Chapter

Challenges of Conservation and Sustainable Management of African Rosewood (*Pterocarpus erinaceus*) in West Africa

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Abstract

Pterocarpus erinaceus is an endemic and threatened plant species in arid and semiarid zones of West Africa and is highly exploited for timber, animal feeding, and various medicinal uses. The species is currently native to the Guinean forest-savannah mosaic ecoregion and reported from Senegal to Cameroon. The values of the main characteristics of the *P. erinaceus* forest stands (density, average diameter, average height and average stem height) vary significantly ($P < 10^{-3}$) from the Guinean zone to the Sahelian zone. It has high technological performance and can be classified as heavy and very hard wood with a density of the order of 0.80 ± 0.07 g/cm^3 and an average hardness of 12 ± 3.7 g/cm^3. The species is the subject of large-scale international traffic between West Africa and Asia, which is by far the greatest threat to the species. The various uses induce repeated mutilation and increase pressures on the species resulting in a significant reduction in its natural populations. In response to this situation, measures are proposed, including large-scale plant production strategies, the definition of minimum felling diameters, policy measures, etc., to meet the restoration needs of natural stands of *P. erinaceus* and the fight against climate change.

Keywords: *Pterocarpus erinaceus*, socioeconomic services, wood properties, uncontrolled logging, sustainable management, West Africa

1. Introduction

During the last decades, the deforestation is, for the developing countries, the second most worrying environmental issue after the climate changes [1–4].

The exploitation rate of the tropical forests reached such an alarming level that its sustainability is questionable. Indeed, demand for timber and non-timber forest products has been increasing worldwide, and forests are endowed with multiple products and services which meet the needs of human populations [5, 6]. However, human actions such as deforestation, overexploitation of natural resources, agriculture, overgrazing and bush fires, coupled with the adverse effects of climate change are currently contributing to the loss of many indigenous plant species of great importance for populations' survival [7]. Among the most exploited species, *Pterocarpus erinaceus* Poir. is a spontaneous and endemic plant species in the Guineo-Sudanian and Sudano-Sahelian phytogeographic zones [8, 9].

P. erinaceus, known as African rosewood, is widely exploited as timber and service wood but also as one of the preferential fuelwood [10, 11] and is estimated to be the most heavily traded tropical hardwood in the world [12]. It has high performance and technological characteristics [13]. *P. erinaceus* is exploited not only for its timber which is traded internationally to Asian countries, mainly China, but also for a range of non-timber products including food for human consumption, fodder for animals, medicinal products, and raw materials for crafts such as tannins, dyes, sap, resin, etc. [9, 10, 14, 15]. For instance, the natural stands of *P. erinaceus* are very exploited, with heavy pressure on the species and habitats. Moreover, illegal and uncontrolled logging of the species, linked to international trade, became the main threat in the last years.

West Africa is experiencing overexploitation of *P. erinaceus* which is the world's leading rosewood-producing region. This region accounts for 80% by volume of all rosewood log export to China in 2016. West Africa is the largest producer of rosewood logs supplying 80% by volume of export to China in 2016. For instance, between January 2015 and December 2016, an annual average of 764,000 m^3 worth US$840 million of rosewood was imported into China from West African countries [12]. Countries heavily affected by overexploitation include Senegal (2010–2014), the Gambia (2011–2012), Benin (2012–2013), Guinea-Bissau (2012–2014), Côte d'Ivoire (2013–2014), Ghana (2013–2014), and Nigeria (2014–2015). The vicious exploitation is not about to slow down since China and Asia's middle class which has increasing demand for rosewood-made furniture is expected to increase at 16–20%. The consequences of uncontrolled exploitation of the species are changes in its population structure and composition, with potential detrimental effect on regeneration capacity, seed production (loss of seed trees), decrease in genetic diversity and risk of genetic erosion, and loss of socioeconomic services to livelihoods. Studies of [16, 17] have shown that poor harvesting and practices by the various stakeholders (farmers, drovers, and peasants) have a negative impact on the development and regeneration of the species.

The increased demand for rosewood from Asia is seriously threatening the region's natural ecosystems and its ability to adapt to climate change. But at the same time, the species is a huge opportunity for trade if the appropriate measures are taken. The objective of this chapter is to present a synthesis of the state of knowledge on natural stands of *P. erinaceus* in West Africa. Specifically, it is a question of presenting the information available on (i) the forms of use and uses of the organs of the species through different communities in West Africa, (ii) the structural parameters of the species and their variability according to ecological zones, (iii) the technological properties of the species and their variability according to the climatic gradient, and (iv) the strategies proposed for the protection, conservation and sustainable management of the species in order to meet the restoration needs of natural stands of *P. erinaceus* and the fight against climate change.

2. Species presentation and geographical distribution

2.1 Species presentation

Pterocarpus erinaceus is a small- to medium-size tree about 12–15m tall, or more, with straight bole, cylindrical up to 1 m in diameter, often low-branched, with open crown, rounded and ovoid to slight buttresses (**Figure 1A**). Its bark is scaly, cracked, blackish, and deeply fissured, with brown spots striped with red threads exuding a translucent reddish resin that hardens quickly on contact with air. Its densely pubescent twigs become glabrous and gray later [18–20].

P. erinaceus leaves are alternate, composed, alternate, once-compound, imparipinnate with hairy linear stipules (falling early) have a long spine 15–25 cm long, on which are inserted 4–5 pairs of leaflets alternate. The terminal leaflet is a little more developed than the smaller inferiors. These elliptical leaflets of 5–10 cm long and 3–6 cm wide have a rounded base or a short wedge-shaped base, a rounded or obtuse apex, usually emarginated (**Figure 1B**). They are papery and thick, with brownish hairs when young, but glabrescent as they age.

Light-yellow papilionaceous flowers (**Figure 2**), coming in loose or short panicles, appear on leafless trees at the end of the dry season, usually between December and February [21] before new leaves develop; but sometimes the inflorescences develop with the young leaves. They are asymmetrical, fragrant, 10–12 mm long, and pedicellate, with embossed petals and with a pubescent calyx with five short teeth [18–20]. They are also often visited by the bees that are probably responsible for the pollination.

The fruit, flat samara, is surrounded by a membranous circular wing more or less pleated, bearing on both sides many spiny hairs, rigid and entangled. It is

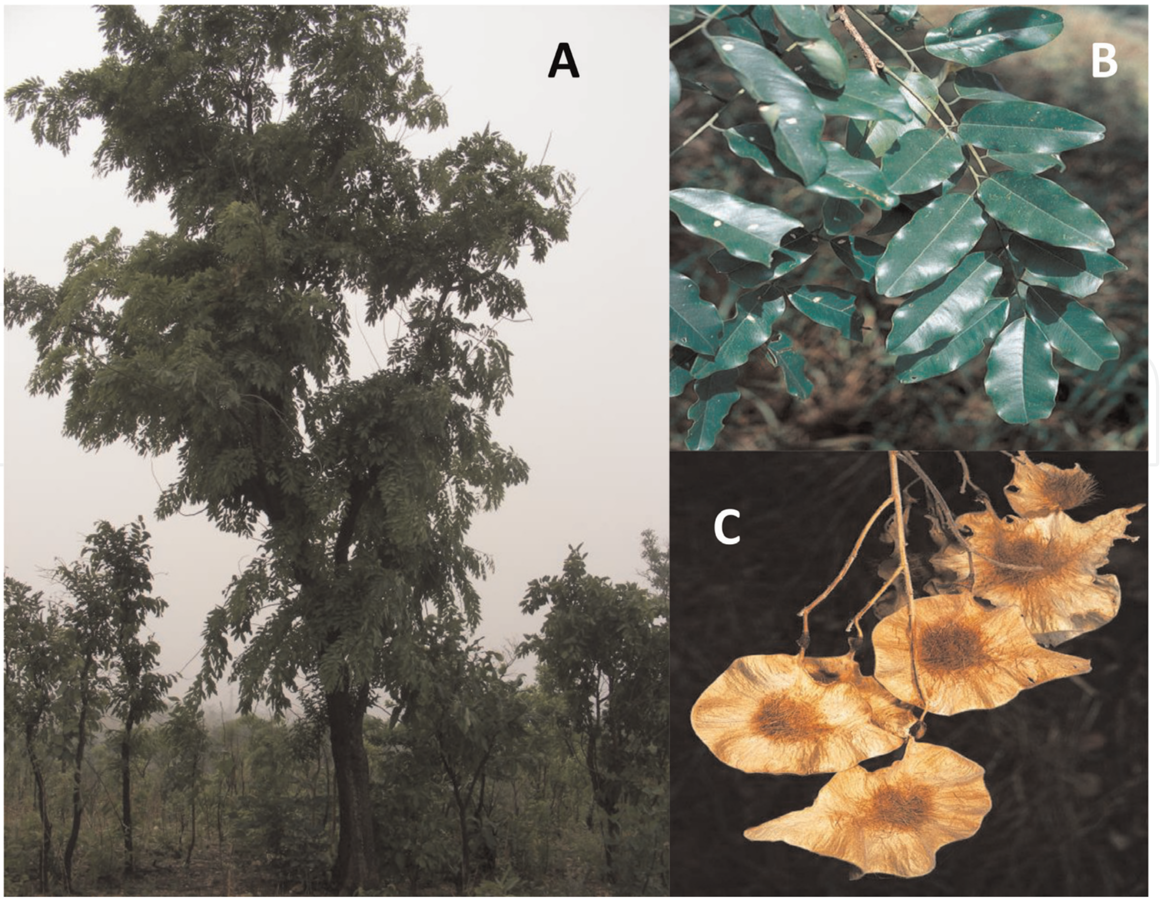


Figure 1.
Pterocarpus erinaceus. (A) Tree in its natural environment, (B) appearance of the leaves, and (C) appearance of the fruits.

Figure 2.
Flowering tree of P. erinaceus.

4–7 cm in diameter and straw yellow in color and persists for a long time on the tree. It contains one–two seeds of often very different sizes [22]. The young fruits are light green and turn light brown when dry (**Figure 1C**). The seeds are flat to slightly thick, about 10 × 5 mm, smooth, and red to dark brown. The seedling has an epigeal germination and leafy cotyledons [17].

2.2 Geographical distribution

The species is native to the Guinean forest-savannah mosaic ecoregion of West Africa (**Figure 3**), which lies between the Guinean rainforest and the Sudanian

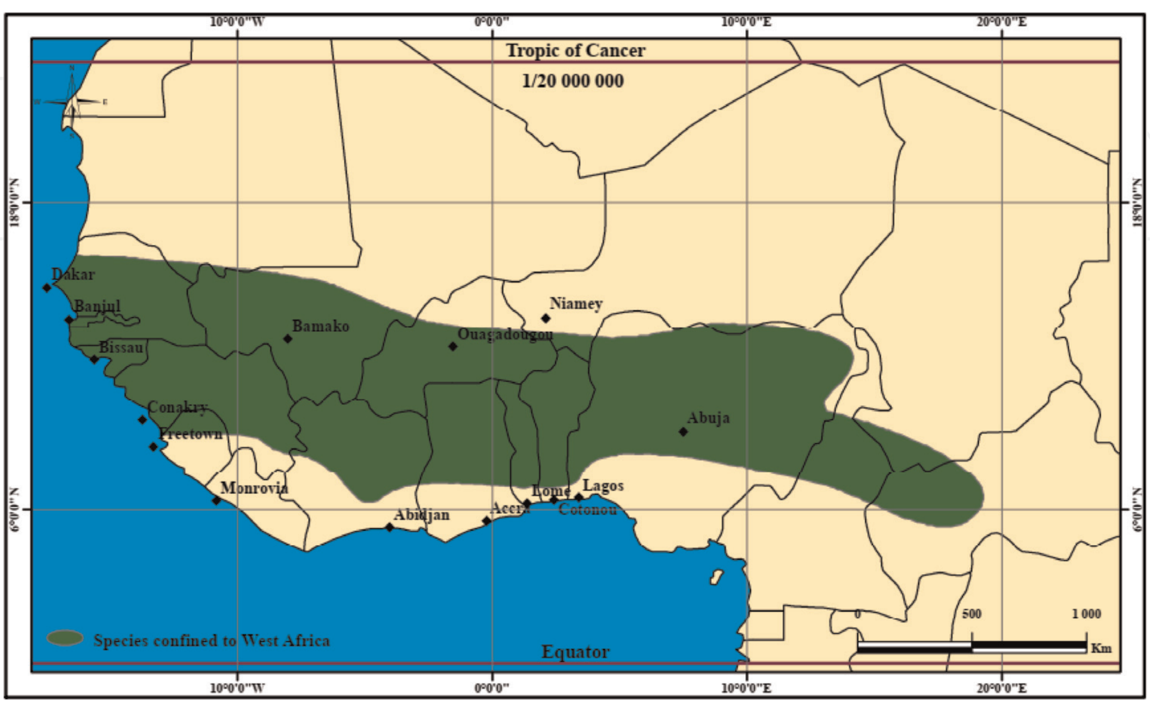


Figure 3.
Distribution de P. erinaceus in West Africa (Source: Ligneux du Sahel V.1.0, 2008).

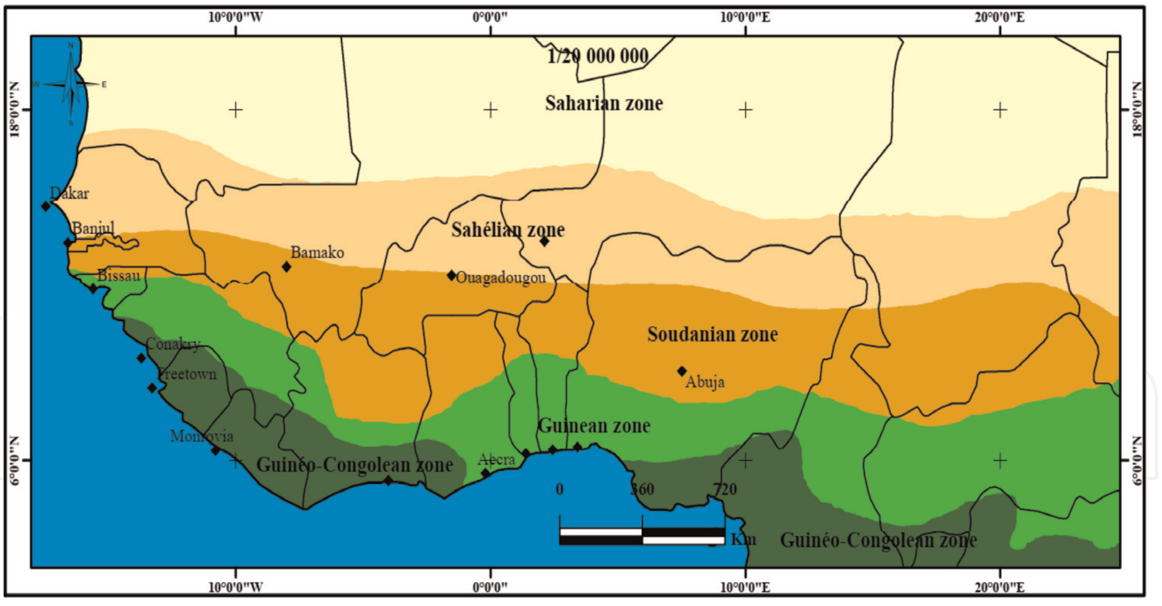


Figure 4.
Ecological zones of West Africa.

savannah [23]. It has been listed throughout the region, including Senegal, the Gambia, Guinea-Bissau, Guinea, Mali, Côte d'Ivoire, Burkina Faso, Ghana, Niger, Benin, Togo, Nigeria, and Cameroon (**Figure 3**). It is present up to the latitude of 14°N, but at this latitude the individuals are small and stunted. From this latitude, the species *P. lucens* dominates and is more abundant. To the south, the range of *P. erinaceus* extends to the moist forest limit in Côte d'Ivoire and the humid coastal savannas in Guinea, Togo, and Benin, where a gallery species, *P. santalinoides*, is common along rivers and temporary streams.

According to [24] classification, based on the total annual classes of rainfall, the species is distributed through three ecological zones, namely, Guinean zone, Sudanian zone, and Sahelian zone (**Figure 4**). *P. erinaceus* grows in dry open forests of semiarid and subhumid soils with an average annual rainfall of 600–1200 mm and a moderate or very long dry season that can last from 8 to 9 months. The average annual temperature in its range is 15–32°C, but the species tolerates high temperatures exceeding 40°C. The tree grows at low altitude (0–600 m) and also grows on shallow soils. Individuals tolerate drought and, once rooted, withstand different annual dry seasons.

3. Socioeconomic status and perceptions of *Pterocarpus erinaceus* in West Africa

Socioeconomic survey carried out in three countries (Burkina Faso, Niger, and Togo) allowed to collect data on uses and perceptions of *P. erinaceus* in West Africa [13]. Results indicate that *P. erinaceus* organs (leaves, barks, roots, sap) are used in the treatment of more than 33 diseases or pathologies in these countries. According to [25], *P. erinaceus* contains a high level of protein (19%) which makes it a very good agroforestry species [26]. The individuals in the farms, the fallows, and the classified forests are frequently pruned to feed the cattle. The leaves of the species are also sold in urban centers in Burkina Faso and Mali, as fodder.

In Burkina Faso, where the resource is relatively more abundant, 30 different local products from *P. erinaceus* wood have been identified including the balafon, the djembe, the mask, the statuettes, etc.:

- In Niger, *P. erinaceus* is the only green fodder during the lean season (April–June). The fodder collection is generally focused on young leaves and flowers. Under the current effect of climate change, stands of *P. erinaceus* are in sharp decline and are tending toward extinction in Niger, which marks the northern limit of its natural range.

- In Togo, it is essentially the exploitation and export of lumber in the form of squares, logs, boards, and other carpentry products that are more developed [27]. Logging is based on the selective collection of key timber and fuel wood in natural habitats [10]. *P. erinaceus* is broadly used as first-class timber wood (**Figure 5**) and fuelwood [10, 28]. These selective collections pose a serious threat to the country's plant genetic resources [29].

The socio-professional category of the populations and the availability of the resource strongly influence the uses of the species in West Africa. The species is highly sought after by craftsmen for making musical instruments such as "balafon" and "djembe" (**Figure 6A** and **B**) especially among para-Gourma people in Burkina Faso, Niger, and Togo.

In addition, the endogenous knowledge of sociocultural communities is quite often contrasted with *P. erinaceus*:

- In Burkina Faso, Nouné and Dioula communities use the parts of *P. erinaceus* especially in measles treatments, spider bites, low back pain, foot pimples, cough, etc. The Dioula communities use the plant for, among other things, cases of general tiredness, heart problems, dermatoses, dysentery, hemorrhoids, diarrhea to provoke menstruation in women, for magico-therapeutic treatments, etc. Diseases treated by Dioula communities are close to those treated by Fulani communities in Burkina Faso. Lele, Mossi, and Komono communities also show almost the same practices of using *P. erinaceus* organs in the treatment of diseases.

- In Niger, the Dandy are distinguished from other ethnic groups with a larger number of diseases treated with the species, including among others gastric

Figure 5.
P. erinaceus logs being loaded into vehicles for export.

Figure 6.
Musical instruments manufactured from P. erinaceus for sale on the Bobo-Dioulasso market in Burkina Faso: (A) balafon and (B) djembe.

problems, anemia, fever, sexual weaknesses, etc. These uses are similar to those observed in Hausa (Tchanga) located in the same geographical area. In contrast, the organs of *P. erinaceus* are used very little in traditional medicine among the Zarmas, Tuaregs and Peulhs communities of Niger.

- In Togo, Para-Gourma, Kabyè, and Tem use the species in the treatment of more than 18 diseases, including impotence, anemia, menstrual periods in women, and dermatoses such as skin scurf, intestinal wounds, and white losses in women. In Kabyè and Tem communities, the organs of the species are also used to facilitate delivery in pregnant women, cure ringworm and scorpion bites, etc.

4. *Pterocarpus erinaceus* stands' patterns in West Africa

4.1 Trees' characteristic variability according to ecological gradient

The analysis of the main characteristics of the *P. erinaceus* forest stands in the three climate zones indicates that the average tree density ranges between 1.17 ± 0.75 trees/ha (Sahelian zone) and 74.9 ± 1.44 trees/ha (Guinean zone). In the Sudanian zone, it is 35.05 ± 41.2 trees/ha. The values of the densities vary significantly from one climate zone to another ($P < 10^{-3}$). For the trees average diameter, the values range between 22.07 ± 8.98 (Guinean zone) and 49.63 ± 19.44 cm (Sahelian) at the Sudanian zone. In this zone, the average diameter is 29.02 ± 15.44 cm. A significant difference was also noted for this parameter within the three zones ($P < 0.001$). Regarding the basal area, the values obtained range from 0.30 ± 0.10 (Sahelian zone) to 3.15 ± 1.30 m^2/ha (Guinean zone). In the Sudanian zone, it is 2.46 ± 2.88 m^2/ha in average. The difference among the three zones is statistically significant ($P < 0.001$) (**Table 1**).

The analysis of the total average height and the average stem height of *P. erinaceus* stands shows various values depending on whether it is in the Sahelian zone, in Sudanian zone, or Guinean zone. For the average total height, the stands of the Sudanian zone (9.51 ± 2.75 m) are significantly different ($P < 0.001$) from the other two zones (10.18 ± 2.27 m for the Sahelian zone and 10.09 ± 2.88 m for the

Structural parameters		Ecological zones			Probability
		Sahelian	Soudanian	Guinean	
Density (trees/ha)	Avg ± SE	1.17 ± 0.75	35.05 ± 41.2	74.9 ± 1.44	<0.001
Average diameter (cm)	Avg ± SE	49.63 ± 19.44	29.02 ± 15.44	22.07 ± 8.98	<0.001
Average height (m)	Avg ± SE	10.18 ± 2.27[a]	9.51 ± 2.75	10.09 ± 2.88[a]	<0.001
Average merchantable height (m)	Avg ± SE	4.08 ± 1.35	3.63 ± 1.49	2.58 ± 2.63	<0.001
Basal area (m^2/ha)	Avg ± SE	0.30 ± 0.10	2.46 ± 2.88	3.15 ± 1.30	<0.001
Height of Lorey (m)	Average	11.34	10.91	11.73	<0.001

NB: Avg, average; SE, standard error.
[a]No significant differences for these values.

Table 1.
Main forest characteristics of the three climatic zones.

Guinean zone). Regarding the merchantable height, it ranges between 4.08 ± 1.35 m (Sahelian zone) and 2.58 ± 2.63 m (Guinean zone). For this parameter, the difference observed among the three zones is statistically significant ($P < 0.001$; **Table 1**). For the height of Lorey, the values obtained for the three zones range between 10.91 m (Sahelian zone) and 11.73 m (Guinean zone) and indicate a significant difference ($P < 0.001$).

4.2 Demographic structures

4.2.1 Distribution of trees in diameter and height classes

The analysis of the demographic structure (distribution of trees in diameter classes and height classes (dbh ≥ 10 cm) of the *P. erinaceus* stands indicates a different situation depending on the climate zone considered (**Figure 7A** and **B**):

- In the Sahelian zone, the distribution of the *P. erinaceus* diameter classes reveals a predominance of the individuals with diameter classes ranging between 30 and 65 cm, that is, 55.09% of the entire stand. The young individuals with diameter class ranking between 10 and 30 cm and larger individuals with diameter ranging between 65 and 100 cm are very poorly represented, that is, 11.13, and 29.77%, respectively, of the stand (**Figure 7A1**).

- In the Sudanian zone, the distribution of diameter classes indicates a predominance of the individuals with diameter class ranging between 15 and 40 cm, that is, 74.4% of the stand. The young individuals with a diameter ranging between 10 and 15 cm and larger individuals with diameter ranging between 40 and 95 are poorly represented, that is, 17.11 and 8.4%, respectively, of the stand (**Figure 7A2**).

- The Guinean zone is characterized by a preponderance of individuals with diameter class ranging between 10 and 25 cm, that is, 69.10% of the stand. The individuals with diameter class higher than 25 cm are poorly represented, that is, 30.8% of the stand. All the structures in diameter are fit ($P > 0.05$) with the theoretical distribution of Weibull and shape parameters $c > 1$, characteristics of the stand with predominance of middle-aged individuals (**Figure 7A3**).

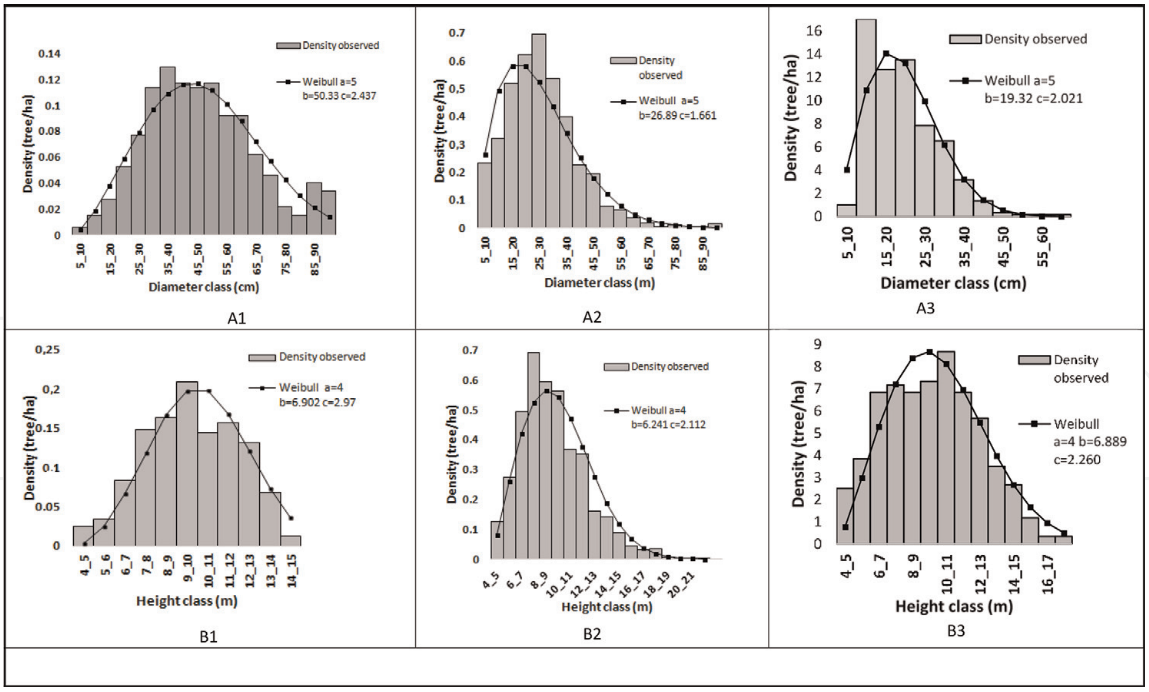


Figure 7.
Demographic structures of the stands of P. erinaceus in Guineo-Sudano-Sahelian zone: (A) diameter distribution and (B) height distribution.

The analysis of the structures shows a modal distribution of height classes for all the three climate zones. The individuals with heights ranging between 8 and 12 m are the most represented. These structures in height fit well with the theoretical distribution of Weibull ($P > 0.05$) with shape parameters c ranging between 2.1 and 2.9 (**Figure 7B1, B2**, and **B3**).

4.2.2 Natural regeneration capacity of P. erinaceus

P. erinaceus has a good regeneration capacity in seed, stump, and roots [16, 25]. Germination tests in Burkina Faso, Côte d'Ivoire, and Mali have shown that the species has a good germination capacity, with rates up to 95% if the seeds are shelled [17, 25, 30]. This should present good prospects for the production of seedlings for reforestation. Unfortunately, if the germination rate is very encouraging, this is not the case for the initial growth of seedlings. The main difficulties associated with the plantation of *P. erinaceus* are precisely the weak growth of young seedlings and their young flexible stem [17, 25]. This makes young seedlings vulnerable to wildfires, pests, trampling of animals, and adverse climatic conditions, preventing most of them from crossing the first years of life [9, 31].

In fact, the dynamics of natural regeneration of *P. erinaceus* show that the young plants come almost exclusively from underground stumps [9]. In natural conditions, the best regeneration technique for this species appears to be the regeneration of cut stems at 10 cm from the soil [17, 25].

5. *P. erinaceus* wood technology and ecological variability in West Africa

5.1 General characteristics of *P. erinaceus* wood

Studies carried out on *P. erinaceus* wood properties show that it could be classified in heavy and very hard wood with a density of 0.80 ± 0.07 g/cm^3 and an

Properties	Mean	Stand deviation	Minimum	Maximum	Coefficient of variation (%)
Basic density (g/cm^3)	0.80	0.06	0.61	0.92	8
Tangential shrinkage (%)	5.7	1	3.2	8.7	17.7
Radial shrinkage (%)	3.2	0.7	1.6	5.3	21.6
Anisotropy	1.8	0.2	1.2	2.2	12
FSP (%)	19.1	2.7	15.3	25	14
MOE (MPa)	14,500	1922	9717	19,127	13
MOR (MPa)	140	26.5	85.8	206.5	18.9
Compressive strength (MPa)	70	10	49	95	14.5
Monnin hardness	12	3.7	5.8	23.8	28.6

Table 2.
Main physical and mechanical characteristics of P. erinaceus wood.

average hardness of 12 ± 3.7 g/cm^3 (**Table 2**). In terms of dimensional stability, radial shrinkage and tangential shrinkage are yielding, respectively, 3.2 ± 0.7 and $5.7 \pm 1.0\%$, making *P. erinaceus* wood a stable wood with shrinkage anisotropy of <2. This high stability of *P. erinaceus* wood can be attributed to the high content of extracts (15.50–19.46%) of *P. erinaceus* wood [32]. Various studies on tropical

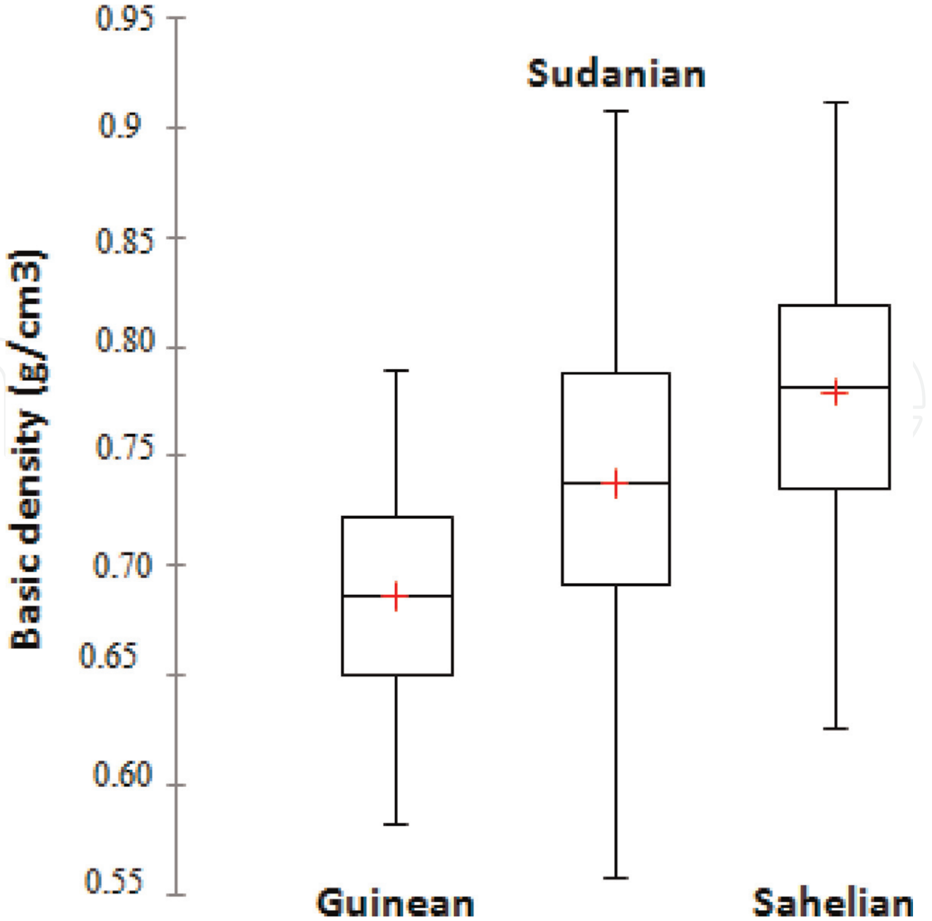


Figure 8.
Variation of basic density according to phytogeographic zones.

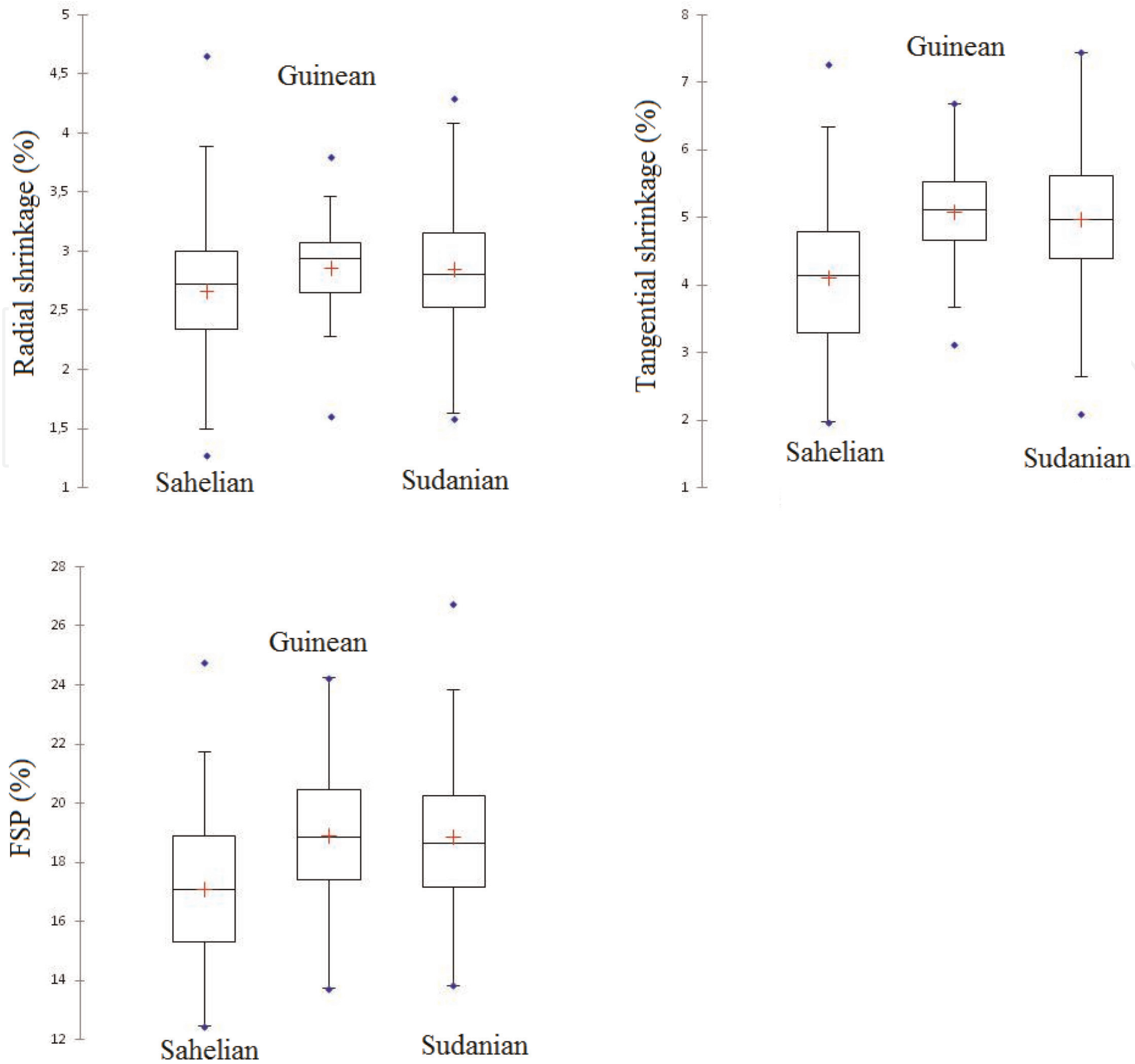


Figure 9.
Variation of radial and tangential shrinkage and FSP according to phytogeographic zones.

species such as *Pterocarpus soyauxii*, *Pterocarpus vernalis*, and *Swietenia macrophylla* confirm the close links between wood stability and extractable content [33]. Indeed, the presence of extracts enhances the stability of the wood by reducing the sensitivity to thermodynamic variations of the environment.

The average compressive and static bending fracture stresses are, respectively, 70 ± 10 and 140 ± 2.5 MPa, and the modulus of elasticity is in the order of 14,500 ± 1922 MPa [13]. The physical and mechanical characteristics of *P. erinaceus* wood confirm that certain uses of this wood in several African countries are quite appropriate, notably the manufacture of acoustic materials [13]. Empirically, the wood of *P. erinaceus* is known and sought, among other things, for making xylophone in West Africa and Sahel. Mostly wood used to produce xylophones are of high density (between 0.80 and 0.95 g/cm^3) and a high modulus of elasticity in the range of 14–20 GPa [34]. Moreover, [35, 36] have shown that the use of wood in such case requires a high insensitive to humidity variations.

5.2 Variability of properties of *P. erinaceus* wood

5.2.1 Variability of physical properties

Analysis of *P. erinaceus* wood density according to phytogeographic zones indicates significant variability ($P < 0.05$). This variability results in an increase in the

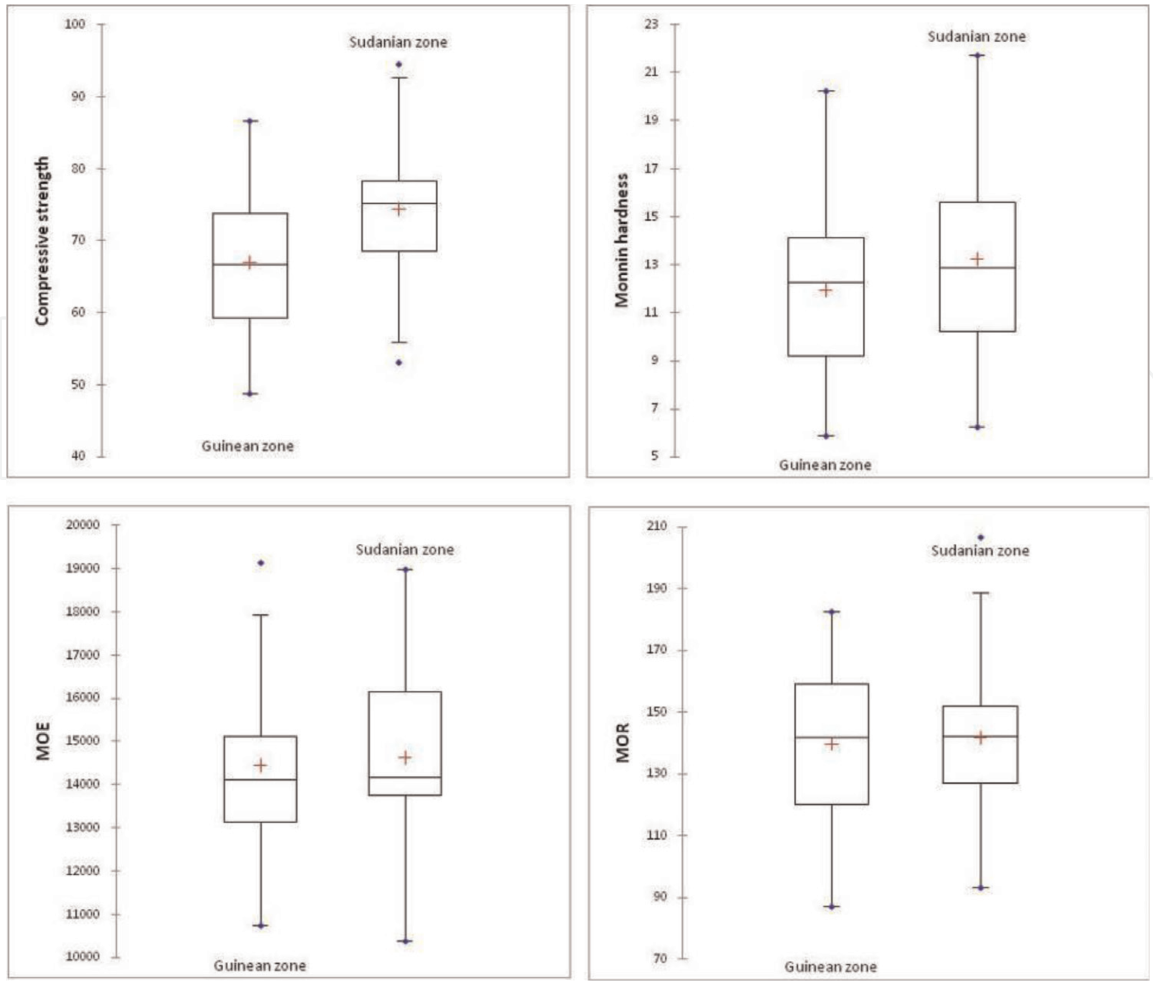


Figure 10.
Variation of mechanical properties according to phytogeographic zones.

density following the decreasing rainfall gradient in North–South [37]. The highest value of density is obtained in the Sahelian zone (0.78 ± 0.01 g/m^3) and the lowest in the Guinean zone (0.68 ± 0.01 g/m^3; **Figure 8**).

Like wood density, radial and tangential shrinkage and FSP vary significantly from one phytogeographic zone to another ($P < 0.05$). Indeed, the trees of *P. erinaceus* from the Sahelian zone present radial (2.7%) and tangential (4.1%) shrinkages significantly lower than those of the Sudanian and Guinean zones. The radial shrinkage gives an average of 2.8 and 2.95% for trees from the Guinean and Sudanian zones, respectively. As for shrinkages, the trees of the Sahelian zone have a FSP (17.1%) significantly lower than the other (**Figure 9**). In other words, the trees of *P. erinaceus* in the Sahelian zone have a more stable wood than the trees in the Guinean and Sudanian zones [37].

Regarding the influence of the radial position, only the FSP is negatively related to the cambial age [13]. This is consistent with the results of [36], which showed the influence of the level of extract, especially with benzene alcohol, on the PSF. For wood density, the work of [37] showed a very small decrease in density as a function of cambial age (R^2 = 0.11). This generally shows that the physical properties of *P. erinaceus* wood remain very little, if any, influenced by cambial age.

5.2.2 Variability of mechanical properties

The climatic variability of the mechanical properties was analyzed according to two phytogeographic zones (Guinean and Sudanian; data on the Sahelian zone are not available). The analysis of the average values of the mechanical properties according to the phytogeographic zones does not indicate a significant difference ($P > 0.05$) for the MOE, the hardness, and the static bending strength (MOR) (**Figure 10**). Indeed, the MOE indicates, respectively, 14,150 ± 1900 and 14,100 ± 2300 MPa for the Guinean and Sudanian zones. For Monnin hardness, the values indicate on average 13.09 ± 3.87 in the Sudanian zone and 12.08 ± 3.33 in the Guinean zone. As regards static bending fracture stresses, it gives an average of 137.5 ± 25.5 MPa in the Guinean zone and 145 ± 27.5 MPa in the Sudanian zone. Only the values of the compressive strength vary significantly from one zone to another ($P < 0.05$). It is 66.5 ± 9.4 MPa in the Guinean zone and 73.5 ± 10.3 MPa in the Sudanian zone.

In terms of the variability of properties according to the age, the analysis of the mechanical properties according to the number of rings counted from pith to bark showed that only the compressive and static bending strength were correlated with the cambial age [13]. The juvenile wood zone appears slightly more "resistant" in compressive strength and MOR than the adult wood zone. But this correlation remains weak, as shown by the coefficients of determination obtained (compressive strength: $R^2 = 0.09$, MOR: $R^2 = 0.13$). Age would therefore have very little influence on the mechanical properties of wood.

6. Restoration and conservation of *P. erinaceus stands in West Africa*

6.1 Large-scale plant production strategies of *P. erinaceus* for restoration programs of degraded forest ecosystems

The production strategies of *P. erinaceus*, like all plant species, are based on the use of classical cultural methods of sexual propagation (seedling germination) and vegetative propagation (horticultural cuttings, layering, etc.).

6.1.1 Sexual propagation

Several studies indicate that natural regeneration is often abundant and that the species may be somewhat invasive enough to be preserved for a few years from grazing, bush fires, vegetation, and pruning [17, 38]. For germination, all the seeds extracted from fruits can be used. It is essential to ensure the good health of these two organs and to avoid taking those who have suffered attacks (animals, insects, fungi, etc.), mechanical damage (breakage, injury, and holes), etc. Germination rates (70–90%) can be obtained with seeds extracted from fruit collected directly on the trees or collected on the ground. With healthy seeds from fruit hulling, sown without pretreatment on cotton soaked in distilled water, average germination rates were recorded at 84% for of 2 days of germination trials.

The substrate used during these trials was composed of vermiculite, vermiculite + earth (1v/1v) and vermiculite + compost (1v/1v), with cotton or paper as support (**Figure 11**). The seedlings of *P. erinaceus* are quite fragile at germination and are not able to support the weight and opacity of a compact substrate. There is no specific pretreatment to apply to seeds, but they can be soaked in water for 24 h before sowing to hasten their hydration and promote homogenous germination. The first germinations are observed 24 h after sowing [38, 39]. The advantage of the use of seedlings lies in the fact that they lead to variability in the monitored seedlings.

The influence of seed storage period on their germination capacity shows greatly variable germination capacities, with a maximum of 93.75% and a minimum of 10.71%, with general decrease in the germination rate between the fifth and the ninth month. The germination capacity varies according to the origin of the seeds.

Figure 11.
Nursery of P. erinaceus on vermiculite in seedling cells.

6.1.2 Vegetative propagation of P. erinaceus

6.1.2.1 Marcottage ability of Pterocarpus erinaceus

6.1.2.1.1 Rooting rate of marcots

Ref. [40] revealed that from 100 marcots monitored, 97 were stripped. The rooting rate observed is 55.67%. In the apical part, 18 marcots were unpacked with an average diameter of 11.33 ± 2.53 mm, and 9 of them rooted, which have a success rate of 50%. In the unattached middle part of 37 with an average diameter of 19.30 ± 4.01 mm, 16 have rooted which gives a rate of 56.75%. Among the 42 marcots of the proximal part whose average diameter is 21.87 ± 3.95 mm, 24 root coots have rooted with a success rate of 57.14%. In general, it was founded that the marcots made in the proximal part of the tree gave the highest success rate (**Table 3**; **Figure 12A, B,** and **C**).

Table 3 illustrates the relationship between the success rate and the diameter classes of marcotted stems. Indeed, the rods' diameter between 20 and 30 mm followed by rods with a diameter of between 10 and 20 mm has the highest success rate. Stems with a diameter of between 5 and 10 mm have only a success rate of 20%.

6.1.2.1.2 Ability of marcots' rooting

The success rate observed is about 55.6% [40]. The analysis of the success rate, i.e., the rate of rooting of the layers, showed that the layers of the proximal part located near the main stem of the tree are more suitable for layering with a rate of 57.14% followed by middle-aged layers with a rate of 56.7%, at the center of the branch; the lowest marcotting ability is observed at the level of the apical layer, i.e., at the end

Levels	Initial number	Average diameter (mm)	Rooted number	Success rate (%)
Apical	18	11.33 ± 2.53a	9	50.00
Median	37	19.30 ± 4.01b	21	56.75
Proximal	42	21.87 ± 3.95c	24	57.14

Table 3.
Rooting rate and number of rooted marcots.

Figure 12.
Marcots ingrained legend: (A) marcot unpacked, (B) marcot with clod of soil, and (C) roots produced and rid of clods of earth.

of the branch toward the terminal buds with a rate of 50%. The evolution of this rate shows that the success of marcottage depends on the age of the marcotted branch part. Indeed, the level located near the main stem is the oldest and in addition has the highest average diameter capable of storing a large amount of sap developed in its liber and supporting rhizogenesis.

6.1.2.2 Budding ability of Pterocarpus erinaceus stem cuttings

Experimental trials were conducted to evaluate the effect of the indoleacetic acid (IAA) dose, cutting diameter and soaking time on the budding, and degeneration and rooting of *P. erinaceus* cuttings (Appendix 2). With this, two sets of experiments were carried out to assess the effect of IAA dose, diameter of cuttings and soaking duration on budding, and degeneration and cutting rooting of *P. erinaceus*. The first experimental tests were designed on the basis of three factors that are diameter of the cuttings with two levels ([0–1.5 cm] and [1.6–3]), the dose of IAA with six levels (0, 500, 750, 1000, 1500, and 2000 mg/l), and soaking duration in IAA with four levels (0, 10, 20, and 30 min).

A total number of 48 ($2 \times 6 \times 4$) treatments, repeated 11 times, were established. The data collected were related to the number of cuttings budged and number of cuttings that degenerated after diameter of shoots as well as number of leaves produced.

Based on these tests, it was pointed out that the budding started on the fourth day after establishment of the tests. The budding rate of the cuttings is 79.8% after 8 weeks. The budding rates are statistically similar whatever the diameter class

(78.89, 80.56, and 80.56%, respectively, for cuttings with diameter comprising [2–2.5 cm], [2.6–3 cm], and [3.1–3.5 cm]). In contrast, levels of IAA dose and soaking duration of cuttings have statistically significant ($P < 0.05$) effects on the budding (**Table 4**). The chances of budding of the cuttings soaked in IAA at doses 750, 1500, and 2000 mg/l are, respectively, 5.70, 2.55, and 3.71 times higher than the control tests (without application of IAA). All cuttings treated with IAA showed a budding rate much higher (>80%) than the one in control tests (62.22%, **Figure 10**). Similarly, budding rates after 8 weeks range from 79.26% for cuttings soaked for 10 s to 89.63% for cuttings soaked for 1 h (**Figure 13**).

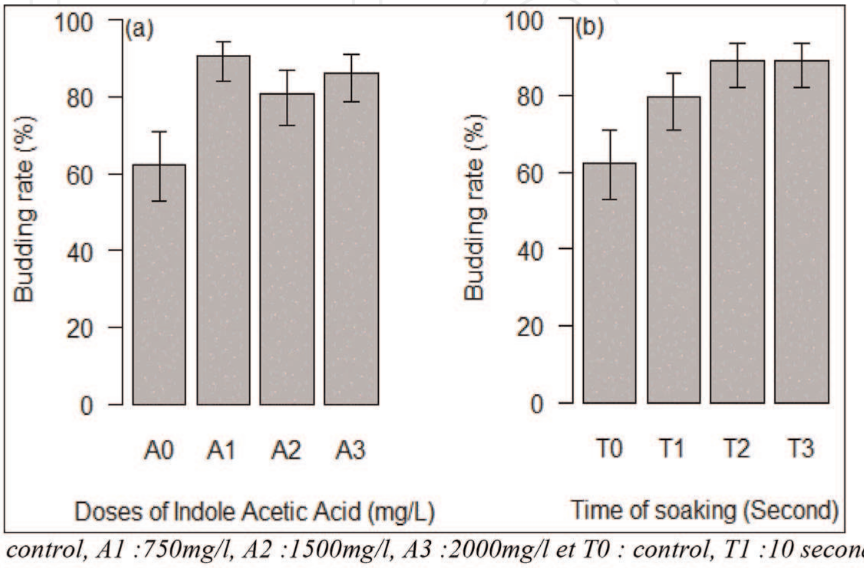
6.1.2.3 Cutting diameter and IAA appropriate dose for successful rooting in P. erinaceus stem cuttings

The efficiency of cutting success is largely related to rooting. Indeed the budding alone does not explain the chances of survival of the young shoots because it is based on the reserves stored by the cuttings to occur. So after the depletion of these reserves in the absence of a root system that can take over to feed the young shoot, it dries up and dies. This explains the favorable budding and bud bursting response

Treatments	Odds ratio	STD	P > |z|
	IAA dose (mg/l)		
750	5.70	1.95	0.000
1500	2.55	0.72	0.001
2000	3.71	1.13	0.000
	Soaking duration (s)		
10	2.32	0.64	0.002
1200	4.86	1.59	0.000
3600	4.86	1.59	0.000

STD, standard error; P, budding probability at 5%.

Table 4.
Effect of diameter class, IAA dose, and soaking time on the budding of P. erinaceus after 8 weeks.



Legend : A0 : control, A1 :750mg/l, A2 :1500mg/l, A3 :2000mg/l et T0 : control, T1 :10 seconds, T2 :1200 seconds, T3 :3600 seconds

Figure 13.
Budding rates of the cuttings according to doses of IAA (a) and time of soaking (b) after 8 weeks.

observed in the three diameter classes. This result corroborates perfectly those of [38, 41] revealing that diameter has a marginal effect on bud development.

However, contrary to previous trials that concluded that stem cuttings of *P. erinaceus* cannot be rooted and degenerated after a while [38, 41], the results of the previous trial show that cuttings with diameters between 2 and 3 cm can root perfectly when soaked in IAA dose of 1500–2000 mg/l for 20 min to 1 h. In this experiment, cuttings with small diameter, non-soaked cuttings (control), and cuttings soaked in IAA for 10 s have not rooted. The cuttings that survived with leafy shoots until 24 weeks are those which made large amount of callus and rooted sufficiently as the callus formation is a necessarypreliminary for cutting rooting (**Figure 14**).

6.2 Minimum felling diameter of *P. erinaceus*

Ref. [42] determined *P. erinaceus* minimum felling diameter to ensure a sustainable management of its natural stands in West Africa. The methodological approach was based firstly on the calculation of the restoration rates and the rotation cycles and secondly on the distribution of the stand basal area in diameter classes. The results show that for the Guinean and Sudanian zones, the best restoration percentage ($P \geq 50\%$) is obtained for 35 m in diameter. Percentages equivalent to 356.5% are therefore obtained for the Guinean zone and 53.4% for the Sudanian zone for a rotation period estimated at 20 years (Appendix 3). In the Sahelian zone, the best restoration percentage ($P \geq 50\%$) is only obtained when testing the 65 cm diameter.

Figure 14.
Rooted cuttings of Pterocarpus erinaceus: a: cutting with callus; b&d: rooted cuttings without clod of soil; c: rooted cuttings with clod of soil.

For this diameter, a restoration rate is obtained at 111.9% for a rotation period estimated at 20 years (Appendix 3).

In addition, the distribution of the basal areas per trees diameter classes recorded in each of the three climate zones indicates a curve which is similar to a bell-shaped distribution. Therefore, for the Guinean and Sudanian zones, the maximum value of the basal area is obtained for the center with diameter class equal to 35 cm (**Figure 15**). As for the Sahelian zone, the maximum value of the basal area is obtained for the center of the diameter class equal to 65 cm.

In view of the foregoing results, two minimum felling diameters for Guineo-Sudano-Sahelian zone in West Africa are considered. This includes the diameter 35 cm for the Guinean and Sudanian zones (P = 356.5% for the Guinean zone and P = 53.4% for the Sahelian zone for a rotation of 20 years) and the diameter 65 cm for the Sahelian zone (P = 111.9% for a rotation period estimated at 20 years).

The analysis of the restoration percentages depending on the diameter classes and the time helps deducing that the *P. erinaceus* stands are restored in a relatively shorter time in Guinean zone. However, the Sahelian zone seems not to offer favorable conditions for the rapid restoration of this species stands (**Figure 13**). The high restoration rate of the species in the Guinean zone may be explained by the fact that the exploitation of the species there is frequently timber. This form of exploitation allows the selective cutting of the large-diameter trees and leaving behind the seedlings. Since the ecological conditions are favorable in this zone (high rainfall), there is a regeneration (usually in the form of stump sprouts), and seeds are produced. However, in the Sahelian zone, the pollarding for fodder is an important exploitation form of the species.

6.3 Conservation measures to preserve *P. erinaceus*

The intensity of the exploitation of the species sparked off concerns about its sustainability among a range of countries including Benin, Burkina Faso, Ghana, Senegal, and Togo. In order to curb the unrestrained exploitation of rosewood, countries (including Ghana and Togo) adopted harvesting and timber/log export

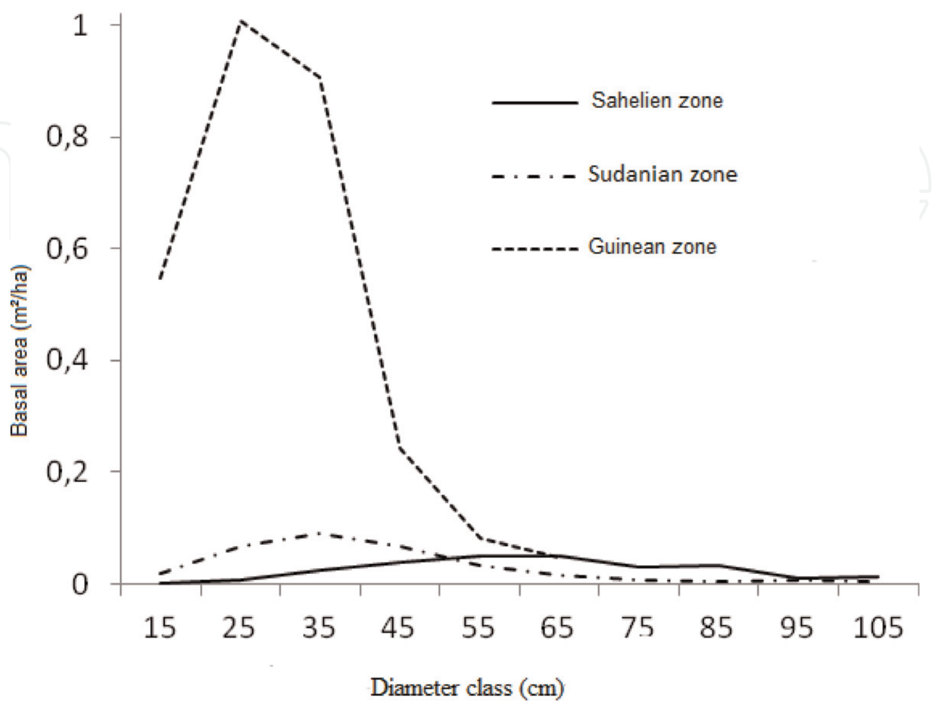


Figure 15.
Distribution of the basal area in terms of diameter classes across climatic zones.

bans. However, these regulations were routinely violated. Chinese custom data showed continuous rosewood export from producer countries under timber/log export ban for well over 2–3 years under after the bans were imposed.

Consequently, seeking stricter control of exploitation and trade of rosewood, Senegal and other range countries in West Africa listed the species on CITES Appendix III in 2016 and later up-listed it to Appendix II in 2017. In spite of the CITES Appendix listing, there are still incidences of illegal logging and trade in the exporting and importing countries. Due to incidence of illegal logging and irregularities in the issuance of CITES permit, Nigeria has recently (effective November 2018) been suspended from trading in *P. erinaceus* until it adequately addresses issues of forest law enforcement trade and governance.

Faced with these situations, some countries have placed a moratorium prohibiting its exploitation (the case of Togo where a moratorium has been put in place since June 2016). This decision of the Ministry of the Environment and Forest Resources of Togo was largely based on the results of our studies and warnings of the status of the species in the country. In 2016, the African Union organized a symposium on the illegal exploitation of the species in Guinea-Bissau. During this symposium, it was clearly pointed out that the abusive exploitation and the bush fires make the renewal of the natural stands of *P. erinaceus* difficult.

The increased rate of unsustainable exploitation and illegal logging of *P. erinaceus* is driven by noncompliance and ineffective enforcement of regulatory framework governing timber exploitation and trade. Rosewood exploitation and trade have continued despite the ban in the affected countries and/or strict trade regulatory control such as CITES. National regulatory frameworks and law enforcers' endeavors within national territories have proved helpless against regional and intercontinental trade dynamics. The situation does not only deprive local communities (where the species is endemic) of due economic benefits but also deprives the state of huge revenue such as taxes and fees that could have been used for national development. For example, in 2013, it was estimated that Ghana lost 70% of the revenue that should have accrued to the state due to illegal exploitation of rosewood [12]. The limited effectiveness of the domestic measures against rosewood exploitation and the recent irregularities in the issuance of CITES permit in Nigeria call for a stronger regional collaboration and robust and technologically advanced timber tracking system and wood identification methods that can help stem illegalities.

P. erinaceus is also one of the priority species that focused the attention of number of scientists. Then several authors have pointed out the increased rate of illegal felling and over export of the species in African countries such as Benin, the Gambia, Ghana, Guinea-Bissau, Nigeria, and Mozambique [43–46]. Faced with this persistent threat, the domestication of this species is important to ensure its sustainability. Several actions have been carried out in favor of the species to reduce the pressure on it and make it an opportunity for the region. Assessing the impact of felling/export ban and CITES designation on the exploitation and trade of the species in Ghana [12] has concluded on the necessary ex situ conservation measures such as seed banking, field gene banking, tissue culture, and plantation development to conserve this endangered plant species in order to avoid the possibility of commercial extinction.

7. Conclusion

The analysis of the state of knowledge on natural stands of *P. erinaceus* in West Africa has shown that different social and sociocultural categories know and use the products of the species. Approximately 46 uses have been identified by the different sociocultural and socio-professional groups. In addition to using the species as lumber, fuel wood, and fodder, *P. erinaceus* is widely used as a medicinal plant.

In terms of the forest characteristics of *P. erinaceus* stands, studies indicate a significant difference in density, average diameter, mean total height, and basal area between the three climatic zones. The Guinean and Sudanian zones seem to present more favorable environmental conditions for the development of *P. erinaceus* stands. Regarding the potential and strategies of natural regeneration, studies have shown that the species has a good capacity of natural regeneration by sowing, stump rejects, suckers, and marcots. This opens up prospects for the production of seedlings and planting trials with *P. erinaceus* for the restoration of degraded natural stands. The results also showed that *P. erinaceus* has a very high ecological plasticity allowing it to adapt in several different climates. This large ecological range of the species offers opportunities to set up conservation plots in reserved areas regardless of site conditions in West Africa.

Studies have shown a difference in the properties of *P. erinaceus* wood according to climatic zones. This difference is reflected in the superiority of the properties of trees from the Sahelian zone followed by those of the Sudanian zone. This result provides information to the West African forest services on the behavior of this species, which could be the subject of a plantation program. In addition, knowledge of the technological characteristics of *P. erinaceus* wood according to the conditions of the environment and the age contributes to the management of the forest resources to ensure a sustainable production of wood. Indeed, these characteristics are among the important criteria to be included in the selection. For a long time confined to the selection of the growth, survival of trees, the current strategy for the genetic improvement of forest species is to include wood quality criteria.

Finally, to promote the rapid restoration of *P. erinaceus* stands, two regionalized minimum felling diameters were proposed based on the results of the structural parameter evaluation and the reconstitution percentage calculations and rotation times. For the Guinean-Sudanian zones, the minimum felling diameter adopted was 35 cm for a restoration percentage of 366.6 (Guinean zone) and 53.4% (Sudanian zone) for a period of 20 years. In the Sahelian zone, the minimum felling diameter adopted was 65 cm for a rotation period of 20 years. These parameters are an essential tool to limit over-logging of forest tree species and to ensure their sustainable management. Various forest authorities will consequently have scientific tools to better protect forest resources through the enforcement of restrictive measures concerning the selective logging of valuable timber.

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Appendices: vegetative propagation protocol by air layering

A.1 Theoretical and methodological framework

P. erinaceus, which is particularly appreciated for its wood and the quality of the fodder it provides, is threatened in several localities in western Burkina Faso [20]. Natural seedlings are very infrequent, and their survival after one or two dry seasons as well as that of young plantations is very low. The study of its regeneration by economic means such as “vegetative propagation” could then promote the regeneration of the species and increase the possibilities of its exploitation and its valorization in Burkina Faso and Niger and in many other forest subregions [22].

Furthermore, the scientific and technical information necessary for good control of reproduction and vegetative propagation of this species is not yet available. In addition, in the field of low-cost vegetative propagation (PVFC), very few trials have been carried out in the world and especially in Africa [22].

Layering consists in inducing the appearance of roots on the stems of a woody species. This is done by contacting the stems with a suitable substrate (soil, sawdust, etc.). When the branch or stem of a woody species is placed directly against the ground to induce the root system, it is called layering. When the contact with the substrate is above ground, it is called air layering.

A.2 Experimental protocol

Beforehand a mixture of earth and sawdust was prepared. The mixture consists of 40% sawdust and 60% earth. For each marcot, two annular incisions spaced from each other by 5 cm in height and without damaging the wood are applied to the branch. This results in a vertical incision of the bark from one annular incision to another. The portion of the bark is removed, leaving bare wood (**Figure A1A**). The consequence is the interruption of the circulation of the sap developed from the upper part to the lower part of the incised stem. The bare part of the bark is wrapped with a transparent plastic sheet containing the mixture of earth and sawdust that serves as a support for the roots.

Then seal the ends together with the tape while taking care not to trap the air. This support covers up to 10 cm on either side of the incised part, that is to say, to create a sufficiently large substrate to allow the possible roots to grow normally (**Figure A1B**). The supply of water is provided by injection with the aid of a syringe. In general, watering was done weekly. If the marcot is dry, a quantity of 20 ml can be injected or twice a 10 ml syringe. After the injection of water, the holes induced by the needle of the syringe are immediately closed with tape to minimize the evaporation of water.

Figure A1.
Aerial carving of P. erinaceus. (A) Annealing of the stem and (B) soil wrapped by a plastic sheet.

B. Experimental design and data collection for vegetative propagation of *P. erinaceus* by stem cuttings

Pterocarpus erinaceus stems were harvested from healthy mature trees whose diameter at 1.30 m ranged from 15 to 35 cm, in the morning before periods of high temperatures to limit their dehydration. Cuttings were collected at approximately the same levels on young branches. Stem cuttings were 15 cm length and with 20 cm diameter. Two sets of experiments were carried out to assess the effect of indoleacetic acid dose, diameter of cuttings and soaking duration on budding, and degeneration and cutting rooting of *P. erinaceus.*

The first experimental tests were designed on the basis of three factors that are diameter of the cuttings with two levels ([0–1.5 cm] and [1.6–3 cm]), the dose of

Figure A2.
Experimental settlement in the nursery: Pterocarpus erinaceus cuttings.

IAA with six levels (0, 500, 750, 1000, 1500, and 2000 mg/l), and soaking duration in IAA with four levels (0, 10, 20, and 30 min). A total number of 48 (2 × 6 × 4) treatments, repeated 11 times, were established. The data collected were related to the number of cuttings budged and number of cuttings that degenerated after diameter of shoots as well as number of leaves produced.

As all cuttings with a diameter comprising between 0 and 1.5 cm having budded (including the control) degenerated within 20 days after budding while some of those with diameter >2 cm rooted, another experimental test was settled in a split plot design based on the previous three factors, changing the modalities as followed: cutting diameter with three levels ([2–2.5 cm], [2.6–3 cm], and [3.1–3.5 cm]), the dose of IAA with three levels (750, 1500, and 2000 mg/l), and soaking duration in IAA with three levels (10 s, 20 min, and 1 h). A total number of 27 (3 × 3 × 3) treatments, repeated three times, were established. The main factor was the cutting diameter.

The subsidiary factors were randomly distributed in the sub-blocks. There was one control in each sub-block exempt of IAA treatment. The experimental tests were conducted on 540 leafless stem cuttings and put in pots filled with forest soil substrate (**Figure A2**). The plots were manually watered one–two times per day. Data collected were related to the cutting budding, bud bursting, number of shoots, shoot diameter, and height. The number of budded cuttings and leafy shoots was noted weekly for 8 weeks. The number of rooted cuttings, diameter, and height of leafy shoots was noted until 24 weeks.

C. Minimum felling diameter of *P. erinaceus* in Guineo-Sudano-Sahelian zone

Diameter classes (cm)		15	25	35	45	55	65	75	85	95	105
Transition time (years)		10	30	50	70	90	110	130	150	170	190
Recovery percentage (%)	Guinean zone	0	37.3	356.5	1589.3	4648.7	4694.9	—	—	—	—
	Sudanian zone	0	6.9	53.4	206.7	534.9	1064.1	1765.5	2312.7	5073.6	5063.5
	Sahelian zone	0	0.3	3.1	14.6	41.9	111.9	235.6	626.6	1282.5	1316.3

Source: Segla et al. [38].

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