Intermediary report II

"Improvement of the conservation status of *Afzelia africana* in Benin" Project (ID: 41122-1)

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1. Introduction

Afzelia africana is a leguminous nitrogen-fixing species that improves soil fertility (Kitin *et al*., 2021) and plays an important role in agroforestry (Hills, 2020). It is a polyvalent tree that is used for timber, charcoal, animal fodder and medicinal purposes (Donkpegan *et al*., 2020). In recent years, Benin has seen illegal logging of the species in protected areas and on private land. This has prompted the government to ban the exploitation and export of its timber since 2017. Despite this measure, the *A. africana* population is still in decline due to ignorance of certain factors. The pressures associated with pruning branches for livestock feed seem to be neglected despite the impacts revealed by several studies (Nacoulma *et al*., 2011, 2016; Sèwadé *et al*., 2016; Amahowe *et al*., 2018). This project entitled "*Improvement of the conservation status of Afzelia africana in Benin*" aims to develop conservation and awareness actions to improve its conservation status. Specifically, the project aims to: (i) Identify habitats favorable to the conservation of *Afzelia Africana*, (ii) Assess the impact of livestock on the demographic structure of *Afzelia africana* populations, (iii) Assess the perception of local communities on the temporal dynamics and local conservation practices of *Afzelia africana*, (iv) Sensitize local populations for the conservation of *Afzelia africana* in Benin. Seven activities are planned to achieve these objectives. This intermediary report II aims to provide an update on the activities carried out to achieve objectives 2 and 3: Livestock impact assessment, ethnobotanical survey, and installation of nurseries for reforestation.

2. Methodology

2.1. Livestock impact assessment

Site selection and data collection

After modelling, the gazetted forests of Ouémé Supérieur (9°11'-9°47'N and 1°58'- 2°28'E) and Alibori Supérieur (10°41-11°11N and 2°15-2°48E) were chosen for data collection on *A. africana* populations. The criteria for choosing these two protected areas were (i) climate zone (Sudanian or Sudano-Guinean), (ii) size and (iii) sensitivity to current and future climate variability. Whatever the climate scenario (SSP2-4.5 or SSP5-8.5), these two forests remain the largest and most favorable protected areas for current and future conservation of *A. africana*. The Ouémé Supérieur gazetted forest is located in the Sudano-Guinean zone. The Alibori Supérieur gazetted forest is located in the Sudanian zone. Thus, in each of these forests, 30 x 30 m plots were randomly installed in the *A. africana* populations, at intervals of at least 200 m from each other (Koutchoro *et al*., 2022). A total of 256 plots were installed, 140 in the Ouémé Supérieur gazetted forest and 116 in the Alibori Supérieur gazetted forest. The installation of these plots was oriented by the presence of *A. africana* individuals. Within each plot, the following data were collected on individuals of the species: $dbh_{1.3m}$ (diameter at breast height, 1.30 m from the ground), total height of individuals with a $dbh_{1.3m} \geq 5$ cm (Gaoue and Ticktin, 2007) and pruning intensity (Photo 1). For small individuals with $dbh_{1.3m} < 5$ cm, a simple count was made

To determine pruning intensity, we counted the number of branches pruned and the total number of branches for each tree stem. To estimate seedling density, we systematically counted all individuals with a $dbh_{1.3m} < 5$ cm in five 5 m × 5 m subplots, established at the four corners and center of each plot. We had therefore defined seedlings as individuals with a $dbh_{1.3m} < 5$ cm (Nacoulma *et al*., 2011). In addition to data on *A. africana* populations, we also collected data on the type of plant community, soil texture and relief for each plot.

Photo 1. (A) Measuring $dbh_{1.3m}$ using a Ruban pi, (B) Measuring sight angles using a Clinomètre for height estimation.

2.2. Ethnobotanical survey

We carried out ethnobotanical surveys among riparian populations of favorable habitats in order to assess their perception of the vulnerability of *A. africana* and the endogenous practices adopted for its conservation (Photo 2). To this end, 270 people were interviewed using simple random sampling: 100 agro-breeders, 50 breeders, 90 farmers, 15 forestry officers, 10 nurserymen and 5 sawyers. Interviews were conducted exclusively in the local language, in order to gather as much information as possible about the species. The triangulation technique was used to control the quality of information provided by respondents. This technique consists in asking respondents the same question in several ways, in order to obtain real information. Thus, the following information was collected using the KoboCollect application: socio-cultural category of respondents (ethnicity, gender, age categories, marital status, level of education, profession and religion), perceptions of respondents on the availability of *A. africana* (rare, less abundant, abundant), population dynamics in recent years (stable, increasing, decreasing), reasons for the species' population decline (harvesting for fodder, logging, agriculture, drought and others), and traditional practices used for its conservation. The age categories of the respondents were defined as follows: young (18-30 years), adult (30-60 years) and old (≥ 60 years) (Assogbadjo *et al.*, 2008; Zon *et al.*, 2022).

Photo 2. Interview with the local community.

2.3. Data analysis

We had calculated pruning intensity (PI, %) using the following formula: PI = (NBP/NTB) x 100, where NBP is the Number of Branches Pruned and NTB the Number of Total Branches in the tree. However, we defined a five-class scale to determine pruning intensity: A0 (no pruning), A1 (1 ± 25 % of branches are pruned), A2 (26 ± 50 % of branches are pruned), A3 (56 ± 75 % of branches are pruned), A4 (76 ± 99 % of branches are pruned) and A5 (100 % of branches are pruned). Also, the density per hectare of adult trees and seedlings of *A. africana* was calculated by dividing the total number of trees by the plot area. The ratio between the number of respondents linked to a specific perception or practice and the total number of respondents was also calculated to obtain the citation frequency.

To test the effect of pruning intensity on dbh and seedling density, we had tested several candidate models (null model, linear models and mixed-effect linear models, Table 1, 2) in R software. The best model was selected on the basis of AIC using the "model.select" function contained in the "MuMIm" package (Bartoń, 2023). Before modeling, all quantitative variables (dbh, density, pruning intensity) were standardized using the "scale" function contained in the "Base" package (R Core Team, 2024). The linear model was the best model, providing the best explanation of the dependent variables (tree dbh and seedling density). However, in this model, after testing the individual effect of each variable, we checked whether the effect of pruning intensity depended on climate zone, soil texture or relief type. We used error bars and multiple regression lines to graphically visualize the results. For seedling density, the best model is Model 3 (Table 1). This model takes into account the interactions and individual effects of each variable (climate zone, soil texture, type of relief). For diameter, model 2, which does not include interactions, is the best model (Table 2). This model only tests the individual effects of each variable on diameter.

Table 1. Selection of the best model predicting impact of pruning intensity on *A. africana* seedling density with climate zone, soil texture and relief type.

N°	Models	AIC	∆AIC
1	lm(scale(Density)~1)	366,2443	75,4399
2	lm(scale(Density)~CZ+scale(Prun)+ST+RT)	342,8596	52,0552
3	lm(scale(Density)~CZ+scale(Prun)+ST+RT+scale(Prun):CZ+ scale(Prun):ST+scale(Prun):RT)	290,8044	0
4	lmer(scale(Density)~1+(1|CZ))	371,2624	80,458
5	lmer(scale(Density)~CZ+scale(Prun)+ST+RT+(1|CZ))	354,2045	63,4001
6	lmer(scale(Density)~CZ+scale(Prun)+ST+RT+scale(Prun):CZ +scale(Prun):ST+scale(Prun):RT+(1|CZ))	312,2093	21,4049

Prun pruning, *CZ* climate zone, *ST* soil texture, *RT* relief type, *lm* linear model, *lmer* mixed effect linear model.

Table 2. Selection of the best model predicting impact of pruning intensity on dbh of *A. africana* with climate zone, soil texture and relief type.

N°	Models	AIC	∆AIC
1	lm(scale(Diam)~1)	635,8443	22,0732
2	lm(scale(Diam)~CZ+scale(Prun)+ST+RT)	613,7711	0
3	lm(scale(Diam)~CZ+scale(Prun)+ST+RT+scale(Prun):CZ+sca le(Prun):ST+scale(Prun):RT)	616,4487	2,6776
4	lmer(scale(Diam)~1+(1|CZ))	625,6915	11,9204
5	lmer(scale(Diam)~CZ+scale(Prun)+ST+RT+(1|CZ))	629,2106	15,4395
6	lmer(scale(Diam)~CZ+scale(Prun)+ST+RT+scale(Prun):CZ+s cale(Prun):ST+scale(Prun):RT+(1|CZ))	636,6208	22,8497

Diam dbh, *CZ* climate zone, *ST* soil texture, *RT* relief type, *lm* linear model, *lmer* mixed effect linear model.

3. Results

3.1. Impact of pastoral livestock on the demographic structure of *A. africana* populations

3.1.1. *A. africana* pruning intensity

The intensity of *A. africana* branch pruning is high in all climate zones. Thus, most of the trees (63.30 %) found in the Sudano-Guinean zone of Benin had 100 % of their branches pruned (Fig. 1, photo 3b), but a few stems were left unpruned (33.03 %, photo 3a). In the Sudanian zone, more than half of *A. africana* trees were fully pruned (56.82 %), with 21.21 % unpruned.

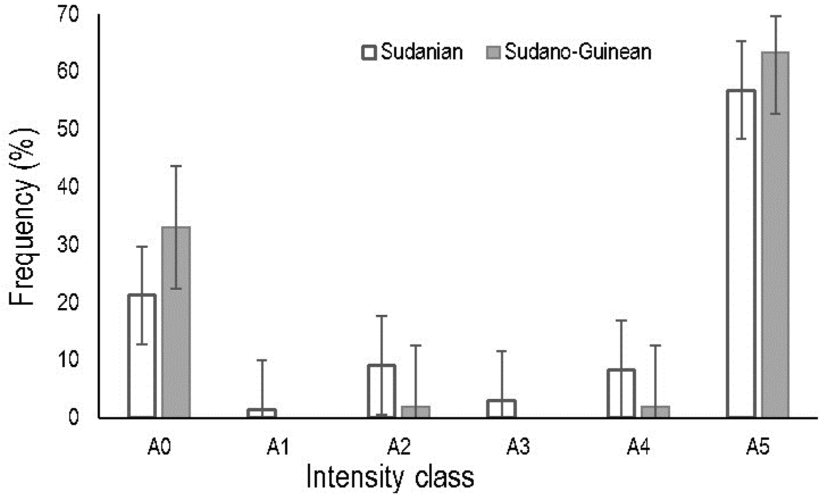

Fig. 1. Pruning intensity of *A. africana* branches in Benin's two climate zones (Sudano-Guinean and Sudanian). In the figure, A0, A1, A2, A3, A4 and A5 represent pruning intensity classes.

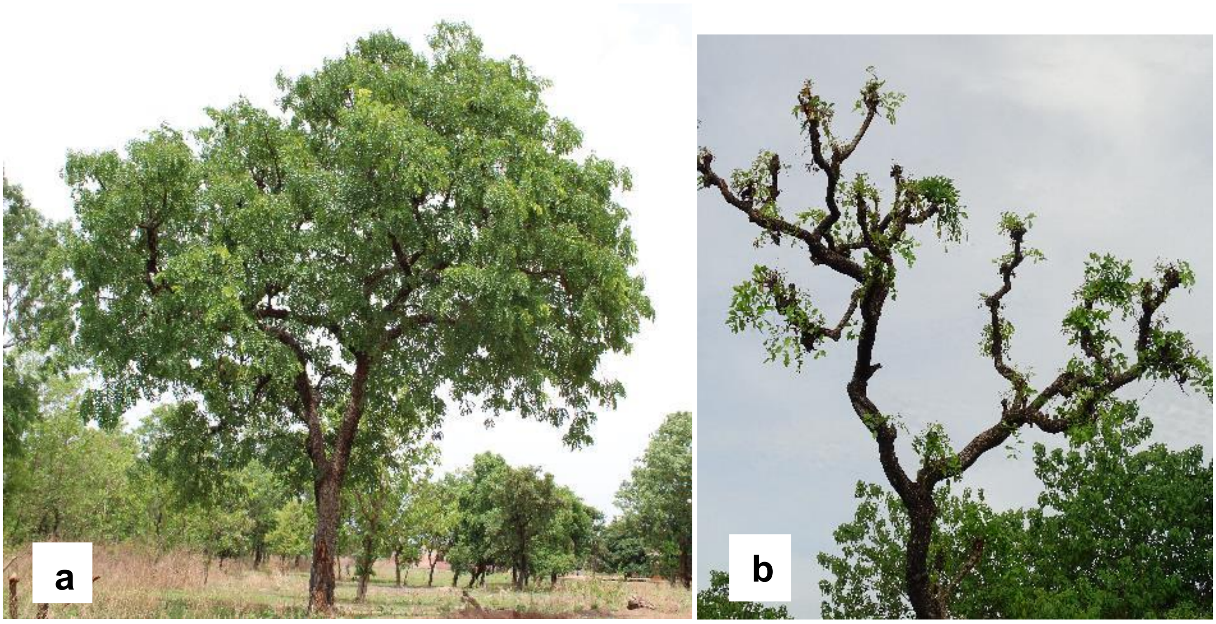

Photo 3. (a) *A. africana* with no pruning, (b) *A. africana* with 100 % of branches pruned.

3.1.2. Pruning impact on *A. africana* tree diameters

The model presented in Table 2 is significant and indicates that the explanatory variables taken into account explain 16.45% of the variability in dbh ($R^2 = 0.1645$, $p = 0.000$). Pruning intensity is positively correlated with dbh of *A. africana* trees ($\beta = 0.162 \pm 0.066$, $p = 0.014$, Table 3, Fig. 2b). Greater the dhb, higher the pruning intensity. Furthermore, our results indicate that relief type, considered separately from pruning, has a significant effect on dbh. On the other hand, tree dbh is significantly higher on hillsides ($\beta = 0.769 \pm 0.372$, $p = 0.040$, Table 3, Fig. 2a).

Table 3. Results of the linear model testing the individual effect of explanatory variables.

Variables	Estimate	SE	t	*p*
Intercept	-0,209	0,262	-0,797	0,426
Sudano-Guinean zone	0,136	0,198	0,687	0,493
Scale(Pruning)	0,162	0,066	2,467	**0,014***
Texture.Silty	0,737	0,691	1,066	0,287
Texture.Silty-clay	0,614	0,322	1,908	0,058

Variables	Estimate	SE	t	*p*
Texture.Silty-sandy	0,323	0,231	1,399	0,163
Texture.Sandy	0,136	0,315	0,430	0,667
Texture.Sandy-clay	-0,258	0,281	-0,916	0,361
Relief.Valley	-0,006	0,400	-0,015	0,988
Relief.Hillside	0,769	0,372	2,064	**0,040***

SE standard error, *t* T-student, *p* probability value, * p < 0.05.

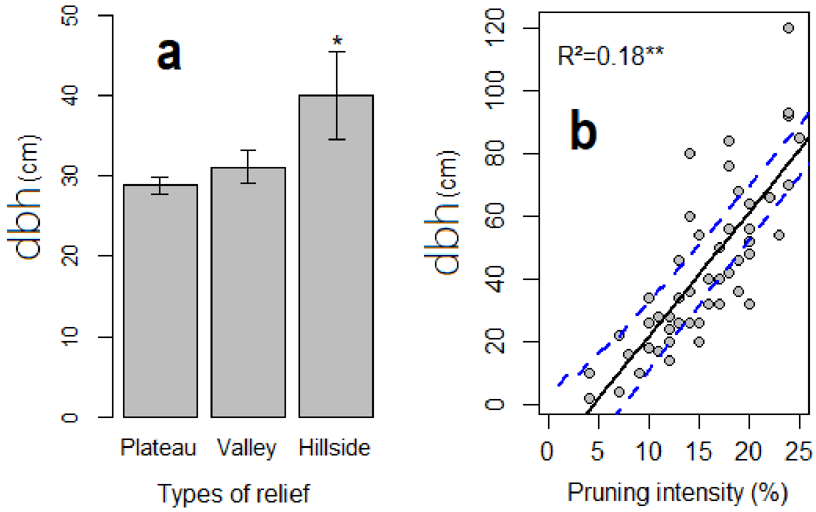

Fig. 2. dbh according to relief type (a) and pruning intensity (b).

3.1.3. Pruning impact on *A. africana* seedling density

The model used (Table 1) was globally significant and showed that the explanatory variables used explained 61% of the variability in seedling density (R^2=0.61, p = 0.000). The results showed that pruning alone did not influence *A. africana* seedling density (β = 0.250 ± 0.406, p = 0.539, Table 4), but its effect depended on soil texture. Indeed, pruning negatively influences *A. africana* seedling density on sandy-silty (β = -1.598 ± 0.406, p = 0.000) and gravelly (β = -0.975 ± 0.417, p = 0.021) textured soils (Table 4, Fig. 3b). In addition, soil texture taken individually (without pruning) had a significant effect on seedling density. We found a significantly higher seedling density on sandy-silty textured soils (β = 1.218 ± 0.439, p = 0.006, Table 4, Fig. 3a).

Table 4. Results of the linear model testing the effect of pruning intensity on seedling density.

Variables	Estimate	SE	t	*p*
Intercept	-0,640	0,446	-1,434	0,155
Sudanian zone	0,352	0,200	1,759	0,081
Scale(Pruning)	0,250	0,406	0,616	**0,539**
Texture.Clay-sandy	-2,457	2,500	-0,983	0,328
Texture.Gravelly	0,795	0,448	1,776	0,079
Texture.Silty	0,000	0,845	0,000	1,000
Texture.Silty-clay	-0,003	0,503	-0,005	0,996
Texture.Silty-sandy	0,040	0,417	0,095	0,924
Texture.Sandy	0,569	0,477	1,192	0,236
Texture.Sandy-clay	0,463	0,471	0,982	0,328
Texture.Sandy-silty	1,218	0,439	2,777	**0,006****

Variables	Estimate	SE	t	*p*
Relief.Valley	4,320	3,169	1,363	0,176
Relief.hillside	-0,601	0,369	-1,630	0,106
Sudano-Guinean zone: Scale(Pruning)	-0,250	0,199	-1,261	0,210
Scale(Pruning): Texture.Clay-sandy	5,678	4,469	1,27	0,207
Scale(Pruning): Texture.Gravelly	-0,975	0,417	-2,336	**0,021****
Scale(Pruning): Texture.Silty-clay	-0,002	0,472	-0,004	0,997
Scale(Pruning): Texture.Silty-sandy	-0,046	0,374	-0,123	0,902
Scale(Pruning): Texture.Sandy	-0,720	0,413	-1,743	0,084
Scale(Pruning): Texture.Sandy-clay	-0,278	0,443	-0,627	0,532
Scale(Pruning): Texture.Sandy-silty	-1,598	0,395	-4,042	**0,000******
Scale(Pruning): Relief.Valley	-4,927	3,799	-1,297	0,197
Scale(Pruning: Relief.Hillside	0,712	0,401	1,775	0,079

SE standard error, *t* T-student, *p* probability value, * p < 0.05, ** p < 0.01, *** p < 0.001.

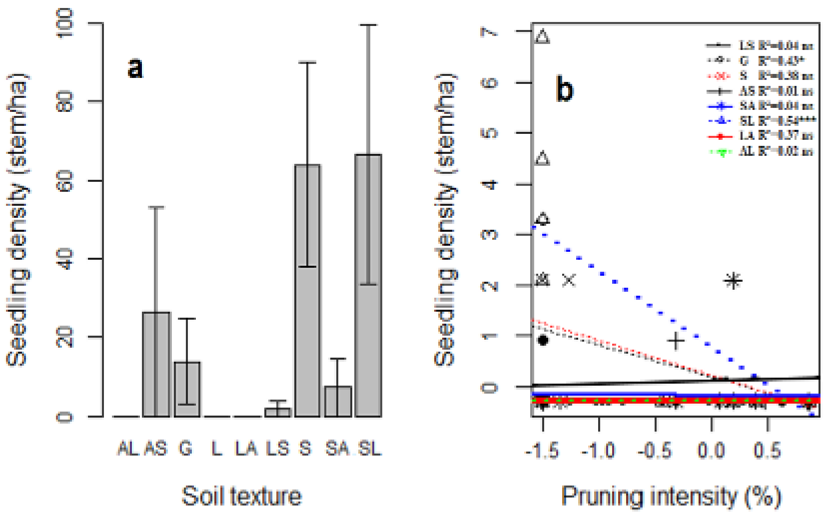

Fig. 3. *A. africana* seedling density according to soil texture (a) and pruning intensity (b). In the figure, AL= Clay-silty, AS = Clay-sandy, G = Gravelly, LA = Silty-clay, LS = Silty-sandy, S = Sandy, SA = Sandy-clay, SL = Sandy-silty.

3.2. Local communities' perception of the temporal dynamics and local conservation practices of *A. africana*

Interviews with riparian populations in favorable habitats enabled us to understand that *A. africana* is less abundant (40.23 %) and sometimes absent in certain localities (4.6 %). 27.59 % respectively stated that *A. africana* is rare and abundant in their locality (Table 5). Similarly, 80.46 % of respondents noted that the species is in decline, mainly due to the pruning of branches for animals (80.46 %, Photo 4) and agriculture (37.93 %, Photo 5). Aware of the species' vulnerability, local communities are adopting traditional practices to conserve it sustainably and avoid its extinction. These include natural assisted regeneration (Photo 6), adopted by 91.95 % of respondents, and reforestation (Photo 7), adopted by 13.79 %. Others use *A. africana* as a shade tree in house yards (5.75 %, Photo 8) and for sacralization (2.3 % Photo 9).

Table 5. Temporal dynamics and local conservation practices for *A. africana*

Modalities	Citation frequency (%)
Availability	
Less abundant	40.23
Rare	27.59
Abundant	27.59
Absent	4.6
Evolution	
Declining	80.46
Increasing	13.79
Stable	5.75
Regression reason	
Pruning	71.26
Agriculture	37.93
Logging	8.05
Drought	2.3
Debarking	1.15
Vegetation fire	6.9
Conservation strategies	
Natural assisted regeneration	91.95
Reforestation	13.79
Shade trees in house yards	5.75
Sacralization	2.3

Photo 4. Pruning of *A. africana* branches for livestock in the Ouémé Supérieur gazetted forest, a protected area favorable to the conservation of the species.

Photo 5. Agriculture in the Ouémé Supérieur gazetted forest, a protected area favorable to the conservation of the species.

Photo 6. Natural assisted regeneration of *A. africana*.

Photo 7. Reforestation of *A. africana* in the Wari-Maro gazetted forest (Sadam, 2023).

Photo 8. Shade tree (*A. africana*) in the yard of a house in the Ewodé village (Bassila municipality).

Photo 9. Fetish tree (sacralization) of *A. africana* in the Kpawa village (Tchaourou municipality).

3.3. Nursery installation

We installed *A. africana* and *Khaya senegalensis* nurseries in the Bétérou village, in the municipality of Tchaourou (Photo 10). The choice of this village for the nurseries was justified by its proximity to the Ouémé gazetted forest and the willingness of the local population to participate in the installation and maintenance of the nurseries. This will make it possible to obtain good seedlings more quickly, and facilitate transport and security of seedlings to reforestation sites.


Photo 10. Nurseries of *A. africana* and *Khaya senegalensis* in the Bétérou village.

Conclusion

A. africana branch pruning intensity is high whatever the climate zone. It is positively correlated with dbh. We found that tree dbh is significantly higher on hillsides. Similarly, pruning has a negative influence on the density of *A. africana* seedlings on sandy-silty and gravelly soils. Interviews with local people living in favorable habitats revealed that *A. africana* is less abundant and sometimes absent in certain localities. Respondents also noted that the species is in decline, mainly due to the pruning of branches for animals and agriculture. Aware of the species' vulnerability, local communities are adopting traditional practices to conserve it sustainably and avoid its extinction. These practices include natural assisted regeneration and reforestation.

We are currently carrying out awareness and environmental education activities. After this stage, we will carry out reforestation in favorable habitats.

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