Land use impacts on *Boswellia dalzielii* Hutch., an African frankincense tree in Burkina Faso

Photo 1.
Seedling of *Boswellia dalzielii*.
Photo P. Sabo.

Prospère Sabo[1, 2]
Amadé Ouédraogo[1]
D. S. J. Charlemagne Gbemavo[2]
Kolawolé Valère Salako[2]
Romain Glèlè Kakaï[2]

[1] University Joseph Ki-Zerbo
Laboratory of Plant Biology and Ecology
UFR/SVT
03 BP 7021, Ouagadougou 03
Burkina Faso

[2] Université d'Abomey-Calavi
Faculté des sciences agronomiques
Laboratoire de biomathématiques et d'estimations forestières
04 BP 1525, Cotonou
Bénin

Auteur correspondant / Corresponding author:
Prospère SABO – prosperesabo90@yahoo.fr

Doi : 10.19182/bft2021.349.a31960 – Droit d'auteur © 2021, Bois et Forêts des Tropiques – © Cirad – Date de soumission : 28 novembre 2020 ; date d'acceptation : 25 mai 2021 ; date de publication : 1er septembre 2021.

Citer l'article / To cite the article
Sabo P., Ouédraogo A., Gbemavo D. S. J. C., Salako K. V., Glèlè Kakaï R., 2021. Land use impacts on *Boswellia dalzielii* Hutch., an African frankincense tree in Burkina Faso. Bois et Forêts des Tropiques, 349 : 51-63. Doi : https://doi.org/10.19182/bft2021.349.a31960

P. Sabo, A. Ouédraogo, D. S. J. C. Gbemavo,
K. V. Salako, R. Glèlè Kakaï

RÉSUMÉ

Impacts des types d'utilisation des terres sur *Boswellia dalzielii* Hutch., arbre à encens africain au Burkina Faso

Boswellia dalzielii Hutch., arbre à encens africain, est une essence aromatique et médicinale de grande importance socio-économique. Elle est actuellement menacée par une exploitation incontrôlée qui nécessite des mesures pour assurer sa gestion durable. La présente étude a mené une évaluation de la structure des peuplements naturels et de leur régénération selon trois types d'utilisation des terres au Burkina Faso : zones boisées, jachères et champs. L'étude a mis en place 60, 50 et 50 parcelles de 50 m × 20 m, respectivement dans des zones boisées, des jachères et des champs, afin d'y étudier la densité d'arbres adultes (dhp ≥ 5 cm), leur diamètre à hauteur de poitrine (dhp), la hauteur totale et leur état sanitaire. Des données ont également été recueillies sur la régénération : densité (dhp < 5 cm), source (semis naturel, drageon, rejet de souche), hauteur totale et diamètre au collet. Les résultats montrent une hauteur totale similaire (7,0 m-9,0 m) mais un dhp significativement moindre ($p < 0{,}05$) dans les zones boisées (moyenne ± SD : 20,5 ± 0,49 cm) et les jachères (29,3 ± 0,64 cm) que dans les terres agricoles (32,8 ± 0,15 cm). La densité des arbres adultes (arbres/ha) était 1,3 et 2,7 fois plus élevée en zone boisée (82,37 ± 6,57) que dans les jachères (62,00 ± 3,98) et les terres agricoles (30,02 ± 1,63). La densité de la régénération en zone boisée était 28 et 6 fois supérieure à celle dans les jachères et les terres agricoles, respectivement. La majorité (> 50 %) de la régénération était issue de drageons, aucune régénération par semis n'a été trouvée dans les terres agricoles. La courbe de distribution des arbres selon les classes de diamètre était en forme de J renversé pour les zones boisées, en cloche pour les zones agricoles et en asymétrie positive pour les jachères, ce qui indique des goulets d'étranglement dans le recrutement. Parmi les sujets rencontrés, 80,18 % étaient en mauvais état sanitaire. Les principales menaces pour cette essence sont l'écorçage intensif et les coupes, sans qu'aucune stratégie de conservation ne soit en place dans la zone d'étude. Nous avons proposé des mesures visant à réduire l'intensité de l'écorçage et des coupes, qui devraient contribuer à une meilleure gestion de cette essence.

Mots-clés : pression anthropique, *Boswellia dalzielii*, conservation, structure des peuplements, Burkina Faso.

ABSTRACT

Land use impacts on *Boswellia dalzielii* Hutch., an African frankincense tree in Burkina Faso

Boswellia dalzielii Hutch., an African frankincense tree, is a socio-economically important aromatic and medicinal tree. It is currently threatened by uncontrolled exploitation, and therefore requires action to ensure its sustainable management. This study assessed the population structure and regeneration of its natural stands across three land use types in Burkina Faso: woodlands, fallows and farmlands. Sixty, fifty and fifty 50 m × 20 m plots were established respectively in woodlands, fallows, and farmlands. All the plots were surveyed for adult tree (dbh ≥ 5 cm) density, dbh, total height and health conditions. Data on regeneration density (dbh < 5 cm), source (generative, stem sprouts, suckers), total height and collar diameter were also collected. The results show similar total tree heights (7.0 m-9.0 m) but significantly ($p < 0.05$) smaller tree dbh in woodlands (mean ± SD: 20.5 ± 0.49 cm) and fallows (29.3 ± 0.64 cm) than in farmlands (32.8 ± 0.15 cm). Adult tree density (trees/ha) was 1.3 and 2.7 times higher in woodlands (82.37 ± 6.57) than in fallows (62.00 ± 3.98) and farmlands (30.02 ± 1.63), respectively. The density of regeneration in woodlands was 28 and 6 times higher than in fallows and farmlands, respectively. The majority (> 50%) of regenerating plants were suckers and no seedling regeneration was found in farmlands. The distribution of trees in diameter classes was inverted J-shaped in woodlands, bell-shaped in farmlands and positive asymmetric in fallows, indicating recruitment bottlenecks. We found that 80.18% of individuals encountered were unhealthy. Intensive debarking and cutting were the main threats to the species and no conservation strategy was in place in the study region. We suggest measures to reduce intensive debarking and cutting, which should contribute to better management of the species.

Keywords: anthropogenic pressure, *Boswellia dalzielii*, conservation, population structure, Burkina Faso.

RESUMEN

Impactos del uso de la tierra en *Boswellia dalzielii* Hutch., un árbol de incienso africano en Burkina Faso

La *Boswellia dalzielii* Hutch., olíbano africano, es un árbol aromático y medicinal con importancia socioeconómica. Actualmente está amenazado por una explotación incontrolada, por lo que es necesario actuar para garantizar su gestión sostenible. Este estudio evaluó la estructura de la población y la regeneración de sus masas naturales en tres tipos de uso del suelo en Burkina Faso: bosques, barbechos y tierras de cultivo. Se establecieron sesenta, cincuenta y cincuenta parcelas de 50 m × 20 m respectivamente en bosques, barbechos, y tierras de cultivo. En todas las parcelas se realizó un estudio sobre la densidad de árboles adultos (dbh ≥ 5 cm), el dbh, la altura total y el estado de salud. También se recogieron datos sobre la densidad de regeneración (dbh < 5 cm), el origen (generativo, brotes del fuste, chupones), la altura total y el diámetro del cuello. Los resultados muestran alturas totales de los árboles similares (7,0-9,0 m), pero un dbh de los árboles significativamente menor ($p < 0{,}05$) en los bosques (media ± DE: 20,5 ± 0,49 cm) y en los barbechos (29,3 ± 0,64 cm) que en las tierras de cultivo (32,8 ± 0,15 cm). La densidad de árboles adultos (árboles/ha) fue 1,3 y 2,7 veces mayor en los bosques (82,37 ± 6,57) que en los barbechos (62,00 ± 3,98) y las tierras de cultivo (30,02 ± 1,63), respectivamente. La densidad de regeneración en los bosques fue 28 y 6 veces mayor que en los barbechos y las tierras de cultivo, respectivamente. La mayoría (> 50 %) de las plantas que se regeneraban eran chupones y no se encontró regeneración por semillas en las tierras de cultivo. La distribución de los árboles en clases diamétricas tenía forma de J en los bosques, de campana en las tierras de cultivo y de asimetría positiva en los barbechos, lo que indica la existencia de cuellos de botella en el reclutamiento. Se constató que el 80,18 % de los individuos encontrados no estaban sanos. El descortezamiento y la tala intensivos son las principales amenazas para la especie, y no existe ninguna estrategia de conservación en la región estudiada. Sugerimos medidas para reducir el descortezamiento y la tala intensivos, lo que debería contribuir a una mejor gestión de la especie.

Palabras clave: presión antropogénica, *Boswellia dalzielii*, conservación, estructura de la población, Burkina Faso.

Introduction

Local people commonly harvest fruits, leaves, flowers, roots, wood, bark and others products from trees for their livelihoods (Gouwakinnou *et al.*, 2011). This can lead to an overexploitation of trees with either single or multiple uses, putting the populations of these species in a regressive dynamic. Threatened populations are characterized either by scarcity, or the absence of small individuals or the decline of breeding trees (Ouédraogo *et al.*, 2006).

Among the important forest resources used in Burkina Faso is *Boswellia dalzielii* Hutch., an African frankincense tree. The species is widespread in the Sahelo-Sudanian savannahs (Arbonnier, 2000), from northern Cameroon to southern Mali, with populations concentrated in Nigeria, Cameroon, Benin, Togo, Ghana, and Burkina Faso (DeCarlo *et al.*, 2019).

Boswellia dalzielii is a plant with high medicinal value in Burkina Faso (Ouédraogo *et al.*, 2006). Its trunk bark decoction is used to treat a plethora of health conditions in both humans and cattle including fever, rheumatism, gastrointestinal disorders (Nacoulma-Ouédraogo, 1996; Ouédraogo *et al.*, 2006). The resins extracted from frankincense trees have been traded at local and international markets for thousands of years (Groom, 1981). They are used for traditional medicine, incense, or industrial purposes (Nussinovitch, 2010). Resin has been and is still used for religious rituals and the traditional coffee ceremony, as well as for yielding volatile oils, which are used in perfumery industry (Leminih and Teketay, 2003).

Despite its widely recognized sociocultural and medicinal potentials, little information is available on the *B. dalzielii* species populations' status in its occurrence regions, particularly in Burkina Faso. Ouédraogo *et al.* (2006) and Ouédraogo and Thiombiano (2012) have examined the pattern of its natural regeneration in eastern Burkina Faso and its abilities of *ex-situ* reproduction by seeds. While it is important to know the status of the species and threats, how exploitation of trees by local people affects the species population is still unclear. Such information is a baseline to engage in a sustainable utilization of the species products and services. Lack of such information is currently hindering the development of conservation strategies and management plans but also a great threat to the species (Bellefontaine *et al.*, 2000).

One of the manifestations of human disturbances on nature, is the change in land uses. Natural vegetation, namely savannahs/woodlands are often burned and converted into farmlands, resulting in a mosaic of landscapes including natural vegetation, farmlands and fallows (Idohou *et al.*, 2016). Understanding how these changes in land use affect the species conditions is essential in designing land use specific recommendations for species management.

Several authors found in East Africa (Ethiopia, Eritrea and Sudan) woodlands that *Boswellia* species have unstable structures (Ogbazghi *et al.,* 2006; Abiyu *et al.,* 2010; Abtew *et al.,* 2012). Bongers *et al.* (2019) concluded that *Boswellia papyrifera* populations are declining. In Cameroon, Kémeuzé *et al.* (2012) showed that *Boswellia dalzielii* populations are threatened. In Burkina Faso, Ouédraogo *et al.* (2006) and Thiombiano *et al.* (2012) also showed that *Boswellia dalzielii* populations are threatened by debarking.

The *Boucle du Mouhoun* region in Burkina Faso benefits from suitable natural conditions that have made it an agricultural production region and it has attracted many immigrants, mainly *Mossi* from more densely populated regions of the country where soils have been impoverished and eroded. The agricultural pressure leads to a rapid conversion of natural savannahs and woodlands into farmlands, resulting in habitat fragmentation and biodiversity loss (Clerici *et al.*, 2007). The negative influence of agricultural land on tree stand and their population structure is linked to improper traditional agriculture practices. Vegetation is often cleared and burned extensively for cropping. As a result, seedlings for regeneration rarely occur and persist in these systems. Several authors have reported that individuals of some agroforestry tree species in younger stages are less numerous in agricultural lands than in unexploited savannahs/woodlands, where younger individuals are more numerous (Schumann *et al.*, 2011; Idohou *et al.*, 2016). Meanwhile, mature trees drop fruit on the ground, which could allow seedling recruitment. The use of fire for land preparation represents a permanent threat to seedlings recruitment on agricultural land, in addition to frequent field clean-ups, and the requirement to have a low density of trees to reduce the competition with crops. However, some adult trees (e.g., usually large and tall ones) are intentionally preserved because of the provision of goods and services like in agroforestry systems (Djossa *et al.*, 2008). Thus, knowledge of structural parameters in the context of land use is an essential ecological requirement to measure the level of use and health of the resources in its biotope (Schumann *et al.*, 2011).

The main objective of this study was to assess the current state of *B. dalzielii* natural stands across three land use types, namely woodlands, fallows, and farmlands. Specifically, the study aims to (i) document the current state of *B. dalzielii*, (ii) investigate land-use activities affecting *B. dalzielii*, (iii) assess the impact of human activities on the regeneration of *B. dalzielii*, and (iv) assess the harvesting intensity and visible damages on the Frankincense trees.

Methods

Study area

This study was carried out in the *Boucle du Mouhoun* Region (figure 1) located in northwestern Burkina Faso (11°27' - 13°42' N and 02°27' - 04°48' E). It covers 34,497 km² area representing 12.6 % of the total surface area of Burkina Faso. The *Boucle du Mouhoun* is divided into six administrative provinces: *Balé*, *Banwa*, *Kossi*, *Mouhoun*, *Nayala* and *Sourou*. Three major sociolinguistic groups dominate the region: *Bwaba*, *Samo* and *Dafing* (RGPH, 2008). The vegetation of the *Boucle du Mouhoun* shows in its northern part (South Sahel sector), a gradient from shrub steppe to tree-lined steppe and in the south, to savannah. In the center (northern Sudanese sector), shrubby and tree-lined savannah dominate. Finally, in the south (southern Sudanese sector), woodlands with gallery forests were noticed along the rivers. The mean annual rainfall ranges between 500 and 1,000 mm and average monthly temperatures range from 23 °C in January to 39 °C in April.

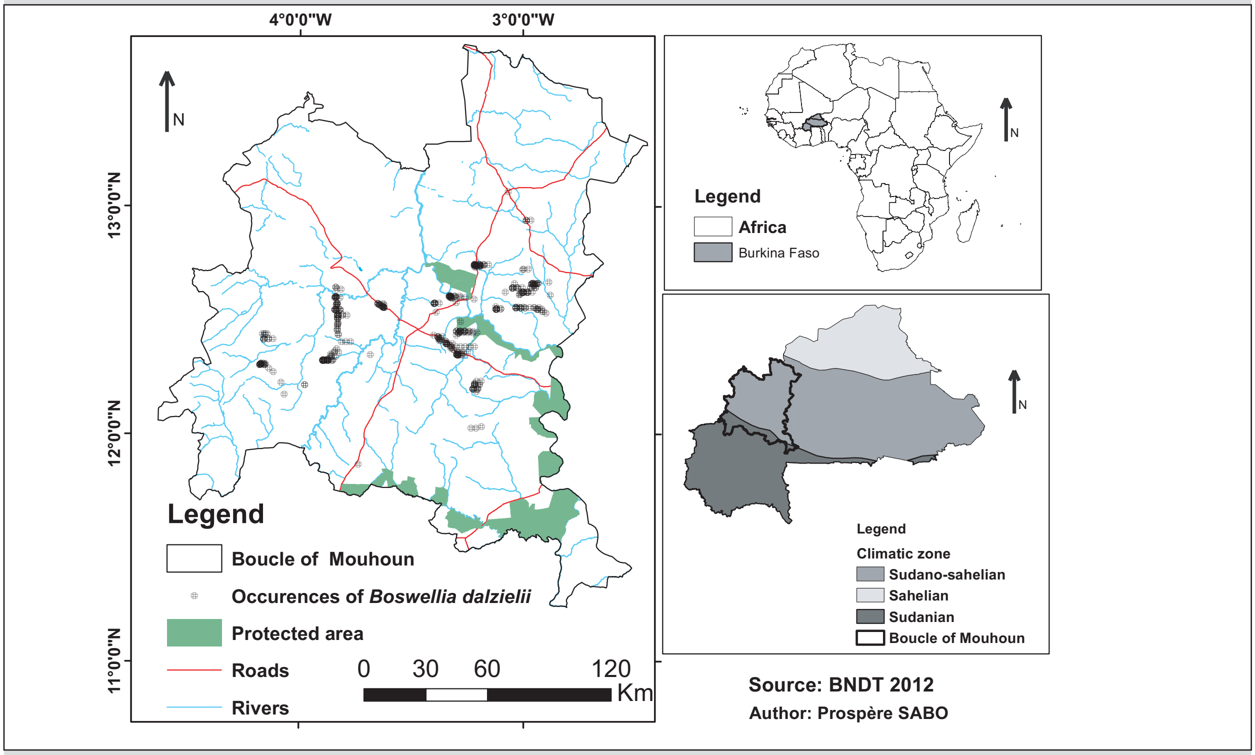


Figure 1.
Map showing the study area.

Study species

Boswellia dalzielii Hutch. (Burceraceae), also known as Frankincense is a medium sized (height 8-15 m) tree with rounded and clear crown, remarkable in the dry season by its yellowish bole (photos 1 & 2). In the study region, trees reached maximum height of 19 m, and a maximum diameter at breast height (dbh) of 77.39 cm. *B. dalzielii* grows in Sudano-Sahelian savannahs with a very marked long dry season (Onana, 1998). The species is often gregarious and grows preferentially on granitic or lateritic scree (Ouédraogo *et al.*, 2006). *B. dalzielii* is native to the tropical regions of Africa (Arbonnier, 2000). It occurs from Côte d'Ivoire to Central Africa (Arbonnier, 2000). The largest populations are found in Burkina Faso, Nigeria and Mali (Emmanuel and Adediji, 2015; DeCarlo *et al.*, 2019). In Burkina Faso, *B. dalzielii* is found from the southern Sahel to southern Sudan (Ouédraogo *et al.*, 2006). In their natural distribution range, trees of the species are threatened because of their overexploitation (Ouédraogo *et al.*, 2006). The life cycle of *B. dalzielii* can be split into seedlings, juvenile trees and adult trees. Seedlings are all individuals with dbh less than 2 cm, individuals between 2-5 cm dbh are considered juvenile while individuals › 5 cm dbh are classified as adults.

Sampling design and data collection

The study area was first explored based on the vegetation and soil map and information from the local populations to confirm the presence of the species. The number *N* of plots considered per land use type, was computed as follows (Dagnelie, 1998):

$$N = \frac{t^2_{1-\alpha/2}\,CV^2}{d^2}$$

In this equation, $t_{1\text{-}\alpha\ /\ 2}$ is the critical value of the *t*-distribution that converges to the Normal distribution for larger samples ($N > 30$) and equals to 2.04 for a probability value $1\text{-}\alpha\ /\ 2$ ($\alpha = 0.05$); CV is the coefficient of variation of basal area of *B. dalzielii* taken as 61.86% (determined in a pre-inventory of 30 plots); d is the marginal error of the estimation of dendrometric parameters (d = 10%). In total, 160 plots of 50 m × 20 m were randomly established: 50 in farmlands, 50 in fallows and 60 in woodlands, representing human disturbance gradient.

Within each plot, size variables namely dbh and total height were measured on all *B. dalzielii* adult individuals (dbh ≥ 5 cm). In addition to the dendrometric parameters, the health status (healthy – *individuals without indices of human exploitation*, moderately unhealthy – *tree partially damaged and still alive*, severely unhealthy – *tree severely debarked*, logged – *tree cut down*) of individuals and indices of human activities on individuals were recorded. Within each plot, five quadrat-subplots of 5 m × 5 m were installed

Photos 2.
Ontogenetic stages of *Boswellia dalzielii*: (a) seedling, (b) juvenile, (c) adult.
Photos P. Sabo.

in the four corners and in the center to count and measure total height and the collar diameter of seedlings and juveniles. In addition, for each seedling and juvenile, the mechanism of regeneration either from seed, sucker or stem sprout was determined by excavation.

Data analysis

Assessing effect of land use on dendrometric characteristics and density of trees and regenerations of *Boswellia dalzielii*

One-way analysis of variance (ANOVA) (Zar, 1999) was applied on mean diameter, basal area and mean height (table I) to assess impacts of land use types on size characteristics of *B. dalzielii*. Assumptions for ANOVA namely normality and equality of populations' variances were checked before using Ryan-Joiner and Levene tests respectively. When significant land use effect is detected, the Student-Newman and Keuls test was applied to classify the land-use types according to their mean values for each size characteristic. Densities of adults, juveniles and seedlings (table I) were compared using generalized linear models with Poisson error distribution. All these analyses were performed in the R statistical package version 3.5.1 (R Core Team, 2018).

Assessing land use impacts on trees and regeneration size class distribution

Tree diameter values were arranged in 5 cm classes and observed class-wise densities (d_i) were calculated as in the equation below (Bonou *et al.*, 2009):

$$d_i = \frac{n_i}{S_p \times N_p}$$

where d_i is the tree density of class i, n_i is the number of individuals in class i, S_p and N_p are plot size in ha (i.e. 0.1 ha) and the total number of plots per land use, respectively.

The observed size class distributions (based on d_i) were adjusted to the Weibull three-parameter distribution. The probability density function (Johnson and Kotz, 1970) of this distribution is:

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

where x is the tree diameter; a (threshold parameter) = 5 cm; b is the scale parameter linked to the central value of diameters and heights; c is the shape parameter of the structure. Observed data were used to estimate parameters b and c based on the maximum likelihood method. These values were used to establish the theoretical distribution following Glèlè Kakaï *et al.* (2016). Log-linear analysis was performed in SAS (2006) to test the adequacy of the observed structure to the Weibull distribution.

Regenerations individuals were grouped into 0.5 m range height classes. Height classes' distribution provides information for better understanding of the potential growth and developmental problems of regenerations (De Steven, 1994).

Impacts of land use on the regeneration mechanisms and health status of *Boswellia dalzielii* individuals

A contingency table showing the number of individuals for each regeneration mechanism was constructed and submitted to a Chi-square test to check whether land use has non-random impacts on the distribution of regeneration mechanism. The same analysis was performed on health status and threats.

Table I.
Population structure and stability parameters.

Parameters	Formula	Definition	References
Tree-density of the stands (N in trees/ha)	$N = \frac{n}{s}$	Average number of trees per plot expressed in trees/ha	Philip, 2002
Mean diameter of trees (D, in cm)	$D = \frac{1}{n}\sum_{i=1}^{n} d_i$	Average diameter of all trees found in the stand	
Basal area (G, in m²/ha)	$G = \frac{\pi}{40000\,s}\sum_{i=1}^{n} d_i^2$	Sum of the cross-sectional areas at 1.3 m above ground level of all *Boswellia dalzielii* trees on a plot	Philip, 2002
Mean height (H, in m)	$H = \frac{1}{n}\sum_{i=1}^{n} h_i$	Average height of all trees found in the stand	
Mean density of regeneration (individuals/ha)	$N_r = \frac{1}{5}\sum_{i=1}^{5} dr_i$ with $dr_i = \frac{n_i}{sq}$	Average number of seedlings and juveniles of *Boswellia dalzielii* per hectare	Poupon, 1970
Recruitment rate (%)	$Tr(\%) = \frac{Individuals\ d < 5\ \text{cm}}{Individuals\ d \geq 5\ \text{cm}} * 100$	Number of individuals dbh < 5 cm divided by number of individuals dbh ≥ 5 cm	Poupon, 1970

Results

Impacts of land use on dendrometric characteristics and densities of *Boswellia dalzielii*

In total, 1,191 individuals of *B. dalzielii* were recorded in the 160 plots. Among the dendrometric characteristics, only the mean diameter varied significantly ($p < 0.05$) according to land use. Trees were larger in farmlands than in fallows and woodlands. Although not significant, trees were taller in farmlands than in other land use types and basal area was higher in woodlands and fallows than in farmlands (table II). Land use type had significant effect ($p < 0.05$) on densities for all ontogenetic stages (table II). There were more adults, juveniles and seedlings in woodlands than in fallows and farmlands (table II). Adult tree density was 1.31 and 2.72 times higher in woodlands than in fallows and farmlands, respectively (table II). Similarly, density of regeneration (juveniles and seedlings) was 6.20 and 26.76 times higher in woodlands than in fallows and farmlands, respectively (table II). The overall rate of natural regeneration of *B. dalzielii* populations is 25.50% for a total number of 242 regeneration trees. This rate is very low in farmlands (4.66%), low in fallows (17.09%) and in woodlands (37.21%).

Impacts of land use on the size class distributions of tree and regeneration of *Boswellia dalzielii*

The diameter size class distribution of trees (figure 2) showed that the probabilities of the goodness of fit tests were all greater than 0.05 (farmlands: Chi-square = 2.13, $p = 0.790$; fallows: Chi-square = 1.03, $p = 0.910$; and woodlands: Chi-square = 1.05, $p = 0.860$) indicating a good fit of the Weibull distribution to the observed size distributions for all land use types. In the woodlands, the distribution followed a reverse J-shaped with a shape parameter $c < 1$, characterizing a higher proportion of individuals in the smaller diameter classes. This distribution was dominated by individuals of diameter between 5 and 30 cm (figure 2a). In fallows, the distribution was asymmetric positive (figure 2b) characterizing stands with predominance of small individuals. Adult trees between 5 and 40 cm diameter were the most represented. In farmlands, the distribution rather showed a bell-shaped diameter distribution (figure 2c) characterized by a large proportion of individuals in the middle diameter classes and lower proportion of individuals in the smaller and larger diameter classes. Trees of diameter between 20 and 45 cm were the most represented.

The height class distribution of regenerations (seedlings and juveniles) showed that the probabilities of the goodness of fit tests were all greater than 0.05 (Farmlands: Chi-square = 3.41, $p = 0.680$; Fallows: Chi-square = 2.76, $p = 0.831$; and Woodlands: Chi-square = 1.91, $p = 0.783$) indicating a good fit of the Weibull distribution to the observed size distributions for all land-use types. This height class

Bois et Forêts des Tropiques – ISSN : L-0006-579X
Volume 349 – 3e trimestre – septembre 2021 – p. 51-63

Table II.
Comparison of the dendrometric parameters of *Boswellia dalzielii* trees according to land use types and soil types: mean (m), standard error (se) and probability values (*P*) of the ANOVA and GLM.

Land use types/ Soil types	Mean diameter (D, cm)		Mean height (H, m)		Basal area (G, m²/ha)		Density (N, stems/ha) Adults		Juveniles		Seedlings	
	m	se	m	se	m	se	m	se	m	se	m	se
Woodland (60)	20.5^{a}	0.49	7.0^{a}	0.11	3.5^{a}	0.24	82.3^{a}	6.57	27.3^{a}	5.82	171.3^{a}	29.83
Fallow (50)	29.3^{b}	0.64	8.9^{a}	2.01	3.6^{a}	0.25	62.0^{b}	3.98	6.0^{b}	2.92	27.6^{b}	12.84
Farmlands (50)	32.8^{c}	0.96	8.8^{a}	0.14	2.8^{a}	0.28	30.0^{c}	1.63	1.0^{c}	0.71	6.4^{c}	3.68
F/Chi-square	17.07		2.51		2.37		1349.90		1842.90		1623.90	
p-value	‹0.001		0.08		0.09		‹0.001		‹0.001		‹0.001	

Statistic tests (F for ANOVA, and Chi-square for Poisson GLM). Means followed by the same letter in the same column are not significantly different at Prob. = 0.05 (Student-Newman-Keuls test). m: mean; se: standard error; p-value: probability.

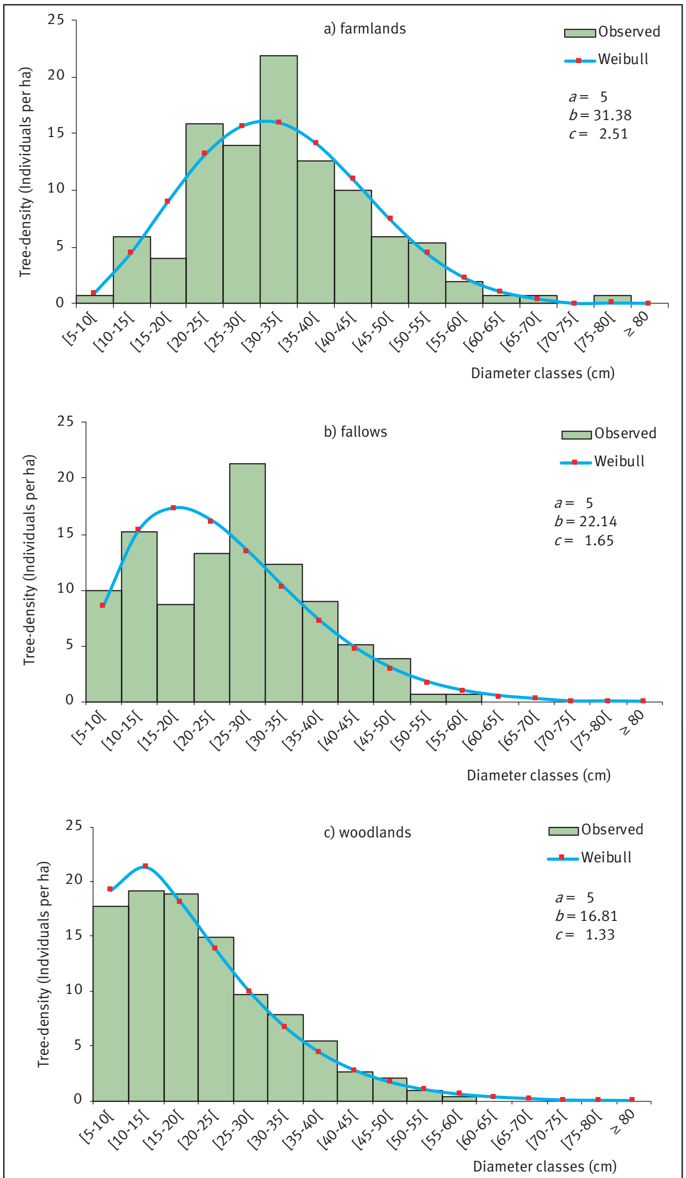


Figure 2.
Stem diameter structures of *Boswellia dalzielii* in three land-use types: a) farmlands, b) fallows, c) woodlands.

distribution of regenerations in all land use types showed a reverse-J shape, with a shape parameter c ‹ 1. Individuals of total height between 0 and 0.5 m were the most abundant (figure 3). Individuals in other height classes were rare (figure 3).

Impacts of land use on the regeneration mechanisms and health status of *Boswellia dalzielii* individuals

Tree regeneration (seedlings and juveniles) mechanisms including suckers, stem sprouts, and seedlings (photos 3) were identified and their occurrence differed significantly across land use types ($p < 0.001$, table III). *B. dalzielii* reproduces mainly through asexual routes (sucker and stem sprouts). Irrespective of the land use types, more than half of regeneration individuals were from suckers and this proportion was higher in farmlands followed by woodlands and fallows. Stem sprouts were mostly found in fallows. Regeneration from seeds were mostly found in woodlands followed by fallows but not in farmlands (table III).

Concerning the health status of *B. dalzielii* individuals (photos 4), there was also significant variation among land use types ($p < 0.001$, table III). Out of a total of 949 identified individuals, 80.18% had indices of human exploitation. More than half of individuals were severely unhealthy in farmlands and fallows. Woodlands were dominated by healthy or moderately healthy individuals, although the proportion of logged and severely unhealthy trees was about 40%. There were more logged trees in woodlands than in other land use types (table III).

With regards to threats to individuals of *B. dalzielii*, cutting, fires, wind and especially the intense debarking were noted (photos 5). Individuals were severely debarked and often have dead parts (branches or trunk) in all land use types. This observation was very pronounced in farmlands and fallows (table III). On the other hand, indices of bush fires and cutting were noted mainly in woodlands.

Bois et Forêts des Tropiques – ISSN: L-0006-579X
Volume 349 – 3rd quarter – September 2021 – p. 51-63

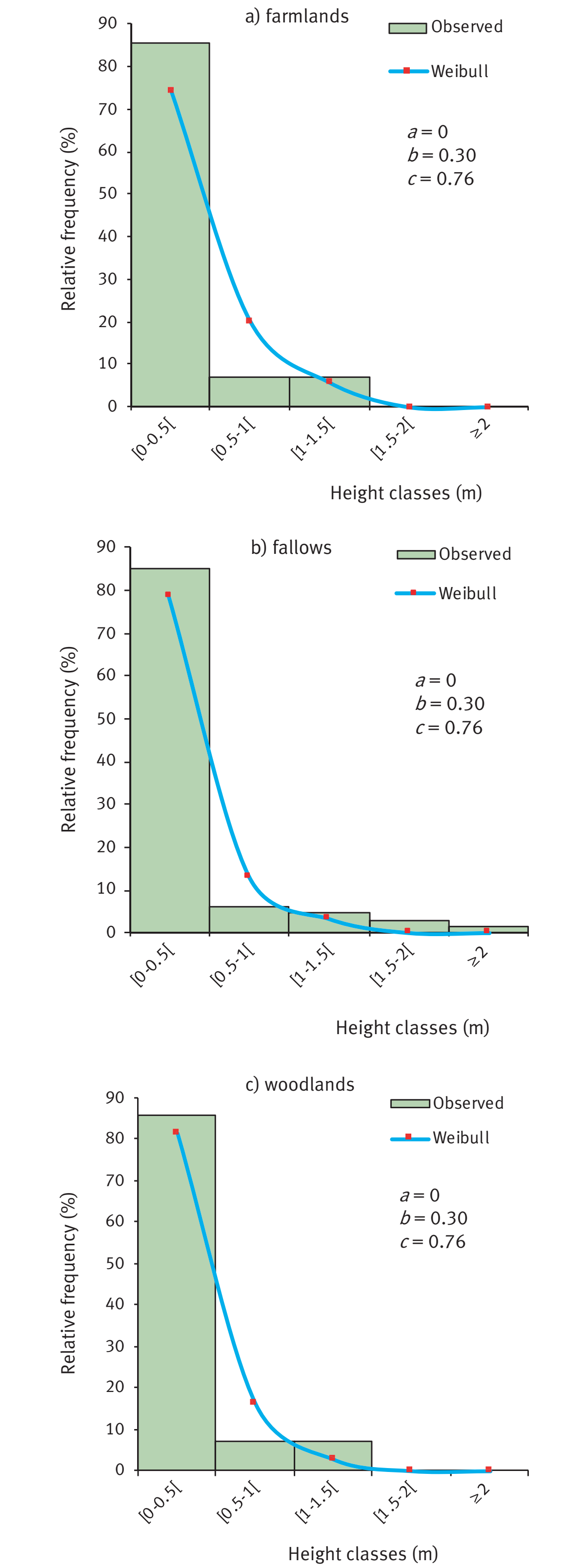


Figure 3.
Stem height distribution of regeneration in three land-use types: a) farmlands, b) fallows, c) woodlands.

Discussion

This study examined the population structure of *B. dalzielii* in relation to land use type. Our results indicated a higher abundance of adult trees in the woodlands than in fallows and farmlands. Similarly, density of regeneration (juveniles and seedlings) was higher in woodlands than in fallows and farmlands. There was a marked difference in the population size class of the Frankincense according to land uses. Concerning, the size class distribution of regenerations height, all land use types showed the same distribution type (reverse-J shape). Irrespective of the land use types, more than half of regenerations were from suckers. Regenerations from seeds were very scare. Concerning the health status of *B. dalzielii* individuals, farmlands individuals were more exploited than fallows and woodlands' individuals.

Land use impacts on the dendrometric parameters of *Boswellia dalzielii* populations

The lack of differences in height of *B. dalzielii* across the three land use types may suggest lack of strong competition for light in the species natural habitats. Indeed, all three land use types are open plant formations. Competition for light has been shown as a key driver of tree size in height in dense vegetation stands (Monzeglio and Stoll, 2008). The largest trees are found in the farmlands compared to fallows and woodlands. In recognition of the medicinal importance of the Frankincense (Ouédraogo *et al.*, 2006), many farmers preserve largest individuals during crop land clearing for the debarking. In addition, these individuals benefit from certain agricultural practices such as weeding and fertilization for their growth (Gouwakinnou *et al.*, 2009; Bazié *et al.*, 2019). The higher density in woodlands compared to fallows and farmlands can be explained by the fact that adult trees of *B. dalzielii* are associated to agriculture in the farmlands. As such it becomes difficult to cultivate annual crops with a high density of trees on farms. Several authors have shown that agricultural land use affects species density (Schumann *et al.*, 2011; Idohou *et al.*, 2016). The higher density in fallows compared to farmlands is due to the gradual recovery of vegetation. Concerning the regeneration, in farmlands, agricultural practices such as plowing, weeding and hilling do not favor the emergence of seedlings or their transition and therefore juveniles. The low density of juveniles in fallows compared to woodlands could be justified by the fact that the vegetation is not completely reconstituted yet. In the Sahel region, the decrease of the practice of fallowing reported by Hänke *et al.* (2016) will undoubtedly compromise vegetation structure, especially for *B. dalzielii* in long term. We conclude that cultivation of crops both reduce seedling regeneration, and may contribute to the lack of small individuals. Similar previous findings indicate that individuals of some agroforestry tree species in small diameter classes occurred at lower density in farmlands when compared to fallows and woodlands, where individuals of smaller diameter classes were numerous (Kelly *et al.*, 2004; Ky-Dembele *et al.*, 2019). In addition, the study

Table III.
Distribution of regeneration mechanism, health status and threats of *Boswellia dalzielii* across land use types.

Variables/levels	Farmlands	Fallows	Woodlands	Chi-square test statistics
Regeneration mechanism of *Boswellia dalzielii* (%) (102 trees)				
Generative	00.00	14.28	18.87	Chi-square = 53.37
Stump sprouting	14.29	28.57	5.67	Df = 4
Sucker	85.71	57.14	75.49	$p < 0.001$
Total trees	7	42	53	
Health status of *Boswellia dalzielii* (%) (952 trees)				
Healthy	6.62	17.1	35.64	Chi-square = 53.15
Moderate	24.5	22.9	17.31	Df = 6
Severe	63.58	54.19	27.7	$p < 0.001$
Logged	5.3	5.81	19.35	
Total trees	151	310	491	
Threats leading to death of *Boswellia dalzielii* (%) (63 trees)				
Debarking	57.15	50	18.75	Chi-square = 164.96
Wind	0	12.5	4.17	Df = 6
Fire	14.28	12.5	18.75	$p < 0.001$
Cutting	28.57	25	58.33	
Total	7	8	48	

area has a high agricultural potential in Burkina Faso, and is subject to rapid expansion of agricultural lands. The expansion of cultivated areas is a source of degradation of woodlands area and one of the most important cause of the loss of natural habitats (Charters *et al.*, 2019). Several species of Frankincense trees such as *Boswellia papyrifera* are threatened due to woodland conversion in Ethiopia and Sudan (Abiyu *et al.*, 2010; Abtew *et al.*, 2012). Ogbazghi *et al.*, (2006) through their study of *Boswellia papyrifera* in Eritrea concluded that land use intensity, especially agriculture had a profound negative effect on tree abundance.

Our results showed that the diameter class distribution of adults Frankincense in woodlands and fallows mainly comprised individuals with small diameter compared to farmlands and suggest a relatively stable population structure, particularly in woodlands and highlights to what extent human activities resulting from change in land use may affect the conservation of a species (Ky-Dembele *et al.*, 2019). The low proportion of individuals in the dbh class 5-20 cm in farmlands suggest a difficulty of recruitment of individuals of this lower diameter class to the next ones suggesting the removal of new plants of *B. dalzielii* while farming. This might


a


b


c

Photos 3.
Regeneration mechanism of *Boswellia dalzielii*: (a) sucker, (b) stump, (c) seedling.
Photos P. Sabo.

Bois et Forêts des Tropiques – ISSN: L-0006-579X
Volume 349 – 3rd quarter – September 2021 – p. 51-63

Photos 4.
Health status of *Boswellia dalzielii*: (a) healthy, (b) moderely, (c) severely, (d) logged.
Photos P. Sabo.

be also due to the combined effects of human impact such as land clearing for agriculture, livestock grazing and/or harvesting of fodder and harvesting of medicinal products. As for regeneration, we also found their majority (78%) was in the height class of 0-0.5 m in all land-types. Admittedly, this stock of individuals constitutes a regeneration potential for *B. dalzielii* but it is not a guarantee of successful renewing of population, as previously pointed for this species and for other dryland species such as *Boswellia papyrifera* and *Pterocarpus erinaceus* by Alemu (2012) and Ouédraogo *et al.* (2012). This low-energy class is known to be very sensitive to environmental factors such as fire and drought (Vieira and Scariot, 2006). Actually, Gijsbers *et al.* (1994) showed that the density of seedlings is high at the beginning of the rainy season but drops considerably in the dry season, a period characterized by occurrence of fires and drought in semi-arid area. This situation makes the survival of juveniles unpredictable because of complex interactions among soil, climatic conditions and regeneration mechanisms including seeds in seed banks and those dispersed into a site as well as stump sprouting. For example, in woodlands where the highest density of seedlings occurred, the transition rate of seedlings to juveniles is only 8.69%. Vieira and Scariot (2006) have shown that individuals of size 0.9-1.2 and 1.2-1.5 mark a stage of survival and significant growth in the renewal of stands. The low proportion of individuals in these classes in the different land use types thus indicates a major concern of erosion of the population (Bationo *et al.*, 2001).

Photos 5.
Threats to *Boswellia dalzielii*: (a) debarking, (b) fire, (c) wind, (d) logging.
Photos P. Sabo.

Others studies have consistently reported the decline of the population of *Boswellia papyrifera* due to lack of regeneration (Ogbazghi, 2001; Bongers *et al.*, 2019). Nevertheless, *B. dalzielii* seems to have developed a survival strategy though reduction of growth and devoting higher energy to the development of a hypertrophied root that contains significant food and energy reserves (Ouédraogo *et al.*, 2006). Seedlings can lose their aerial part by drying out or following an accident (fire, grazing) and survive as geophytes during the dry season. The regrowths of the next rainy season are then more vigorous than those of the previous year (Ouédraogo *et al.*, 2006).

Land use impacts on the regeneration mechanisms and health status of *Boswellia dalzielii* individuals

Suckering is the most abundant regeneration mechanism in the three land use types suggesting a possible adaption of the species to different biotic and abiotic stressors but at the same time suggest that individuals from seeds have relatively lower resistance to drought, fire, improper agricultural practices and livestock grazing. Indeed, suckering is a survival strategy that some species develop to compensate for the limitation of sexual reproduction in disturbed areas (Bellefontaine *et al.*, 2000). According to Setterfield (2002), fire encourages vegetative propagation of species and indicates that regeneration reliant to sexual reproduction is disadvantaged by frequent fire. In addition, in view of the seed properties of *Boswellia dalzielii*, such as absence of seed dormancy and the production of non-viable and embryo-lacking seed (Ouédraogo *et al.*, 2006), regeneration from root suckers remains the most appropriate way for the reproduction of the species. In the Horn of Africa, Ogbazghi (2001) and Eshete (2002) have also observed this mode of reproduction for *Boswellia papyrifera*. Unfortunately, vegetative propagation (sucker and stump) is not favorable to natural conservation of species, even if it contributes to short-term population maintenance, because the lack of sexual recruits will limit the input of genetic variation (Setterfield, 2002).

Nevertheless, vegetative propagation also has the advantage of being less water-intensive and ensuring rapid seedling growth (Bellefontaine *et al.*, 2000). The use of mechanical means in the farmlands often results in root notches that cause seedlings to appear in these areas.

The high proportions of harvested *B. dalzielii* trees show that this species is used and particularly appreciated by local populations as medicine as previously reported (Nacoulma-Ouédraogo, 1996; Ouédraogo *et al.*, 2006; Kémeuzé *et al.*, 2012). The harvesting patterns across the three land use types showed that the species is severely over-exploited in all land use types due to bark harvesting combined with agricultural practices. However, harvesting disrupts the tree physiological functioning and stimulates a higher hormonal activity in order to close the wound quickly (Thiombiano *et al.*, 2003). Several studies have shown the negative effect of debarking by tapping on *Boswellia* species (Ogbazghi, 2001; Rijkers *et al.*, 2006) leading to a declining population trend (Bongers *et al.*, 2019).

Implications for the management of *Boswellia dalzielii*

The present study investigated the land use impacts on the size characteristics, stand structure and regeneration of *B. dalzielii* in the Sudano-Sahelian region of Burkina Faso. Our analysis provides evidence that human disturbances contribute to unstable stands of *B. dalzielii*. In addition, excessive debarking, fire and wind prevent good recruitment despite a fairly high seedling density in woodlands. It is therefore important to carry out assisted natural regeneration in order to allow a better transition between the stages in order to have a stable population in the medium term. To do this, actions such as the establishment of firewalls will be necessary. Also, agricultural practices that maintain a sufficient number of individuals can significantly contribute to the persistence of *B. dalzielii* in agroforestry systems. The bark is the most sought part in the species, limiting the harvesting rate and promoting best harvest practices can also contribute to a better management of the species.

Conclusion

Analysis of the status of *B. dalzielii* stands revealed that they are unstable in the farmlands, unstable in fallow and stable in woodlands. Natural regeneration is slow and weak. Drought and fires prevent the establishment of seedlings growing during the rainy season and their transition from juvenile to adult stage. Overall, this study contributed to new information about the stands structure of *B. dalzielii*. However, long-term studies monitoring of harvested and non-harvested populations will provide better insights and refine management actions. Meanwhile, it is urgent to increase the reforestation and awareness activities of the populations concerned in the conservation of plant biodiversity in the fragile and unstable studied stands.

Acknowledgement
The authors would like to thank the Islamic Development Bank (IDB) and Aromatic Plant Research Center (APRC) for its financial support. They also thank the guides for their kind assistance in data collection. The authors declare that they have no conflict of interest.

References

Abiyu A., Bongers F., Eshete A., Gebrehiwot K., Kindu M., Lemenih M., *et al.*, 2010. Incense woodlands in Ethiopia and Eritrea: regeneration problems and restoration possibilities. *In*: Bongers F., Tennigkeit T. (eds). Degraded forests in Eastern Africa: management and restoration. London, UK, Earth Scan, 133-152. https://www.researchgate.net/publication/285743882_Incense_woodlands_in_Ethiopia_and_Eritrea_regeneration_problems_and_restorations_possibilities/link/5678f0fd08aebcdda0ecaf13/download

Abtew A. A., Pretzsch J., Mohamoud T. E.-S., Adam Y. O., 2012. Population status of *Boswellia papyrifera* (Del.) Hochst in the dry woodlands of Nuba Mountains, South Kordofan State, Sudan. Agriculture and Forestry, 54 (1/4): 41-50. http://89.188.43.75/agricultforest/old/20120514-03Alemuetal.pdf

Alemu B. Y., 2012. Carbon stock potentials of woodlands and land use and land cover changes in north western lowlands of Ethiopia. MSc thesis, Hawassa University, Ethiopia, 129 p. https://hdl.handle.net/10568/25151

Arbonnier M., 2000. Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest. Cirad/MNHN/UICN, France, 541 p.

Bationo B. A, Ouédraogo S. J., Guinko S., 2001. Stratégies de régénération naturelle de *Detarium microcarpum* Guill. et Perr. dans la forêt classée de Nazinon (Burkina Faso). Fruits, 56 : 271-285. https://doi.org/10.1051/fruits:2001129

Bazié P., Ky-Dembele C., Jourdan C., Roupsard O., Zombré G., Bayala J., 2019. Synchrony in the phenologies of fine roots and leaves of *Vitellaria paradoxa* in different land uses of Burkina Faso. Agroforestry Systems, 93 (2): 449-460. https://doi.org/10.1007/s10457-017-0135-0

Bellefontaine R., Edelin C., Ichaou A., Du Laurens D., Monsarrat A., Loquai C., 2000. Le drageonnage, alternative aux semis et aux plantations de ligneux dans les zones semi-arides : protocole de recherches. Science et changements planétaires/Sécheresse, 11 (4) : 221-226. https://www.jle.com/fr/revues/sec/e-docs/le_drageonnage_alternative_aux_semis_et_aux_plantations_de_ligneux_dans_les_zones_semi_arides_protocole_de_recherches_230087/article.phtml

Bongers F., Groenendijk P., Bekele T., Birhane E., Damtew A., Decuyper M., *et al.*, 2019. Frankincense in peril. Nature Sustainability, *2* (7): 602-610. https://doi.org/10.1038/s41893-019-0322-2

Bonou W., Glèlè Kakaï R., Assogbadjo A. E., Fonton H. N., Sinsin B., 2009. Characterisation of *Afzelia africana* Sm. habitat in the Lama Forest reserve of Benin. Forest Ecology and Management, 258: 1084-1092. https://doi.org/10.1016/j.foreco.2009.05.032

Charters L. J., Aplin P., Marston C. G., Padfield R., Rengasamy N., Bin Dahalan M. P., *et al.*, 2019. Peat swamp forest conservation withstands pervasive land conversion to oil palm plantation in North Selangor, Malaysia. International Journal of Remote Sensing, 40 (19): 7409-7438. https://doi.org/10.1080/01431161.2019.1574996

Clerici N., Bodini A. H., Eva A., Grégoire J.-M., Dulieu D., Paolini C., 2007. Increased isolation of two Biosphere Reserves and surrounding protected areas (WAP ecological complex, West Africa). Journal for Nature Conservation, 15: 26-40. https://doi.org/10.1016/j.jnc.2006.08.003

Dagnelie P., 1998. Statistiques théoriques et appliquées. Statistique descriptive et bases de l'inférence statistique. Bruxelles, Belgique, De Boeck, 508 p.

De Steven D., 1994. Tropical tree seedling dynamics: Recruitment patterns and their population consequences for three canopy species in Panama. Journal of Tropical Ecology, 10 (3): 369-383. http://www.jstor.org/stable/2560320

DeCarlo A., Johnson S., Okeke-Agulu K. I., Dosoky N. S., Wax S. J., Owolabi M. S., *et al.*, 2019. Compositional analysis of the essential oil of *Boswellia dalzielii* frankincense from West Africa reveals two major chemotypes. Phytochemistry, 164: 24-32. https://doi.org/10.1016/j.phytochem.2019.04.015

Djossa B. A., Fahr J., Wiegand T., Ayihouénou B. E., Kalko E. K., Sinsin B. A., 2008. Land use impact on *Vitellaria paradoxa* C.F. Gaerten. stand structure and distribution patterns: a comparison of Biosphere Reserve of Pendjari in Atacora district in Benin. Agroforestry Systems, 72 (3): 205-220. https://doi.org/10.1007/s10457-007-9097-y

Emmanuel A. O., Adediji J. A., 2015. Morphometric study of testes of adult Wistar rats treated with aqueous extract of *Boswellia dalzielii* stem back. Journal of Dental and Medical Science, 14 (10): 26-79.

Eshete A., 2002. Regeneration status, soil seed bank and socio-economic importance of *Boswellia papyrifera* (Del.) Hoschst. in two woredas of North Gonder zone, Northern Ethiopia. SIDS, Uppsala, Sweden, Agris, FAO. https://agris.fao.org/agris-search/search.do?recordID=KE2005100716

Gijsbers H. J. M., Kessler J. J., Knevel M. K., 1994. Dynamics and natural regeneration of woody species in farmed parklands in the Sahel region (Province of Passore, Burkina Faso). Forest Ecology and Management, 64 (1): 1-12. https://doi.org/10.1016/0378-1127(94)90122-8

Glèlè Kakaï R., Bonou W., Lykke A. M., 2016. Approche méthodologique de construction et d'interprétation des structures en diamètre des arbres. Annales des Sciences Agronomiques, 20 : 99-112. https://pdfcookie.com/download/approche-methodologique-de-construction-et-dinterpretation-des-structures-en-diametre-des-arbres-wrvrdnp5dz2o

Gouwakinnou G. N., Kindomihou V., Assogbadjo A. E., Sinsin B., 2009. Population structure and abundance of *Sclerocarya birrea* (A. Rich) Hochst subsp. *birrea* in two contrasting land-use systems in Benin. International Journal of Biodiversity and Conservation, 1 (6): 194-201. https://academicjournals.org/article/article1379947232_Gouwakinnou%20et%20al.pdf

Gouwakinnou G. N., Lykke A. M., Assogbadjo A. E., Sinsin B., 2011. Local knowledge, pattern and diversity of use of *Sclerocarya birrea*. Journal of Ethnobiology and Ethnomedicine, 7 (1): 8. https://doi.org/10.1186/1746-4269-7-8

Groom N., 1981. Frankincense and myrrh: a study of the Arabian incense trade. London, New York, Longman ELT, 285 p.

Hänke H., Börjeson L., Hylander K., Enfors-Kautsky E., 2016. Drought tolerant species dominate as rainfall and tree cover returns in the West African Sahel. Land Use Policy, 59: 111-120. https://doi.org/10.1016/j.landusepol.2016.08.023

Idohou R., Assogbadjo A. E., Azihou F., Glèlè Kakaï R. G., Adomou A., 2016. Influence of the landscape context on stand structure and spatial patterns of the doum palm (*Hyphaene thebaica* Mart.) in the Republic of Benin (West Africa). Agroforestry Systems, 90 (4): 591-605. https://doi.org/10.1007/s10457-016-9920-4

Johnson N. L., Kotz S., 1970. Distributions in Statistics: Continuous Univariate Distributions. New York, USA, John Wiley & Sons, 756 p.

Kelly B. A., Bouvet J.-M., Picard N., 2004. Size class distribution and spatial pattern of *Vitellaria paradoxa* in relation to farmers' practices in Mali. Agroforestry Systems, 60: 3-11. https://doi.org/10.1023/B:AGFO.0000009400.24606.e3

Kémeuzé V. A., Mapongmetsem P. M., Tientcheu M. A., Nkongmeneck B. A., Jiofack R. B., 2012. *Boswellia dalzielii* Hutch: état du peuplement et utilisation traditionnelle dans la région de Mbé (Adamaoua-Cameroun). Science et changements planétaires/Sécheresse, 23 (4) : 278-283. https://doi.org/10.1684/sec.2012.0365

Ky-Dembele C., Dayamba S. D., Savadogo P., Kalinganire A., Bayala J., Muchugi A., Ramni A., 2019. Land use dictates diversity, density and regeneration of woody species in southwestern Mali, West Africa. Tropical Ecology, 60 (1): 114-128. https://doi.org/10.1007/s42965-019-00015-2

Leminih M., Teketay D., 2003. Frankincense and myrrh resources of Ethiopia: I distribution, production, opportunities for dryland development and research needs. SINET, Ethiopian Journal of Science, 26 (1): 63-72. https://www.ajol.info/ index.php/sinet/article/view/1820

Monzeglio U., Stoll P., 2008. Effects of spatial pattern and relatedness in an experimental plant community. Evolutionary Ecology, 22 (6): 723-741. https://doi.org/10.1007/s10682-007-9197-1

Nacoulma-Ouédraogo O. G., 1996. Plantes médicinales et pratiques médicales traditionnelles au Burkina Faso : cas du plateau central. Thèse de doctorat d'État, Faculté des sciences et techniques, Université de Ouagadougou, Burkina Faso.

Nussinovitch A., 2010. Plant Gum Exudates of the World: Sources, Distribution, Properties and Applications. Boca Raton, FL, USA, CRC Press, 101-102.

Ogbazghi W., 2001. The distribution and regeneration of *Boswellia papyrifera* (Del.) Hochst. In Eritrea. PhD thesis, Wageningen University, Netherlands, 144 p. https://edepot.wur.nl/194745

Ogbazghi W., Rijkers T., Wessel M., Bongers F., 2006. Distribution of the frankincense tree *Boswellia papyrifera* in Eritrea: the role of environment and land use. Journal of Biogeography, 33 (3): 524-535. https://doi.org/10.1111/j.1365-2699.2005.01407.x

Onana J. M., 1998. Les Buséracées du Cameroun : taxonomie, biométrie foliaire et biologie. Thèse de doctorat, Université de Yaoundé I, Cameroun, 267 p.

Ouédraogo A., Thiombiano A., 2012. Regeneration pattern of four threatened tree species in Sudanian savannas of Burkina Faso. Agroforestry Systems, 86 (1): 35-48. https://doi.org/10.1007/s10457-012-9505-9

Ouédraogo N., Lompo M., Sawadogo R. W., Tibiri A., Hay A. E., Koudou J., *et al.*, 2012. Étude des activités anti-inflammatoire, analgésique et antipyrétique des décoctés aqueux des feuilles et des racines de *Pterocarpus erinaceus* Poir. (Fabaceae). Phytothérapie, 10 (5) : 286-292. https://doi.org/10.1007/s10298-012-0732-z

Ouédraogo A., Thiombiano A., Hahn-Hadjali K., Guinko S., 2006. Diagnostic de l'état de dégradation des peuplements de quatre espèces ligneuses en zone soudanienne du Burkina Faso. Science et changements planétaires/Sécheresse, 17 (4) : 485-491. https://www.jle.com/fr/revues/sec/e-docs/diagnostic_de_letat_de_degradation_des_peuplements_de_quatre_especes_ligneuses_en_zone_soudanienne_du_burkina_faso_272388/article.phtml

Philip S. M., 2002. Measuring Trees and Forests. 2nd ed. London, UK, CABI Publishing, 310 p.

Poupon H., 1970. Sur la croissance de quelques espèces de pin dans ses rapports avec le climat du Nord de la Tunisie. Thèse de doctorat, Université de Paris, Faculté des sciences d'Orsay, France, 131 p. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers20-09/07380.pdf

R Core Team, 2018. R: A language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing. https://www.R-project.org/

RGPH, 2008. Recensement général de la population et de l'habitation de 2006. Burkina Faso, Institut national de la statistique et de la démographie, 52 p. http://www.cns.bf/IMG/pdf/RGPH_2006.pdf

Rijkers T., Ogbazghi W., Wessel M., Bongers F., 2006. The effect of tapping for frankincense on sexual reproduction in *Boswellia papyrifera*. Journal of Applied Ecology, 43: 1188-1195. https://doi.org/10.1111/j.1365-2664.2006.01215.x

SAS, 2006. SAS Online Doc 9.3. SAS Institute Inc., USA, 176 p.

Schumann K., Wittig R., Thiombiano A., Becker U., Hahn K., 2011. Impact of land-use type and harvesting on population structure of a non-timber forest product-providing tree in a semi-arid savanna, West Africa. Biological Conservation, 144: 2369-2376. https://doi.org/10.1016/j.biocon.2011.06.018

Setterfield S. A., 2002. Seedlings establishment in an Australian tropical savanna: effects of seed supply, soil disturbance and fire. Journal of Applied Ecology, 39: 949-956. https://doi.org/10.1046/j.1365-2664.2002.00772.x

Thiombiano A., Wittig R., Guinko S., 2003. Conditions de multiplication sexuée chez les Combretaceae du Burkina Faso, Revue d'Écologie – La Terre et la Vie, 58 (4) : 361. http://hdl.handle.net/2042/55562

Thiombiano A., Schmidt M., Dressler S., Ouédraogo A., Hahn-Hadjali K., 2012. Catalogue des plantes vasculaires du Burkina Faso. Boissiera : mémoires des Conservatoire et Jardin botaniques de la Ville de Genève, 65 : 1-391. https://dialnet.unirioja.es/servlet/articulo?codigo=4170248

Vieira D. L. M., Scariot A., 2006. Principles of natural regeneration of tropical dry forests for restoration. Restoration Ecology, 14 (1): 11-20. https://doi.org/10.1111/j.1526-100X.2006.00100.x

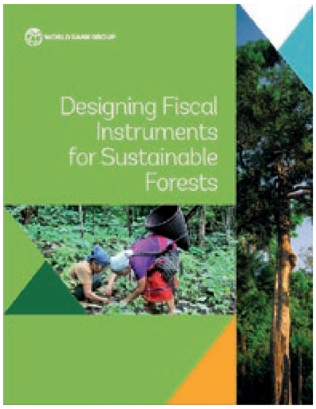
Zar J. H., 1999. Biostatistical analysis. Noida, India, Pearson Education, 634 p.

Sabo *et al.* – Contribution des auteurs

Contributor's role	Names of authors
Conceptualisation	P. Sabo, A. Ouédraogo, K. V. Salako
Formal analysis	P. Sabo
Investigation and enquiry	P. Sabo
Methods	P. Sabo, A. Ouédraogo, C. D. S. J. Gbemavo, K. V. Salako, R. Glèlè Kakaï
Funding	A. Ouédraogo
Supervisors	A. Ouédraogo, R. Glèlè Kakaï
Validation	C. D. S. J. Gbemavo, A. Ouédraogo, K. V. Salako, R. Glèlè Kakaï
Writing - Preparation of the original draft	P. Sabo
Writing - Revision and editing	P. Sabo, A. Ouédraogo, C. D. S. J. Gbemavo, K. V. Salako, R. Glèlè Kakaï

Cirad - Campus international de Baillarguet,
34398 Montpellier Cedex 5, France
Contact : bft@cirad.fr - ISSN : L-0006-579X

Bois et Forêts des Tropiques – ISSN: L-0006-579X
Volume 349 –3rd quarter – September 2021



THE WORLD BANK, 2020. **DESIGNING FISCAL INSTRUMENTS FOR SUSTAINABLE FORESTS.** USA, CLIMATE INVESTMENT FUNDS, 330 P.

This publication is an urgent call to action and provides policy makers with information to enable the design and implement fiscal policies that reduce incentives for deforestation, forest degradation, and land use change and instead encourage forest conservation, sustainable management, and green global value chains. Existing fiscal policies already provide incentives, oftentimes incentivizing short-lived economic growth through exhausting natural resources and merely turning natural capital into physical capital without creating net value. This book aims to empower decisionmakers to harness the power of fiscal policy for consciously creating incentives that direct development onto a more sustainable path. This book offers a vital reference for policy makers to do just that moving forward.
Summary adapted from the publisher's.

The World Bank, 1818 H Street,
NW Washington, DC 20433, USA.
https://www.climateinvestmentfunds.org/sites/cif_enc/files/knowledge-documents/designing_fiscal_instruments.pdf

DAÏNOU K., TOSSO D. F., BRACKE C., BOURLAND N., FORNI E., HUBERT D., KANKOLONGO M., LOUMETO J. J., LOUPPE D., NGOMANDA A., NGOMIN A., TCHUANTE TITE V., DOUCET J.-L., 2021. **GUIDE PRATIQUE DES PLANTATIONS D'ARBRES DES FORÊTS DENSES HUMIDES D'AFRIQUE.** BELGIQUE, PRESSES UNIVERSITAIRES DE LIÈGE, 322 P.

En Afrique, les plantations d'arbres sont amenées à se développer pour plusieurs raisons : restauration des capacités de production et des services rendus par les forêts naturelles, valorisation des terres agroforestières, récolte plus aisée du bois et des produits forestiers non ligneux, atténuation des effets des changements climatiques, etc. Les espèces exotiques n'offrant que des services spécifiques, il importe de redynamiser la plantation d'espèces locales. C'est l'objet de ce livre, qui s'est focalisé sur les essences des forêts denses humides, en capitalisant des résultats d'essais passés ou récents de six pays africains, et en mobilisant des compétences et connaissances de treize spécialistes. L'ouvrage aborde de façon pratique les différentes étapes d'un programme sylvicole : récolte et gestion des semences, construction et gestion des pépinières, modalités d'installation et de conduite des plantations. Une estimation des coûts et de la rentabilité de telles plantations est également fournie. Enfin, le livre décrit en détail l'itinéraire sylvicole de 50 espèces d'arbres des forêts denses humides africaines. Ce guide est destiné à un large public : aménagistes, techniciens et ingénieurs forestiers, étudiants et scientifiques intéressés par la sylviculture tropicale.
Résumé adapté de celui de l'éditeur.

Presses Universitaires de Liège,
place de la République Française,
4000 Liège, Belgique.
http://hdl.handle.net/2268/259075