Spatial Distribution of *Pterocarpus erinaceus* Poir. (*Fabaceae*) Natural Stands in the Sudanian and Sudano-Guinean Zones of West Africa: Gradient Distribution and Productivity Variation across the Five Ecological Zones of Togo

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Authors’ contributions

This work was carried out in collaboration between all authors. Authors KK, KAD, MA and BBA designed the study, wrote the protocol and interpreted the data. Authors SKN, AK, RH and RAR anchored the field study, gathered the initial data and performed preliminary data analysis. Author while author SKN managed the literature searches and produced the initial draft. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARRB/2015/14771

Editor(s): (1) George Perry, University of Texas at San Antonio, USA.

Reviewers: (1) Lucas Ricardo Petigrosso, National University of Mar del Plata, Argentina. (2) Anonymous, Turkey. (3) Said Laarabi, Biology, University Mohammed V, Morocco. (4) Anonymous, Cameroon.

Complete Peer review History: http://www.sciencedomain.org/review-history.php?id=797&id=32&aid=7178

Original Research Article

Received 20th October 2014
Accepted 10th November 2014
Published 9th December 2014

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ABSTRACT

**Aims:** This study aims to analyze the structure of some populations and the natural regeneration potentials of *Pterocarpus erinaceus* Poir. According to the environmental conditions, taking into account the 5 ecological zones of Togo. Especially, it aims to: (i) Describe the geographical distribution of the species in Togo, (ii) Analyze the influence of environmental variables (climates, soils and type of vegetation) on the structural characteristics of natural stands and (iii) Determine the natural regeneration potentials of the species.

**Place and Duration of Study:** Fieldworks were done from 10 October to 15 December 2013 throughout Togo.

**Methodology:** Forestry inventory was carried out on 200 plots of 1000 m² randomly set up in *P. erinaceus* natural stands in the 5 ecological zones of Togo. In each plot, total height, the merchantable height and diameter at breast height (DBH) ≥ 10 cm were measured. The regeneration was studied in sub-parcels of 25 m² set up in the previous parcels of 1000 m². In these sub-parcels, the natural seedlings, coppices, sucker which the DBH is less or equal to 10 cm were counted. The geographic coordinates of each tree are registered with the GPS.

**Results:** The results show that *P. erinaceus* had a wide distribution and tolerance range in Togo. Trees populations' average density is between 57±23 N/Ha and 76.5±42 N/Ha. The average diameter, the average total height, the basal area are significantly different for the stands of the 5 ecological zones (*P*= 0.00). Diameter distribution indicates a reversed-J in ecological zones 2, 4 and 5 i.e. dominated by small diameters structure of *P. erinaceus* (Poir.); and unimodal distribution in zones 1 and 3. The study shows that a seedling which is the main strategy of regeneration is not significantly different between the stands studied. Results also show a good natural regeneration capacity of *P. erinaceus* by a coppice.

**Conclusion:** This study enables to describe the main characteristics of the natural stands of *P. erinaceus* in Togo and constitute therefore a useful source of information for the management of natural stands notably that of *P. erinaceus*.

*Keywords:* *Pterocarpus erinaceus* (Poir.); Togo; Dendrometric characteristic; population structure.

1. **INTRODUCTION**

During the last decades, the deforestation constitutes for the developing countries, the most disturbing second environmental problem after the climate change [1,2,3]. Just like these countries, Togo is not exempted from this crucial problem of deforestation. Estimated at 449 000 ha in 1970, the forests surface area in Togo hasn’t stopped regressing as years pass by. In 1980, ten years later, this area fell to 287 000 ha, representing a variation of −36 per cent [4]. In 1990, according to MERF [5], it was only about 140 000 ha, that is, a variation of −51 per cent. According to FAO [6], these forests represent only 5% of the land surfaces against 30% recommended and they disappear in a deforestation rate of 5.1%. This phenomenon leads Togo to be one of the African countries that present the highest net loss of forest in percentage [6]. Currently, the situation is still disturbing because the logging is practiced while ignoring the principles of the sustainable forest management [7].

The selective logging of some species of quality timber in the forest stands threatens dangerously the plant genetic resources [8,9]. Among the most current exploited and threatened in Togo, is the *Pterocarpus erinaceus* (Poir.), a multi-purpose endemic species of the guineo-sudanian and sudano-sahelian zones [10,11] and an important species which fixes atmospheric nitrogen. It is extremely used in Togo as timber [12]. In 2008, Togo exported about 3500 m³ made of the *P. erinaceus* out of which only 500 m³ were exploited legally [13]. Moreover, Togo has become the transit market of the sub-regional trade of the *P. erinaceus* unbarked log. This species is also used a lot as a first class energy wood in Togo [14]. Furthermore, *P. erinaceus* is used in Togo for a whole range of non-timber products including food for human consumption, fodder for animals [15], medicines and raw materials for handicraft (tanning, dye, sap, resin, ...etc...).

Despite the overexploitation of this species, the country does not have at its disposal scientific and technical information to help orient its
silviculture. Moreover, few studies are available to know the current state of the natural stands in Togo in order to establish adequate management strategies. The present study is aimed at describing and analyzing the structure of populations and the natural regeneration potentials of the *P. erinaceus* according to the environmental conditions by taking into account the 5 ecological zones of Togo [16] in order to contribute to the sustainable management of natural populations of *P. erinaceus*. Especially, it aims to: (i) Describe the geographical distribution of the species in Togo, (ii) Determine the dendrometric characteristics of natural stands according to the environmental variables (climates, soils and type of vegetation) and (iii) Determine the natural regeneration potentialities of the species.

2. MATERIALS AND METHODS

2.1 Description of the Study Zone

The current work was carried out on the whole country of Togo. Covering a surface area of about 56600 km², Togo is located between 6° and 11° of north latitude and in between 0° and 2° of eastern latitude. Though the country is located to some extent at the central part of the southern coast of West Africa, it presents an heterogeneity characterized by the climates, soils and vegetation of North-south type. Ern [16] defines the 5 ecological zones in Togo. The northern part of the country corresponds to the ecological zone 1. It is the zone of the northern plains corresponding essentially to the sudanian savannahs with a tropical climate characterized by a rainfall varying between 800 and 1000 mm/year. The soils are of tropical ferruginous type with some less developed and others less humic. The ecological zone 2 corresponds to the northern part of the mounts of Togo. There are mosaics of dry forests and savannahs. The climate is a tropical one with a rainfall ranging between 1200 and 1300 mm/year. The soils discovered are essentially tropical ferruginous ones with some soils on alluviums and some less developed. The ecological zone 3 corresponds to the vast areas of the central part of Togo, dominated by some inselbergs (rock hills elevated in the form of dome) with altitudes between 200m and 400m. The climate is of tropical type with a rainfall varying between 1200 and 1500 mm/year. It is covered essentially with guinean woodland savannahs [17]. The soils discovered essentially are of tropical ferruginous types, shallow with vertisols. The ecological zone 4 is the domain of semi-deciduous moist forests [18]. The pluviometry is in between 1300 and 1600 mm/year. The altitudes are generally comprised between 600 and 800 m and reach 986 m at Agou mountain and the soils are ferralitic and less developed. The ecological zone 5 is the coastal plain of Togo. It is defined as a littoral uplands zone characterized by an abnormal deficit of rainfall (800 to 1200 mm/year). The soils are ferruginous, hydromorphic, humified with vertisols (Fig. 1).

2.2 Biological Data of *P. erinaceus*

*P. erinaceus* is a small to medium-sized tree 12–15 m tall with a diameter of 1.2–1.8 m. In the drier part of its range it has an open, spreading form and is low-branching, but under favorable rainfall and soil conditions, much larger specimens with clean straight boles 6–8 m long or more can be found [19]. Exceptionally tall trees reaching 35 m height have been reported [20]. The bark of the trunk is dark gray and rough, with scales that curl up at the ends. The leaves are once-compound, imparipinnate, and 30 cm long. There are 10–15 alternate or subopposite leaflets, 6–11 cm long and 3–6 cm wide [19]. The flowering tree is showy and very attractive, with masses of golden-yellow flowers that completely cover the canopy. In its native range, *P. erinaceus* flowers from December to February [21]. The fruit is 4–7 cm in diameter, indehiscent and broadly winged, giving it a “flying saucer” appearance. “The seeds are kidney-shaped to oblong. Pterocarpus erinaceus is a prolific seed producer and is easy to propagate by planting nursery-raised seedlings or rooted cuttings. *P. erinaceus* is found in open dry forests of semiarid and subhumid lands with mean annual rainfall of 600–1200 mm and a moderately to very long dry season that can last 8–9 months. Mean annual temperature in the tree’s natural range is 15–32°C, but it tolerates high temperatures reaching over 40°C [22]. *P. erinaceus* is found throughout West and Central Africa, ranging from Senegal in the west to the Central African Republic in the east. It is distributed up to 14°N but is a stunted, small tree at this latitude, where another species, *Pterocarpus lucens*, takes over and becomes more abundant. Southward, the range extends to the limit of the humid forest in Cote d’Ivoire and the humid coastal savannas in Guinea, Togo, and Benin.
2.3 Data Collection

The data needed to characterize the natural stands of the *P. erinaceus* were obtained from forest inventories in the stands of the *P. erinaceus* across the 5 ecological zones considered in this study as the first stratification level of the sampling. Within each ecological zone (or stratum), a random sampling was conducted focusing on the *P. erinaceus* stands. The observation units are plots of 1000 m² (40 m x 25 m) randomly demarcated in the stands of the *P. erinaceus* with regular intervals of 200 m. In each stratum, 20 plots were limited to the *P. erinaceus* stands bringing them to a total of 100 plots for the entire Togo. The data collected in these plots concern only the *P. erinaceus* trees ≥10 cm with diameter at breast height (DBH), i.e. 1.30 m from the ground. The total height and the merchantable height have been also measured. The measurements of the diameter are done with a tape while the ones concerning the total height and the merchantable height are conducted with a graduated board (for trees with less than 5 m height) and with Relascope of Bitterlich for trees with height over 5 m. The geographic coordinates of each tree are registered with the global positioning system (GPS). An assessment of the regeneration potential is conducted in the sub-parcels of 25 m² (5 m x 5 m). These sub-parcels out of which four are set up in each angle and the fifth in the centre (Fig. 2) are demarcated within the parcels of 1000 m². In these sub-parcels, the natural seedlings, coppices, sucker the DBH of which is less than or equal to 10 cm were counted following the methodology of Sopkon et al. [23].
2.4 Analysis and Data Processing

2.4.1 Structure of the *P. erinaceus* natural stands

The dendrometric parameters retained to characterize the *P. erinaceus* stands in the 5 ecological zones studied are the density (N/ha = number of stems/ha), the average diameter, the basal area, the average total height and the average merchantable height. The average diameter and the average total height and the merchantable height are appreciated directly by an arithmetic calculation. The density (N) of the trees is assessed in terms of number of stems per hectare according to the following formula: \( N = \frac{n}{s} \) whereby \( n \) is the number of trees on the plot and \( s \) the area of the plot (per hectare). The basal area \( G \) (m²/ha) is the sum of the cross sections at 1.30 m height from the ground of all the trees of the sampling plot. It is calculated with the formula \( G = \sum \pi d^2/4s \) whereby \( d \) is the diameter at 1.30 m and \( s \) the area of the plot (per hectare). The basal area is used with the merchantable height of trees to estimate the biovolume of the stands in each zone. The biovolume is defined as the volume of wood which enables to estimate the potential of the plant community. It is calculated with the formula of Dawkins [24]: \( V = 0.53 \sum G_i h_i \) with \( V \): Biovolume of all the species (m³/ha) whereby \( G_i \): Basal area of each species i (m²/ha) and \( h_i \): Merchantable height of each species (m) and 0.53 the coefficient of form. The above defined parameters are calculated per plot. The average and the standard error are later on calculated by taking into account the 20 plots. Therefore five average measures of the dendrometric parameters for each of the 5 ecological zones were considered. The coefficient of variation \( C \) enabling to account for the variability of the forestry characteristics is also calculated. An Anova test is then conducted thanks to software R on each of the parameters in order to compare the stands of the five ecological zones using the extensive linear path model.

2.4.2 Diameter distribution of the *P. erinaceus* populations

In order to establish the structures, histograms were built in grouping the trees per classes of diameter of 10 cm of amplitude and per classes of height of 2 cm. The structures observed for the diameters and the heights were adjusted to the distribution of Weibull of 3 parameters due to its flexibility [25], density function \( f \) of which is expressed for a tree having \( x \) diameter or height as follow:

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

\( x \): diameter of trees;
\( a \): Location parameter – it is equal to 0 if all the categories of trees are considered (from seedlings up to the seed bearers during the inventory); it is not nil if the trees considered have a diameter or a height superior or equal to \( a \).
\( b \): Is the scale parameter; it is linked to the central figure of the diameters or heights of trees of the stand considered.
\( c \): Is the shape parameter linked to the structure in diameter or height considered.

This distribution of Weibull can take many forms according to the figure of the parameter of form \( C \) linked to the structure in diameter (Table 1). Bailey and Dell [26] firstly describe tree diameter distributions with the Weibull function which since then has been used extensively for the modeling of stand tables.

The test of Kolmogorov-Smirnov is then conducted in each case in order to check the adequacy of the structure observed with the distribution of Weibull.
Table 1. Various forms of the Weibull distribution depending on the value of \( c \)

| \( c \) | Distribution in «J reversed» characteristics of multispecific and uneven-aged stands |
|-------|----------------------------------------------------------------------------------|
| \( C < 1 \) | Decreasing exponential distribution, characteristics of endangered populations |
| \( 1 < C < 3.6 \) | Positive asymmetrical distribution, characteristics of monospecific stands with mainly young species or of small diameters |
| \( C = 3.6 \) | Symmetrical distribution; normal structure, characteristics of uneven-aged or monospecific stands of the same species |
| \( C > 3.6 \) | Negative asymmetrical distribution, characteristics of monospecific stands mainly with old species |

Source: [27]

2.4.3 State of the potential natural regeneration

The density of the natural regeneration (seedlings, coppices, suckers and marcots) is estimated and the relative importance of each mode of regeneration is calculated in percentage for the five ecological zones considered. A variance analysis is then conducted in order to compare the variability of the future state density of the studied stands in the five ecological zones.

3. RESULTS

3.1 Distribution of \( P. \) erinaceus in Togo

The distribution of the \( P. \) erinaceus in the 5 ecological zones of Togo (Fig. 3) indicates that the species is spread across the whole country. It presents a vast geographical distribution, i.e. has a large tolerance range.

Indeed, in zone 1, it is present in the fallows, cultivations but dominantly in the sudanian woodlands savannah. The best stands were found in the Oti-Kéran Park which is the most protected area in the zone 1. In the zone 2, the \( P. \) erinaceus is found in the fallows, cultivations and dominantly in the savannahs and the open woodland. In the zone 3, the species is also present in fallows but dominantly in the Guinean woodland savannahs. In the zone 4, the forests, the Guinean woodland savannahs and dominantly the abandoned fallows and the cultivations constitute the main habitats of the species. It should all the same be noted that in these first four ecological zones, the species is also present in the non-prospected zones (Fig. 4). In the zone 5, the stands are made up of the \( P. \) erinaceus of small diameters spread over the cultivations and the fallows. These trees are left by the owners of the cultivated lands either to have shade or to be cut and used as timber or firewood later. The species is however present in the guinean woodland savannahs in the Togodo protected area. Nevertheless, the species is not found close to the coastal area on the "Continental Terminal" soils, quaternary marine sand and valleys.

3.2 Dendrometric variabilities of \( P. \) erinaceus Stands

The average density of trees is in between 57±23 stems/ha (zone 2) and 76.5±42 stems/ha (zone 4) (Table 2). Among the stands studied, the values obtained do not show significant differences (\( P = 0.42 \)). For the average total height, it is estimated at 11.24±3.46 m, 12.40±3.52 m, 11.14±2.74 m, 10.11±2.82 m and 8.16±2.17 m respectively for the stands of the zones 1, 2, 3, 4, 5. The variance analysis of the values obtained for this parameter shows a significant difference for the five zones (\( P < 0.00 \)). The average diameter of the stands is estimated at 29.93±9.6 cm (zone 1), 25.32±10.92 cm (zone 2), 25.86±9.5 cm (zone 3), 21.71±8.06 cm (zone 4) and 16.06±5.25 cm (zone 5). This parameter is significantly different for the 5 zones (\( P < 0.00 \)). The basal area varies from 5.62±1.70 m²/ha to 1.81±0.01 m²/ha. It shows a significant difference among the stands of the 5 zones (\( P < 0.00 \)). The merchantable height is between 2.38±0.83 m and 3.10±1.58 m. For this parameter, there is a significant difference between the stands. The biovolume is from 4.68 ± 0.03 m³/ha (zone 1) to 20.62±0.14 m³/ha (zone 5). The values calculated vary significantly between the stands studied (\( P < 0.00 \)).

3.2 Demographic Structure of \( P. \) erinaceus Stands

The distribution of trees per diameter class shows a different situation taking into account the 5 zones. In the stands of the ecological zones 2, 4 and 5 (Fig. 5), the distribution is in the form of reverse-J diameter distribution. The parameter of
the form of the distribution of Weibull (1 < c <3.6) indicates in these three zones that the stands were dominated by the *P. erinaceus* with small diameter. This distribution is more pronounced for the stands of zones 4 and 5 with c value of Weibull estimated respectively to 1.09 and 1.36. For the stands in these 3 zones, the young trees of the *P. erinaceus*, mainly those belonging to class 10-20 cm DBH are the most represented followed by class 20-30 cm DBH. At the level of the ecological zones 1 and 3, the *P. erinaceus* stands show a modal distribution with an increasing abundance (Fig. 5) of intermediary stems comprising between 20 and 30 cm. The test of Kolmogorov-Smirnov conducted on each structure indicates a good adjustment according to Weibull distribution ($P > 0.05$).

The distribution of trees in total height classes indicates globally a modal distribution for all the zones (Fig. 6). The trees having a height from 10 to 16 m are the most represented in the ecological zones 1, 2 and 3 while, in the ecological zones 4 and 5 the most represented trees are those which are from 6 to 12 m high. The test of Kolmogorov-Smirnov indicates a good adjustment according to the distribution of Weibull ($P > 0.05$).

Fig. 3. Distribution of *P. erinaceus* trees inventoried in the 5 ecological zones of Togo
Table 2. Dendrometric characteristics of the *Pterocarpus erinaceus* stands in the five ecological zones: mean, standard error and coefficient of variation

| Characteristics                   | Zone1          | Zone2          | Zone3          | Zone4          | Zone5          |
|-----------------------------------|----------------|----------------|----------------|----------------|----------------|
| Density (stems/ha)                | 71.50±42.46, b | 57±22.55, b    | 74.5±38.18, b  | 76.50±42.21, b | 73.50±44.51, b |
| Average diameter (cm)             | 29.93±9.60, a  | 25.32±10.92, a | 25.86±9.50, a  | 21.71±8.06, a  | 16.06±5.25, a  |
| Average total height (m)          | 11.24±3.46, a  | 12.40±3.52, a  | 11.14±2.74, a  | 10.11±2.82, a  | 8.16±2.17, a   |
| Average commercial height (m)     | 3.10±1.58, b   | 2.80±1.52, b   | 2.38±0.83, b   | 2.52±1.21, b   | 2.50±2.3, b    |
| Basal area (m²/ha)                | 5.62±1.70, a   | 3.40±0.78, a   | 4.41±0.40, a   | 3.23±0.30, a   | 1.81±0.1, a    |
| Biovolume (m³/ha)                 | 20.62±0.14, a  | 10.19±0.10, a  | 11.69±0.07, a  | 9.29±0.06, a   | 4.68±0.03, a   |

*Mean values of dendrometric characteristics significantly different between the stands of the 5 zones studied, b Mean values of dendrometric characteristics none significantly different between the stands of the 5 zones studied
Fig. 4. Number of trees of *P. erinaceus* per habitat and per zone

Fig. 5. Diameter classes of *P. erinaceus* trees in the five ecological zones studied
3.4 State of the Potential Natural Regeneration

The density of the potential regeneration (Table 3) varies from one ecological zone to the other. The most important is noted in the zone 4 (123.5 N/ha) and the lowest in the zone 1 (43 N/ha) but the ANOVA test shows that the variation between the stands of the different zones is not significant ($P=0.39$). Considering the strategies of regeneration, seedling is the most observed (273.5 N/ha). In the zones 1, 2, 4 and 5, it seems to be the most applied for the species. The densities of the seedling in these zones are estimated respectively at 28 N/ha, 80 N/ha, 78 N/ha and 31 N/ha. The coppices are estimated at 162 N/ha; they are estimated at 15 N/ha, 18 N/ha, 61 N/ha, 46 N/ha and 23 N/ha respectively in the five ecological zones. The suckers were not observed during the investigations on the field.

4. DISCUSSION

This study on the $P. \text{erinaceus}$ trees allowed providing information on the distribution and the structure on the natural stands of this important tree species in Togo. The information collected are the essential ecological indicators to measure the level of logging, the dynamics and the health of the $P. \text{erinaceus}$ resources in its natural biotope and the qualitative and quantitative development of the forestry stands [28]. The densities of the $P. \text{erinaceus}$ stands studied in Togo do not show significant differences from one ecological zone to the other. Otherwise the values observed in this study at the regional scale (stratum) are relatively inferior to those found by Adjonou et al. [12] in Abdoulaye gazetted forest in the zone 3 (regional scale: Between 57±23 N/ha to 76.5±42 N/ha versus plot scale in Abdoulaye Forest: 114 ± 1.1 N/ha to 136±1.6N/ha). Independently from the study scale, the densities of the $P. \text{erinaceus}$
stands observed in Togo (in anthropic or protected area), are relatively higher than those found by other authors in similar studies. Glele and al. [29] found for the *P. erinaceus* stands in Benin Republic in the same ecological conditions, the population densities of 22.86 N/ha in savannahs and 91.4 N/ha in forest. Camara [30] in Casamance (Senegal) found the population densities varying between 35 and 111 N/ha. Grace [31] and Phillips and al. [32] underlined that other factors are responsible for the difference in stands’ densities such as soils, topography, climate, vegetation cover, role of pollinators…, etc... The result on the dendrometric parameters such as the average diameter and the average total height presents significant difference between the stands in the 5 ecological zones. This difference of the forest productivity is determined by the species functional group composition and the resource availability per site [33,34,35]. Seydack [36] suggested that the understanding of these site effects is necessary for an effective tropical forest management. In the current study, the zones 1, 2 and 3 seem to be favorable to the development of the *P. erinaceus* stands. These three zones present indeed the highest values of the average diameter and the average total height. This result confirms also the fact that the *P. erinaceus* is indicated as being a species from African savannahs and dry woodlands of Guineo-sudanese and Sudano-sahelian regions [10,11,37]. In zones 4 and 5, the *P. erinaceus* trees are dominantly present in the fallows and in the cultivations, explaining the low value of the dendrometric parameters obtained in these two zones. These trees are, most of the time, left by the owners of the cultivated lands as agroforest trees either to have shade or to be cut and used as timber or fire wood later. In these zones, the human pressure on the species (logging and farming) is higher. In these two regions, the *P. erinaceus* also presents the lowest basal area value (3.23±0.30 for zone 4 and 1.81±0.1 for zone 5). Globally, when considering the 5 zones, all the basal area values are weak (maximum 5.62±1.70 recorded in zone 1). Roger and Rabarison [38] consider the basal area as being below 7 m²/ha for open forest stands as for the *P. erinaceus* population. These authors also indicate that the values of biovolume are considered to be low for being inferior to 50 m²/ha, as for the 5 zones of this study.

The demographic structure of the *P. erinaceus* stands are mostly (Zone 2, 4 and 5) in the form of reversed-J, indicating a regular dynamics [39] and stability [40]. The exponential DBH distribution was consistent with a population at demographic balance [41]. Those which had a modal distribution (zone 1 and 3) mean that in these two zones, the *P. erinaceus* presents a demographic deficit of young trees, as showed by many case studies on trees DBH distribution [42,43]. Therefore, the demographic structure in the modal distribution is, most of the time, interpreted as an old naturally declining population, with insufficient renewal by young individuals [43]. Nevertheless, an uneven-aged stand put under diverse anthropogenic pressures can also have the unimodal trend noted [7,29]. In the case of the *P. erinaceus* stands studied, the dominance of the small diameter trees observed could explain the illegal and selective logging that takes place in the natural stands. The species is extremely logged in Togo as timber or for charcoal production [13,14]. The low values of biovolume (<50 m³/Ha) were certainly due to the loggings, harvestings for fodder, mutations of different parts of the species. According to Adjonou [7], in addition to the export of logs to China, the percentage of the national consumption of the species could reach 10% considering the wood products and derivatives. All these pressures could also explain the low potentials of wood obtained in the different stands studied.

### Table 3. Status and strategy of regeneration of *P. erinaceus*

| Regeneration density | Zone 1 (N/ha and %) | Zone 2 (N/ha and %) | Zone 3 (N/ha and %) | Zone 4 (N/ha and %) | Zone 5 (N/ha and %) | Total (N/ha and %) |
|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Total Mean          | 43 (100%)           | 98 (100%)           | 119 (100%)          | 124 (100%)          | 54 (100%)           | 438 (100%)          |
| Seedlings           | 28 (65.48%)         | 80 (81.54%)         | 58 (48.95%)         | 78 (62.75%)         | 31 (57.40%)         | 275 (62.80%)        |
| Coppices            | 15 (34.52%)         | 18 (18.46%)         | 61 (51.5%)          | 46 (37.5%)          | 23 (42.60%)         | 163 (37.20%)        |
| Suckers             | 0 (0%)              | 0 (0%)              | 0 (0%)              | 0 (0%)              | 0 (0%)              | 0 (0%)              |
| Marcots             | 0 (0%)              | 0 (0%)              | 0 (0%)              | 0 (0%)              | 0 (0%)              | 0 (0%)              |

*N/ha = number of stems per hectare*
Alike the density of old trees, the density of future seedlings (regeneration) does not show significant differences between the stands studied. The regeneration strategies of the *P. erinaceus* in this study show that the species has a good regeneration capacity by seedlings and coppices; the modes of suckers and marcots haven’t been observed during the investigations. But Cuny et al. [37] and Adjonou et al. [12] showed that the *P. erinaceus*, could also be multiplied by sucker and marcots. Other researchers showed a good capacity of germination of the *P. erinaceus* in Burkina Faso, Côte d’Ivoire and Mali, with a germination rate reaching up to 95% when seeds were scarified [37,44,45]. Recent studies confirmed these results and showed that the species is fit for forms of asexual reproduction such as marcotting [46]. This strategy offers rapid regeneration perspectives of the *P. erinaceus* at low cost through vegetative propagation. In the same point of view, Adjonou et al. [12] affirm that this capacity of the *P. erinaceus* to regenerate is a good opportunity of plant production through the nursery. Trial plantations of large and medium scale of local species such as young seedlings of the *P. erinaceus* are therefore expected for the restoration of the degraded natural stand or for the afforestation and/or reforestation of other domains. Some conservation compartments in reserved zones independently of conditions of the site in Togo may be put in place. The large tolerance range of the species observed in this study is also an asset. The species presents indeed a very high ecological plasticity that enables it to adapt itself in many environments or types of habitats with different climates in Togo. However, if the rate of the start of growth can be a bit interesting, it isn’t the case of the initial growth in plantation [12]. According to the same authors, the main constraints for the success of reforestations are this low growth during the first years and the flexuous port that demand a follow-up and a delicate care before the species reaches a good future development. The best regeneration technique of this species seems to be the application of a coppice method with a felling section of 10 cm from the ground [37,44]. With a naked root, the transplantation can be done with seedlings of more than one meter height, of two or three years of age. Encouraging results were obtained with this method (average height of 2.9 m to 5.5 years on ferruginous loamy soil). Row spacings ranging from 3 x 3 m to 5 x 5 m are recommended for timber plantations [37] while for the plantations meant for fodder, the spacing expected is of 1 m x 2 m [44].

5. CONCLUSION

This study enables to describe the main characteristics of the natural stands of the *P. erinaceus* in Togo and constitutes therefore a useful source of information for the management of natural stands notably that of the *P. erinaceus*. It results from this study that the stands of zone 2 present the lowest density of species (57 N/ha). The dendrometric characteristics notably the average diameter, the average total height, the basal area are significantly different for the stands of the 5 ecological zones. The diameter distribution of the trees indicates a reversed-J model in the zones 2, 4 and 5, i.e. a regular dynamics in these stands. In contrary, the stands in the zones 1 and 3 present a modal distribution showing a demographic deficit of young trees. Concerning the regeneration strategies, the study showed that seedlings and coppices are the most important whereas the suckers and marcots have not been observed in the stands.

Therefore, the results of this study showed that the *P. erinaceus* presents in Togo a very high ecological plasticity enabling it to be adapted to many environments and under diverse climates. This large tolerance range of the species offers opportunities to set up conservation plots in the reserved zones independently from the sites conditions in Togo. In addition, the study offers perspectives for the production of seedlings in nursery and trials of plantation of the *P. erinaceus* to restore the degraded natural stands.

ACKNOWLEDGEMENTS

To the Commission of the West Africa Economic and Monetary Union (UEMOA) that financed this research within the framework of the Project "Support for Higher Education in the member countries of UEMOA (PAES)".

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Angelsen A, Kaimowitz D. Rethinking the causes of deforestation: lessons from economic models. The Work Bank Research Observer. 1999;14(2).

2. Arcand JL, Guillaumont P, Jeanneney-Guillaumont S. Deforestation and the real
13. Novinyo et al.; ARRB, 6(2); 89-102, 2015; Article no.ARRB.2015.067

exchange rate. Journal of Development Economics. 2008;86:242-262.
3. Damett O, Delacote P. Unsustainable timber harvestin, deforestation and the role of certification. Ecological Economics. 2011;70:2121-1219.
4. MERF/FAO. Plan d’Action Forestier National du Togo-phase 1 (PAFN1-Togo 20011-20019), Projet TCP/TOG/3203(D), Lomé, Togo. 2011:47.
5. MERF. Plan d’Action Forestier National (PAFN), Togo, Lomé; 1996.
6. FAO. State of the world’s forests. Rome. Available:www.fao.org/docrep/013/i2000f00.htm. 2011
7. Adjonou K. Structure and biological indicators of sustainable management of dry forests relics of Togo. Doctoral thesis. Université de Lomé-Togo. 2011;119.
8. Medjibe VP, Putz FE, Starkey MP, Ndonga AA, Memiaghe HR. Impact of selective logging on above-ground forest biomass in the mounts of Cristal in Gabon. Forest Ecology and Management. 2011;262: 1799-1806.
9. Rist L, Shanley P, Sunderland T, Sheil D, Ndoye O, Liswanti N, Tieguhong J. The impacts of selective logging on non-timber forest products of livelihood importance. Forest Ecology and Management. 2012;268:57-89.
10. Ouedraogo A, Adjima T, Hahn-Hadjiali K, Guinko S. Diagnosis of the state of degradation of the stands of four woody species in the Sudan region of Burkina Faso. Sècheresses. 2006;17(4):485-491.
11. Sylla SN, Samba RT, Neyra M, Ndoye I, Giraud E, Willems A, et al. Phenotypic and Genotypic Diversity of Rhizobium Nodulating Pterocarpus erinaceus and P. lucens in Senegal. System. Appl. Microbiol. 2002;25:572–583.
12. Adjonou, K, Ali N, Kokutse AD, Kokou K. Studying the dynamics of natural populations of Pterocarpus erinaceus Poir. (Fabaceae) surexploités au Togo. Bois et Forêts des Tropiques. 2010; n°306(1):33-43.
13. MERF/OIBT. Second Assessment Report of the sustainable forest management (SFM) in Togo (2005-2009). Rapport proviso ire. 2010:56.
14. Kokou K, Nuto Y, Atsri H. Impact of charcoal production on woody plant species in West Africa: A case study in Togo. Scientific Research and Essay. 2009;4(8):881-893.
15. Petit S, Mallet B. Pruning of fodder trees : detail of a pastoral practice. Bois et Forêts des Tropiques. 2001;270(4):35-45.
16. Ern H. Die Vegetation Togos. Gliederung, Gefährdung, Erhaltung. Willdenowia. 1979:9:295-312.
17. Aubréville A. The forests of Dahomey and Togo. Bulletin du Comité d'études historiques. 1937;29:1-113.
18. Akpagana K. Research on moist forests of Togo. Thèse. Univ. Bordeaux 3, France. 1989;181.
19. Lely HV. The useful trees of northern Nigeria. Crown Agents for the Colonies, London. 1925;128.
20. von Maydell HJ. Trees and shrubs of the Sahel. Their characteristics and uses. Eschnorn, GTZ. 1983;531.
21. ICRAF. Agroforestry tree database (CD ROM). ICRAF, Nairobi; 1998.
22. Aubreville A, Sudano-Guinean forest flora. A.OF – Cameroun-AEF. Société d'Éditions Géographiques, Maritimes et Coloniales, Paris. 1950;523.
23. Sokpon N, Biaou SH, Ouinsavi C, Hunhyet O. Technical foundation for the sustainable management of woodlands of northern Benin: Rotation, minimum diameter of explotablity and Regeneration. Bois et Forêts des Tropiques. 2006;287:45-57.
24. Dawkins AC. The management of natural tropical high-forest, with special reference to Uganda. Commonwealth forestry, Institute University of Oxford. England. 1959;155.
25. Johnson NL, Kotz S. Continuous Univariate Distributions-I, New York: John Wiley; 1970.
26. Bailey RL, Dell TR. Quantifying diameter distributions with the Weibull function. For. Sci. 1973;19:97–104.
27. Husch B, Beers T, Kershaw J. Forest Mensuration, 4th ed. Ronald Press Company, London; 2003.
28. Oosterhoom M, Kapelle M. Vegetation structure and composition along an interior-edge-exterior gradient in a Costa Rican montane cloud forest. Forest Ecology and Management. 2000;126(3):301-307.
29. Glele KRL, Sinsin B, Palm R. Study dendrometric of Pterocarpus erinaceus Poir. Natural formations in the Sudanese zone in Benin. Agr. Afr. 2008;20(3):245-255.
30. CAMARA Y. Effect of shortening of fallow periods on the regeneration of Pterocarpus
erinaceus Haute Casamance (Senegal). Mémoire d’ingénieur des Eaux et Forêts, École nationale des cadres ruraux, République du Sénégal. 1997;32.

31. Grace JB. The factors controlling species density in herbaceous plant communities: An assessment. Perspectives in Plant Ecology, Evolution and Systematics. 1999;2(1):1-28.

32. Phillips RD, Peckall R, Hutchinson MF, Linde CC, Xu T, Dixon KW, al. Specialized ecological interactions and plant species rarity: The role of pollinators and mycorrhizal fungi across multiple spatial scales. Biological Conservation. 2014;169:285-295.

33. Baker TR, Swaine MD, Burslem DFRP. Variation in tropical forest growth rates: Combined effects of functional group composition and resources availability. Perspect. Plant. Ecol. Evol. Syst. 2003;6:21-36.

34. Gourlet-Fleury S, Picard N. Growth behaviour of trees and relationship with some descriptors of the environment. In: Gourlet-Fleury S, Guehl JM, Laroussinie O. (Eds.), Ecology and Management of a Neotropical Forest. Elsevier SAS, Paris. 2004;229–253.

35. Kariuki M, Rolfe M, Smith RGB, Vanclay JK, Kooyman RM. Diameter growth performance varies with species functional-group and habitat characteristics in subtropical rainforests. For. Eco. Manage. 2006;225:1-14.

36. Seydack AHW, Durheim G, Louw JH. Spatiotemporal interactive growth dynamics in selected South African forests: Edaphoclimatic environment, crowding and climate effects. Forest Ecology and Management. 2011;261:1152-1169.

37. Cuny P, Sanogo S, Sommer N. Arbres du domaine soudanien. Leurs usages et leur multiplication. IER, Sikasso, Mali & Intercopération, Bern, Switzerland. 1997;122.

38. Roger E, Rabarison H. Biological context of forest conservation in Madagascar. In:

Etude sur la politique de conservation des ressources forestières à Madagascar. 2000:53.

Rasatasihoarana HTF. Ecological reconnaissance of forest areas in the south Menabe for a delineation of new protected areas. Rapport final Atelier de Joachim; 2007.

39. Fongnz Jessie FE, Tsabang N, Nkongmenock BA, Nguenang GM, Auzel P, Christina E, et al. The tree stands Sanctuary Gorilla Mengamé south Cameroon. Tropical Conservation Science. 2008;1(3):204 - 221.

40. Fournier F, Sasson A. Ecosystèmes forestiers tropicaux d’Afrique. ORSTOM-UNESCO, Paris. 1983;473.

41. Condit R, Sukumar R, Hubbell SP, Foster RB. Predicting population trends from size distributions: A direct test in a tropical tree community. Am. Nat. 1998;152(4):495–509.

42. Engone Obiang NL, Njomanda A, Hymas O, Chézeauxl E, Picard N. Diagnosing the demographic balance of two light-demanding tree species population in Central Africa from their diameter distribution. Forest Ecology and Management. 2014;313:55-62.

43. Duvall CS. Pterocarpus erinaceus Poir. In: Louppe D, Oteng-Amoako AA, Brink M. (Editors). Prota 7(1): Timbers/Bois d’œuvre 1, PROTA, Wageningen, Netherlands; 2008.

44. Louppe D, Ouattara N. Planting some local tree species growing. Korhogo (Côte d’Ivoire). IDEFOR, Korhogo, Côte d’Ivoire. 1993;12.

45. Bafio BA, Kalingaire A, Bayala J. Potential of wood in the practice of conservation agriculture in arid and semi-arid areas of West Africa: Insights from candidate systems: Overview of some candidate systems. ICRAF Technical Manual n° 17. Nairobi: World Agroforestry Centre; 2012.

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