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Article

Impact of salinity on density and mechanical strength of *Avicennia germinans* wood exposed to marine oil pollution in the Gabon Estuary

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Abstract: Located at the interface between land and sea, mangroves develop both near the sea and inland. However, mangroves that develop inland have to cope with variable, high salinity; and urban pollution, as is the case with the mangroves of the Ambowé lagoon in Greater Libreville. Salinity is an important parameter for mangrove growth. The aim of this work was; yes itto show the impact of salinity on the density and mechanical strength of *A. germinans* wood exposed to hydrocarbon pollution. To this end, wood samples taken from the polluted Ambowé site were analyzed in the laboratory for wood and physical-mechanical properties. The data obtained were compared with wood samples taken from the unpolluted Oveng site, which has a higher salinity. The results show that for the polluted wood showed wider rings, lower wood density and mechanical strength with values of 0.91 ± 0.05 and 70.28 MPa, respectively. Also, the rings and vessels of Oveng wood are narrower than those of Ambowé wood. These differences are linked to salinity. Salinity therefore affects the density and mechanical strength of *A. germinans* wood exposed to hydrocarbon pollution.

Keywords: Mangroves; oil pollution; salinity; density; mechanical strength

1. Introduction

Mangroves develop at the interface between land and sea, and inland. This position gives mangroves an important ecological and socio-economic role. Ecologically, they stabilize coastlines against coastal erosion, protecting coastal populations from floods, tsunamis and storms; they also provide habitat for numerous fishery resources, including fish, crabs and shrimps; and they act as carbon sinks [1], sequestering 3 times more carbon dioxide than other types of tropical forest [2]. On a socio-economic level, local populations practice artisanal fishing and crab trapping, which are directly dependent on the resources sheltered by mangroves [3]. They feed on these resources and sell them to meet their own needs.

However, mangroves that develop inland are under greater anthropogenic pressure, notably from pollution and deforestation. A recent study by the [4] shows that mangroves in Gabon have declined by 6.5%. Between 2000 and 2014 in the Libreville region alone, losses were estimated at 86.01 km^2 [5]. In addition to this factor, which is causing a decline in the number of mangrove trees, pollution is also affecting the properties of mangrove wood. Multifactorial urban pollution (plastic waste, paint, motor oil, etc.) at the Ambowé site in Greater Libreville has altered the anatomical and chemical properties of *Avicennia germinans* wood [6]., while open dumping at the Alenakiri site has caused the death of standing mangrove trees [7].

Inland mangroves, on the other hand, face urban pollution and variable salinity. Indeed, the fact that mangroves growing near the sea are flooded twice a day on average by seawater, have an almost constant salinity [8], unlike those growing inland, which have a variable salinity [9]. Salinity is a key factor in mangrove growth. Low salinities are favorable to mangrove growth [10], but high salinities compromise mangrove growth [11]. In areas of high salinity, there is an increase in vessel density and a decrease in vessel diameter [12]. Urban pollution also compromises mangrove growth, and can even lead to their destruction. Certain pollutants, such as heavy metals, cannot be biologically or chemically degraded, and can therefore only accumulate in the mud and wood tissues of mangroves [13], and their effects are very quickly cumulative, and above certain threshold levels, mangroves begin to wither [14]. A case in point is the pollution of the Alenakiri site, characterized by an open dump that caused the death of standing *Avicennia germinans* trees [6]. Oil pollution also clogs the lenticels in mangrove roots, virtually suffocating the mangroves and causing them to die [15]. In addition to the impact of pollution at tree level, it also modifies the properties of mangrove wood. Hydrocarbon pollution at the Ambowé site, for example, altered the anatomical structure of *Avicennia germinans* wood at both macroscopic and microscopic levels, and caused a sharp drop in the content of apolar extractables [16].

Salinity is a key factor in mangrove growth. Low salinities are favorable to mangrove growth, but high salinities compromise mangrove growth [9,11]. A correlation has been established between salinity and the density of mangrove wood, and in areas of low salinity, *A. germinans* wood has a low density [8]. Indeed, wood density depends on the proportion of the number of fibers, but above all on the thickness of the fiber walls [16], and in areas of low salinity, *A. germinans* has a low fiber wall thickness [8]. Density also varies significantly between species, diameter classes and environmental salinity [17].

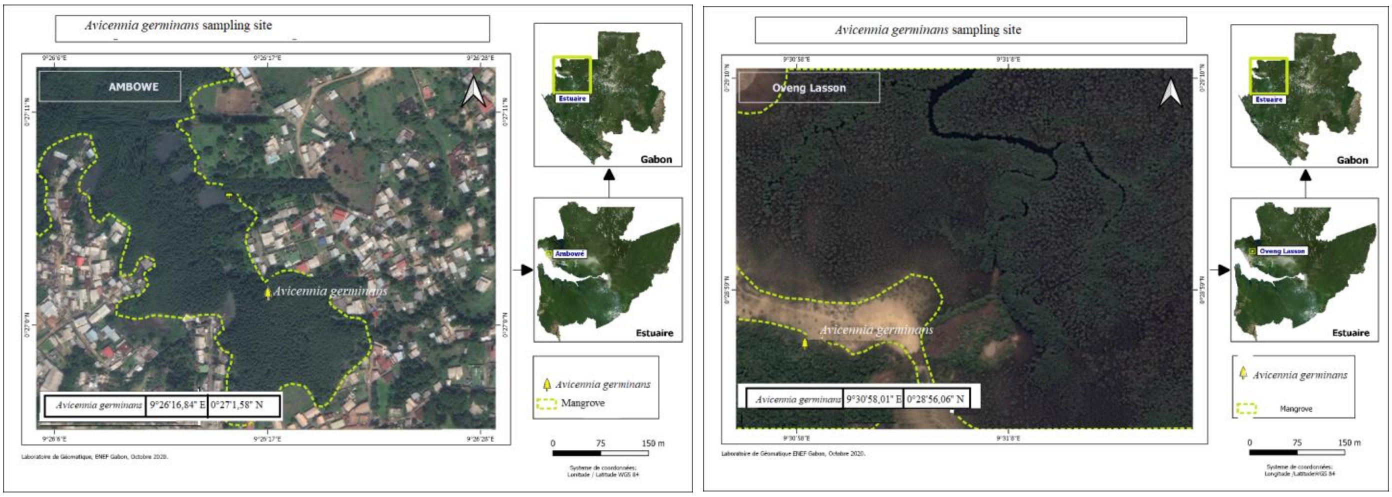
The mangroves of Libreville, Gabon’s political capital, precisely those at the Ambowé lagoon site, are subject to hydrocarbon pollution, but also to high salinity, especially in the dry season. Previous studies indicate that wood can manifest changes in chemical and mechanical properties through cambium dysfunction in response to environmental stresses [18]. However, since there are two factors that can affect the quality of mangrove wood, it is important to decouple salinity from pollution in order to identify the factor responsible for the quality of *A. germinans* wood. Despite the work carried out by the aforementioned authors, no studies showing the impact of salinity on the physicomechanical properties of mangrove wood exposed to hydrocarbon pollution have been published in the past.

Thus, the aim of this work was to show the impact of salinity on the internal structure, density and mechanical strength of *A. germinans* wood exposed to hydrocarbon pollution.

2. Material and methods

2.1. Study sites and sampling

Avicennia germinans trees were collected from two different sites in the Libreville area. The Ambowé polluted site (0°27′663″ N; 9°26′1485″ E) with a soil salinity of 29.3 g/l is located in the middle of an urban area. This site is subject to intense human activity, which discharges fishing and motor oils, plastic and other domestic waste. On the other hand, the unpolluted oveng site (0°28′5169″ N; 9°30′9994″ E), with a salinity of 35.36 g/l, is not located in an urban area (**Figure 1**). On each site, three vigorous *A. germinans* trees of similar diameter (70–80 cm) were harvested. Five centimeters thickness trunk discs were cut at 1.3 m above the ground.



(a) **(b)**

Figure 1. The various study sites. **(a)** Ambowé polluted site; **(b)** Oveng unpolluted site.

2.2. X-ray tomography

To determine whether the pollution had altered the internal structure of the material, X-ray tomography analyses were carried out on 1cm^3 wood blocks using a 39-watt X-ray tomograph (RX solutions, France). The acquisition parameters used were a voltage of 107 kW and a current of 74 µA at the anode. Voxel size was 12.8 µm.

2.3. Wood density analysis

The dimensions of the wood specimens were chosen in accordance with NF ISO 13061-17 (16 June 2018). Twenty-two heartwood samples measuring 30 mm × 20 mm × 20 mm in longitudinal, radial and tangential directions respectively were stabilized at 20% relative humidity in a laboratory (12 ± 2 °C and 65 ± 5% relative humidity) for constant mass sample conditioning for 2 weeks. The 6 faces were then measured with a caliper to obtain precise measurements. These specimens were then weighed using a balance (Sartorius model SIWSBBP-1-06-H), precision ± 0.001 g, to obtain the mass of the specimen in the anhydrous state. The density of each specimen was measured as the ratio between the anhydrous mass and the volume of wood in each specimen at 12% moisture content, according to the following formula:

$$D = \frac{M0}{V}$$

where,

M_0 = oven-dry mass of the wood;

V = specimen volume.

2.4. Axial compression force

The same specimens used to calculate density were used for axial compression testing. The test consists in subjecting a specimen in the shape of a square prism, placed between two press platens, to two opposing axial forces until the specimen breaks Testing began as soon as the top plate came into contact with the specimen. The test starts as soon as the top plate comes into contact with the sample

The specimens (30 mm × 20 mm × 20 mm) were subjected to a load of 20 KN and a feed rate of 0.05 under progressively increasing force until the specimens broke.

The curve of applied force F versus displacement Δl of the force cell was obtained using the test machine's acquisition program (**Figures 2** and **3**)

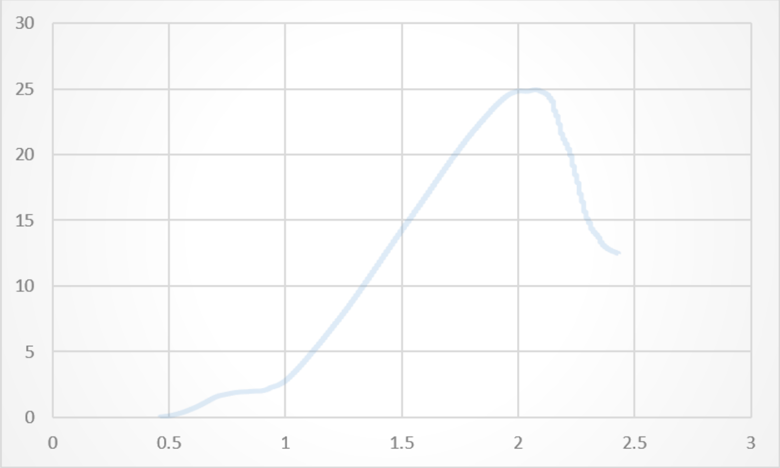


Figure 2. Force vs. displacement curve for *Avicennia germinans* wood collected at the polluted Ambowé site (Fc,0 = 70.28 Mpa).

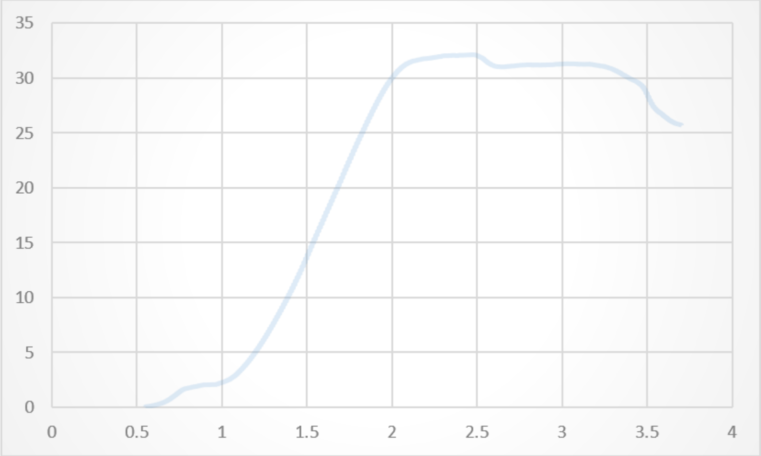


Figure 3. Force vs. displacement curve for *Avicennia germinans* wood collected at the unpolluted Oveng site (Fc,0 = 78.28 Mpa).

The compressive failure stress ϭ corresponds to the maximum stress reached (**Figures 2** and **3**). The ultimate compressive stress parallel to the grain of each specimen was calculated in N/mm^2 (MPa) using the formula:

$$\sigma \mathrm{e}, 0, \mathrm{c} = \frac{F\mathrm{max}}{a \times b}$$

where

$F_{\max}$ = maximum load in KN;

a et b are the cross-sectional dimensions of the specimen, in mm.

2.5. Data analysis

All the data were analyzed using Student's t-test at a significance level $\alpha = 0.05$.

3. Results and discussion

3.1. Wood anatomy

Wood is a material with an internal structure comprising a number of tissues, including vessels, parenchyma and growth rings. **Figure 4** shows the internal structure of wood from the unpolluted Oveng and polluted Ambowé sites. This figure shows that for unpolluted wood from Oveng, the width of the rings between two parenchyma bands (or rings) is narrow, in contrast to polluted wood from Ambowé, which has wider growth rings. Detienne et al. [19] suggested that these parenchyma bands could be growth ring boundaries, and Nazim et al. confirmed this by showing the irregularity of growth rings in areas of high salinity. Also, the vessel diameter of unpolluted wood from Oveng appears smaller than that of polluted wood from Ambowé. Salinity is a key factor in mangrove wood anatomy [20]. Although both sites have high salinities, the salinity of the unpolluted Oveng site is higher than that of the polluted Ambowé site, so the diameter of the vessels of the unpolluted Oveng wood appears narrower than that of the vessels of the polluted Ambowé wood. These results corroborate the work of Schmitz et al. [21], which indicates that low-salinity conditions present wider vessels.

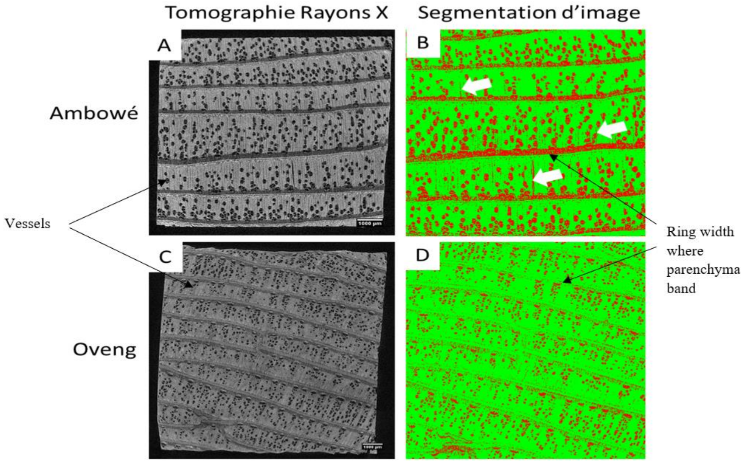


Figure 4. Analysis of *A. germinans* wood samples using x-ray tomography. **(A)** and **(B**) Ring width and vessel diameter wider for polluted Ambowé wood; **(C)** and (**D)** Ring width and narrow vessel diameter for unpolluted Oveng wood.

3.2. Density wood

The density of polluted Ambowé wood (0.91 ± 0.05) is significantly lower (Student's test, $P < 0.05$) than that of unpolluted Oveng wood (1.12 ± 0.04) (**Figure 5**). The reduced density of polluted wood could be explained by the larger vessel size and wider tree rings. Indeed, high salinity reduces vessel size [22] and increases fiber wall thickness, thus increasing wood density. Yáñez Espinosa et al. [8] reported that in areas of low salinity, *A. germinans* has a low fiber thickness. *Avicennia germinans* wood collected from sites with different salinities, 30.09 g/L and 12.57 g/L, exhibited fiber wall thicknesses that were around 4.8 µm (with a vessel lumen diameter of 3.2µm) and 3.8 µm (with a vessel lumen diameter of 5.5 µm) respectively [8]. Previous studies by some authors on a range of species have shown that increasing wood density correlates with decreasing vessel lumen [23]. High wood density is a function of fiber wall thickness in *A. marina* [24].

Nazim et al. [20] have shown that irregular ring formation occurs in areas of high salinity (**Figure 6**), and this is the case of the cross-section of unpolluted wood from oveng with higher soil salinity, which shows irregular growth rings (**Figure 4C,D**). Trouy [16] indicates that fast-growing softwoods (with wide rings) are therefore less dense than slow-growing softwoods (with narrow rings). Ring formation in mangrove wood depends on salinity, which in turn depends on the season. During the dry season, when salinity is high, *R. mucronata* forms bands of light wood, and during the rainy season, when salinity is low, it forms dark wood [25]. This suggests that high salinity generates narrow rings in mangrove wood, and consequently contributes to increasing the density of *A. germinans* wood.

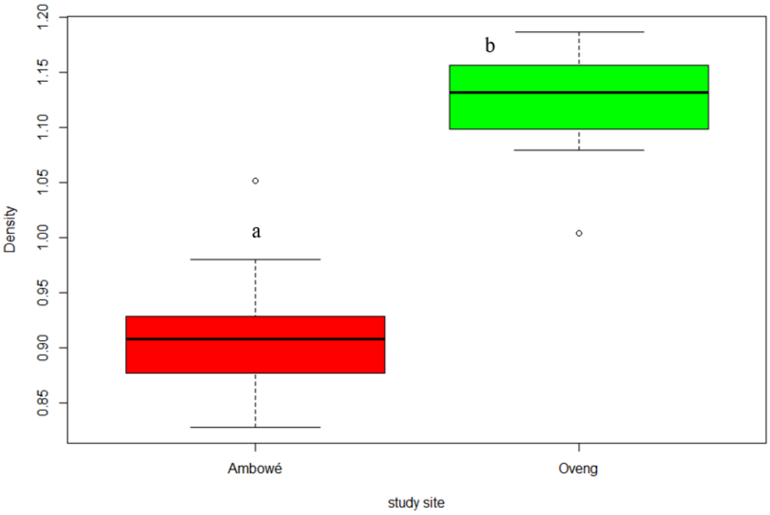


Figure 5. Effect of salinity on the density of *A. germinans* wood samples exposed to hydrocarbon pollution. In red, the polluted Ambowé site. In green, the unpolluted site (green). Different letters showed groups that are significant difference (test de student; $p < 0.05$).

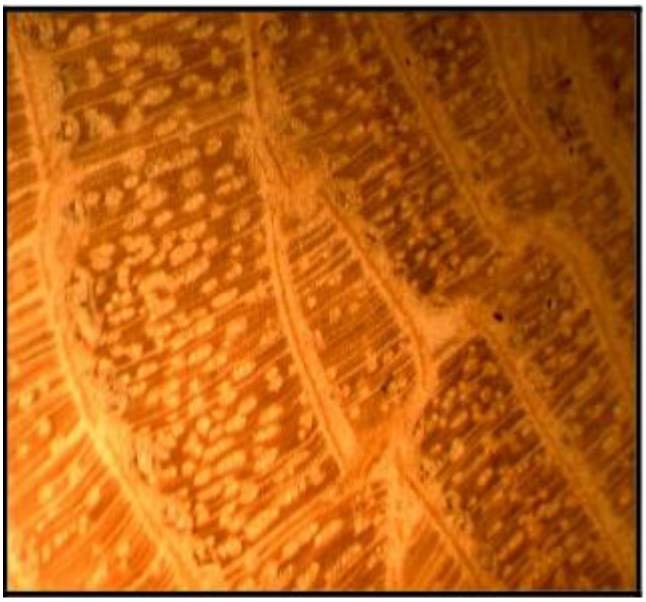


Figure 6. Cross-section showing irregular growth rings in *A. marina* wood [20].

3.3. Mechanical resistance wood

Figure 7 shows the axial compressive strength of *A. germinans* wood taken from the polluted Ambowé site and the unpolluted Oveng site. This figure shows that the axial compressive strength of unpolluted wood from Oveng (78.28 MPa) is significantly higher (Student's test; $p < 0.05$) than that of polluted wood from Ambowé (70.28 MPa). These results correlate with wood density (**Figure 5**). Wood density is important in defining the mechanical properties of wood and the strength of their performance [26]. In fact, the density of wood depends on the proportion between the number of fibers and the thickness of their walls, and it is these tissues that give wood its mechanical strength [16]. in view of the above, this suggests that it is salinity that is responsible for wood quality, and thus salinity takes precedence over hydrocarbon pollution in conferring mechanical strength to *A. germinans* wood.

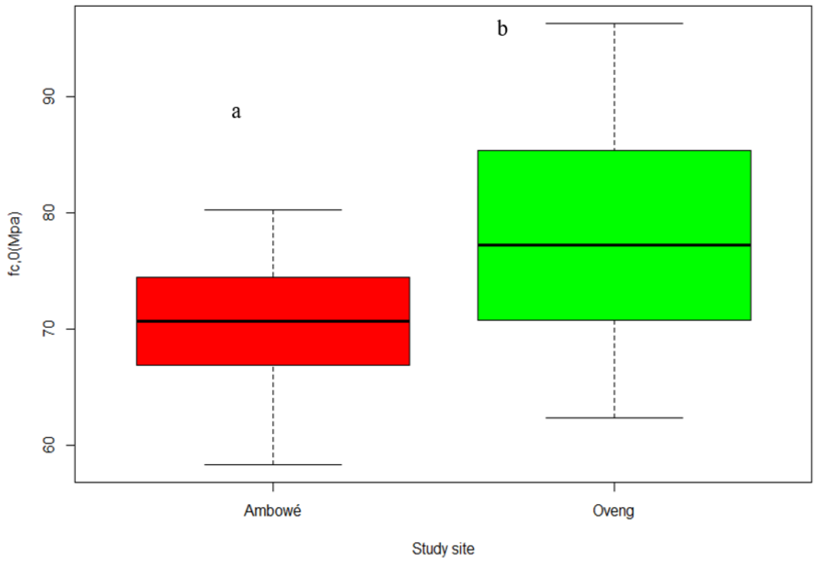


Figure 7. Effect of salinity on the mechanical strength of *A. germinans* wood. Different letters showed groups that are significant difference (test de student, $p < 0.05$).

4. Conclusion

The aim of this work was to demonstrate the impact of salinity on the density and mechanical strength of *A. germinans* wood exposed to hydrocarbon pollution. In the presence of hydrocarbon pollution, salinity reduces vessel diameter and ring width. This increases the density and mechanical strength of *A. germinans* wood.

Author contributions: Conceptualization, STR and BA; methodology, STR and BA; writing—review and editing, MISB; writing—original draft, MISB; supervision, ABT and GP. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest: The authors declare no conflict of interest.

References

1. Poirier A. The vulnerability of ocean carbon sinks to ocean acidification (French) [Master's thesis]. Sherbrooke University; 2013.

2. Donato DC, Kauffman JB, Murdiyarso D, et al. Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience. 2011; 4(5): 293-297. doi: 10.1038/ngeo1123
3. Spalding M. World Atlas of Mangroves. Earthscan; 2010.
4. FAO. Global Forest Resources Assessments. Country reports 2020. Gabon. FAO; 2020.
5. Okanga-Guay M, Assoumou EO, Aken IA, et al. Monitoring spatial and environmental changes in mangroves in Gabon's Estuary Province (French). HAL open science; 2019.
6. Mabicka Iwangou SB, Soulounganga P, Besserer A, et al. Investigation of the Anatomical Variability of the Trunk and Root Tissues of Rhizophora racemosa (G. Mey) and Avicennia germinans (Linné): A Bioaccumulation of Heavy Metals and Pollution Effects on Mangrove Trees Study. Current Perspectives on Chemical Sciences. 2020; 2: 144-155.
7. Mabicka Iwangou SB, Safou Tchiama R, Besserer A, et al. Modification of the Chemical Composition and the Natural Durability of Avicennia Germinans (Linné) Mangrove Tree of the Estuary Region of Gabon Exposed to Marine Hydrocarbons Pollution. SSRN; 2023.
8. Yáñez Espinosa L, Angeles G, López Portillo J, et al. Variación anatómica de la madera de Avicennia germinans en la Laguna de la Mancha, Veracruz, México. Botanical Sciences. 2009; 85: 7-15. doi: 10.17129/botsci.2298
9. Naidoo G. Factors Contributing to Dwarfing in the Mangrove Avicennia marina. Annals of Botany. 2006; 97(6): 1095-1101. doi: 10.1093/aob/mcl064
10. Naidoo G. Effects of nitrate, ammonium and salinity on growth of the mangrove Bruguiera gymnorrhiza (L.) Lam. Aquatic Botany. 1990; 38(2-3): 209-219. doi: 10.1016/0304-3770(90)90006-7
11. Triwilaida Intari SE. Factors affecting the death of mangrove trees in the Pedada Strait, Indragiri Hilir, Riau, with reference to the site conditions. Bulletin Penelitian Hutan; 1990.
12. Mabicka Iwangou SB, Safou Tchiama R, Besserer A, et al. Impact of Salinity on the Infradensity of Avicennia Germinans Wood Collected from Different Habitats in Greater Libreville. Open Journal of Environmental Biology. 2024; 9(1): 025-029. doi: 10.17352/ojeb.000044
13. Tam NFY, Wong YS. Spatial variation of heavy metals in surface sédiments of Hong Kong mangrove swamps. Environmental Pollution. 2000; 110(2): 195-205. doi: 10.1016/S0269-7491(99)00310-3
14. Herteman M. Assessment of the bioremediation capacities of a mangrove impacted by domestic wastewater. Application to the Malamani pilot site, Mayotte (French) [PhD thesis]. Université Paul Sabatier - Toulouse III.
15. Evans CW. The effects and implications of oil pollution in mangrove forests. International Oil Spill Conference Proceedings. 1985; 1985(1): 367-371. doi: 10.7901/2169-3358-1985-1-367
16. Trouy MC. Wood anatomy. Formation, functions and identification (French). QUAE; 2015.
17. Virgulino-Júnior PCC, Gardunho DCL, Silva DNC, et al. Wood density in mangrove forests on the Brazilian Amazon coast. Trees. 2019; 34(1): 51-60. doi: 10.1007/s00468-019-01896-5
18. Ray R, Majumder N, Chowdhury C, et al. Wood chemistry and density: An analog for response to the change of carbon sequestration in mangroves. Carbohydrate Polymers. 2012; 90(1): 102-108. doi: 10.1016/j.carbpol.2012.05.001
19. Detienne P, Jacquet P, Mariaux A. 1982. Tropical wood identification manual: Volume 3: French Guiana (French). Cirad; 1982.
20. Robert, E.M.R., Koedam, N., Beeckman, H., Schmitz, N., 2009. A safe hydraulic architecture as wood anatomical explanation for the difference in distribution of the mangroves Avicennia and Rhizophora. Functional Ecology 23, 649–657. https://doi.org/10.1111/j.1365-2435.2009.01551.x
21. . Schmitz N, Robert EMR, Verheyden A, et al. A Patchy Growth via Successive and Simultaneous Cambia: Key to Success of the Most Widespread Mangrove Species Avicennia marina? Annals of Botany. 2007; 101(1): 49-58. doi: 10.1093/aob/mcm280
22. Schmitz, N., Robert, E.M.R., Verheyden, A., Kairo, J.G., Beeckman, H., Koedam, N., 2007. A Patchy Growth via Successive and Simultaneous Cambia: Key to Success of the Most Widespread Mangrove Species Avicennia marina? Annals of Botany 101, 49–58. https://doi.org/10.1093/aob/mcm280
23. Hacke UG, Sperry JS, Pockman WT, et al. Trends in wood density and structure are linked to prevention of xylem implosion by negative pressure. Oecologia. 2001; 126(4): 457-461. doi: 10.1007/s004420100628
24. Santini NS, Schmitz N, Lovelock CE. Variation in wood density and anatomy in a widespread mangrove species. Trees. 2012; 26(5): 1555-1563. doi: 10.1007/s00468-012-0729-0

25. Beeckman H, Boeren I, Couralet C, et al. Opening the black box of African wood (French). In: Mettens P (editor). Science Connection 18. Science 8 à B: Bruxelles; 2007.
26. Niklas KJ, Spatz H. Worldwide correlations of mechanical properties and green wood density. American Journal of Botany. 2010; 97(10): 1587-1594. doi: 10.3732/ajb.1000150