population structural characteristic of Z. zanthoxyloides

Comment [B19]: Where is your result about it ?

The distributions in diameter by plant formation at the level of the Llama FC generally indicate a non-normal appearance, i.e. they do not present a Gaussian appearance and therefore lead to the conclusion that the regularity of the Z. zanthoxyloides structure is not assured. This left asymmetry had been reported on different tropical species by various studies such as Cassou et al. (1997) had reported on the African population of palm trees in Burkina Faso, Kperkouma et al. (2005) on the Shea butter trees of Donfelgou in Togo, Bonouet al. (2009) on the populations of Afzelia africana in Benin. However, it had been mentioned by authors that some species with a bell-shaped distribution within small patches might exhibit an inverted J-shape when the patches are larger (Pulido *et al.*,2001). The scale of a classified forest could therefore have played a role in the adjustment obtained with the Weibull distribution. The density function (f) of the diameter (x) required for the dendrometric study of the species is justified by its efficiency. According to (Bonou, 2009), the use of the Weibull distribution probability density function is becoming increasingly universal to model the diameter distributions of homogeneous and uneven-aged forest stands.

As far as the N'Dali Classified Forest is concerned, the species is absent as already reported in a previous study (Djagouni et al., 2010). The observation is identical to what is observed in the FC of Wari-Maro.

Anthropogenic pressures and destruction of Z. zanthoxyloides populations

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This plant is constantly cut down during the establishment of agricultural areas in the south as well as in northern Benin. For the agricultural production of food crops such as maize, forests are gradually cleared by ploughing with a gradual uprooting that first takes into account the less robust stumps in order to better ensure the availability of nutrients and the aeration of the soil layers (Bajwa, 2014). Generally, after farmers have worked the land, the roots of Z. zanthoxyloides are recovered by those who want to sell them. Otherwise, the roots become a nuisance and are used as fuel. All this not only reduces the extent of the species' populations but also reduces the potential for its regeneration on wastelands. But it is good to note that the studies of Quiroz *et al.* (2014) in Benin report that the roots of the species were sold cheaper on the market (1.15 USD/kg) comparé aux racines des plantes en général (2.21 USD/kg). This should reduce the pressure a little, at least from the point of view of collections for commercial purposes. Botha et al. (2007) argued that price is not the best indicator of the availability of a medicinal herb.

CONCLUSION

The distribution of *Z. zanthoxyloïdes* is more confined in the Guinean zone of Benin and benefits from a more favorale protection situation in the Classified Lama Forest. The decrease in mature trees in fallow and anthropogenic areas recommends that development actions be carried out to ensure its current and future availability. In addition, propagation actions by cuttings successfully tried by the same authors are a recommended avenue. We suggest, however, that further studies are needed to make available maps of the current and past distribution of this species to guide conservation actions.

REFERENCES

Adesina, S. K. (2005). The Nigerian Zanthoxylum; chemical and biological values. *African Journal of Traditional, Complementary and Alternative Medicines*, *2*(3), 282-301.

Adomou A. C., Agbani O. P., Sinsin, B., 2011. Plantes. 21-46. *Protection de la Nature en Afrique de l'Ouest : Liste Rouge pour le Bénin. International Institute of Tropical Agriculture Ibadan Nigeria*

Assogbadjo A. E., GlèlèKakaï R. L., Sinsin B., Dieter P., (2010). Structure of *Anogeissusleiocarpa*Guill., Perr. natural stands in relation to anthropogenic pressure within Wari-Maro Forest Reserve in Benin. *African Journal Ecology* 48 (3) : 644–653.

Avossèvou-Ayisso, C., Avohou, T.H., Oumorou, M., Dossou, G., Sinsin , B., 2011.Ethnobotany of Pentadesmabutyraceain Benin : A quantitative approach.*Ethnobotany Research & Applications 9, 151-166.*

Bajwa A. A., 2014. Sustainable weed management in conservation agriculture. Crop Protection, 65: 105-113. doi: 10.1016/j.cropo.2014.07.014

Botha, J. Witkowski, E.T.F., Shackleton, C. M, 2007. Factors influencing prices of medicinal plants traded in the Lowveld, South Africa. Int. J. SustnainableDev . World 14,450-469 .

Bonou, W., GlèlèKakaı¨, R., Assogbadjo, A.E., Fonton, H.N., Sinsin, B., 2009. Characterisation of Afzeliaafricana sm. Habitat in the lama forest reserve of Benin. Forest Ecology and Management 258, 1084–1092.

Bossokpi, I. (2003). Study of the biological activities of FagarazanthoxyloidesThesis, Faculty of Medicine, Pharmacy and Odontostomatology, University of Bamako, Mali.

Cassou J. and Depomier D., 1997. “In Announcement: Tri-Party Meeting on Agroforestry,” Sikasso, Burkina Faso.

Codjia, J. T. C., Assogbadjo, A. E., & Ekué, M. R. M. (2003). Diversity and valorization

local level of forest plant food resources in Benin. Cahiersagricultures, 12(5), 321-331.

Dagnelie, P., 1998. Theoretical and applied statistics, vol. 2. De Boeck and Larcier, Belgium, Paris.

Djagoun, S. C. A. M., GlèlèKakaï, R., Konnon, D., Sewade, C., Kouton, M., Bonou, W., ...&Fandohan, B. (2010). Potential of food and medicinal forest plant resources of the classified forest of Ouémé Supérieur and N’Dali in Northern Benin. Fruits, Vegetable and Cereal Science and Biotechnology, 4(1), 47-54

Furukawa T., Fujiwara K., Kiboi S. K., ChaloMutiso P. B., 2011. Threshold change in forest understory vegetation as a result of selective fuelwood extraction in Nairobi, Kenya. *Forest Ecology and Management.* 262, 962–969.

Gaoue, O. G., Ticktin, T., 2007. Patterns of harvesting foliage and bark from the multipurpose tree Khayasenegalensis in Benin: variation across ecological regions and its impacts on population structure. *Biological Conservation.* 137, 424–436.

GlèlèKakaï, R., Sinsin, B., 2009. Structural description of two Isoberlinia dominated vegetation types in the Wari –Forest Reserve (Benin). *South Africa Journal of Botany 75, 43-51*

GlèlèKakaï, R., Akpona, T. J. D., Assogbadjo, A. E., Gaoué, O. G., Chakeredza, S., Gnangle, P. C., ... & Sinsin, B. (2011). Ecological adaptation of the shea butter tree (Vitellariaparadoxa CF Gaertn.) along climatic gradient in Bénin, West Africa.*African journal of ecology*, *49*(4), 440-449.

Guendehou F. J., 2012. Ecological evaluation and use of Zanthoxylumzanthoxyloideswartern. (Rutacecae) in Lama Forest Reserve. Thesis of Master, Faculty of Agronomic Sciences, University of Abomey-Calavi, Benin. 60 p

Houehanou T. D., Assogbadjo A. E., GlèlèKakaï R. Kyndt T., M., Sinsin B., 2013a. How far a protection area contributes to conserve habitat species composition and population structure of endangerd African tree species. *EcologicalComplexity*. 13, 60-68.

Husch B., Beers T., Kershaw J., 2003. Forest Mensuration, 4th ed. Ronald Press Company, London in Africa. SRP, Exeter, London. Shahabuddin, G., Prasad, S., 2004. Assessing ecological sustainability of non-timber forest produce extraction: the Indian scenario. *Conservation and Society.* 2, 235–250.

IUCN, 2008. List of tropical Woods Used and Sold for Woodturning and their Endangerment Status. http://www.bradturnsgreen.com/Wood%20Status%20List.pdf.

Jacob, T., & Gardes, L. (2010). Propositions relatives au développement des connaissances de la population de dugongs de Nouvelle-Calédonie. Période, 2012, 33.

Kperkouma. W., Sinsin. B., K. Guelly, Kokou. K andAkpagana. K. , “Typologie et Structure des Parcs Agroforestiers Dans la Prefecture de Donfelgou,” *Sécheresse*, Vol. 1, No. 3, 2005, p. 8.

Leakey R. R., Tchoundjeu Z., Schreckenberg K., Shackleton S. E., Shackleton, C. M., 2005. Agroforestry tree products (AFTPs): targeting poverty reduction and enhanced livelihoods. *International Journal of Agricultural Sustainability*, *3*(1): 1-23.

Pote J., Shackleton C., Cocks M., Lubke R., 2006. Fuelwood harvesting and selection in Valley Thicket, South Africa. *Journal of Arid Environments.* 67, 270–287.

Pulido, F. J., Dı́az, M., & de Trucios, S. J. H. (2001). Size structure and regeneration ofSpanish holm oak Quercus ilex forests and dehesas: effects of agroforestry use on their longterm sustainability. *Forest Ecology and Management*, *146*(1-3), 1-13.

Queiroz, E. F., Hay, A.-E., Chaaib, F., van Diemen, D., Diallo, D., and Hostettmann, K. (2006). New and bioactive aromatic compounds from Zanthoxylum zanthoxyloides. *Planta Medica***72**, 746-750.

Queiroz D., Towns A., Legba S. I., Swier J., Brière S. Sosef M., van Andel T., 2014. Quantitafying the domestic market in herbal medicine in Benin, West Africa. *Journal of ethnopharmacology*. 151, 1100-1108

Rondeux J., 1999. Measuring forest stands. Gembloux agronomic presses, 2nd ed. Gembloux, 521 p.

Salako V. K., GlèlèKakaï R., Assogbadjo A. E., Fandohan B., Houinato M. & Palm R., 2003. Efficiency of inventory plots patterns in the quantitative analysis of vegetation: case study oftropical woodland and dense forest in Benin. Southern forests 75 (3): 137-143

Sinsin B., EyogMatig O., Assogbadjo A. E., Gaoué O. G., Sinadouwirou T., 2004. Dendrometric characteristics as indicators of pressure of Afzeliaafricana Sm. Dynamic changes in trees found in different climatic zones of Benin. *Biodiversity and conservation*. 13, 1555-1570.

Van Laar A. &Akça A. 2007. Forest mensuration. Springer, Dordrecht. 383 p.

Yaoitcha A., 2016. Biologie de la conservation des plantes ligneuses médicinales au Bénin : Diversité, Vulnérabilité et Priorisation. Thèse de doctorat de l'UAC. 177 p.