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# Illegal Harvesting of Locally Endangered *Olea europaea* Subsp. *cuspidata* (Wall. ex G. Don) Cif. and Its Causes in Hugumburda Forest, Northern Ethiopia

**Mekdes Ourge [1,2,*], Ole Hofstad [1], Kari Klanderud [1], Katrine Eldegard [1] and Sarah Tewolde-Berhan [2]**

1 Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, P.O. Box 5003, NO-1433 Ås, Norway; ole.hofstad@nmbu.no (O.H.); kari.klanderud@nmbu.no (K.K.); katrine.eldegard@nmbu.no (K.E.)

2 College of Dry Land Agriculture and Natural Resource, Mekelle University, P.O. Box 231 Mekelle, Ethiopia; saratbge@gmail.com

* Correspondence: mekdes.ourge@nmbu.no; Tel.: +47-467-177-40

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**Abstract:** *Olea europaea* L. subsp *cuspidata* (Wall. ex G. Don) Cif., an endangered tree species in dry Afromontane forests, has multiple uses in local communities in Ethiopia, making it susceptible to overexploitation. The study investigated the rates and causes of *O. europaea* harvesting in the Hugumburda National Forest Priority Area (NFPA). We measured the diameter at stump height of harvested stumps from 70 (20 × 20 m) plots and estimated the time since cutting to determine the biomass of *O. europaea* wood harvested annually in the forest. We performed a socioeconomic survey of the reasons for wood harvesting by conducting 163 stratified random individual interviews in the villages surrounding the forest. The average annual quantity of *O. europaea* wood illegally harvested from the forest was estimated to be 430 kg ha$^{-1}$, mainly for farm implements, fuel wood, and fumigation purposes. The results of a General Linear Model (GLM) show that the extraction of *O. europaea* wood in the forest is higher at higher elevations than at lower, and the number of *O. europaea* stumps in the forest is higher at an intermediate distance to the villages. We show that *O. europaea* is harvested in the forest despite the fact that the forest is protected. Permanent sample plots should be established to monitor the increment.

**Keywords:** African olive; dry Afromontane forest; fuel wood; farming implements; multipurpose tree; socioeconomic survey

## 1. Introduction

Dry Afromontane forests are dominant in Ethiopian highlands [1,2]. The highlands cover more than 50% of the country's total area, and common practices there are crop production and livestock rearing [2,3]. Illegal logging and agricultural land expansion towards the forest edge are the main factors contributing to forest degradation [4–6]. The energy demands of the increasing population are mainly supported by biomass [7,8], which is derived from fuel wood, agricultural residues, and cow dung. Most people in the local communities cannot afford alternative energy sources [9], and the low incomes earned by rural families are often inadequate to meet their basic needs. As a result, forests close to the local communities have been affected by illegal logging both for home consumption and as a means of generating income [10]. The illegal harvesting of wood may lead to the destruction of the forests, and therefore the Ethiopian government has declared and implemented policies for managing

58 National Forest Priority Areas (NFPAs), covering 3.6 million ha, with the purpose of maintaining forest genetic resources. However, these policies have not been successful, as wood harvesting has continued to take place in the protected areas [11].

Hugumburda National Forest Priority Area (hereafter Hugumburda forest) has higher plant diversity compared with other forests and NFPAs in northern Ethiopia [12]. *Olea europaea* subsp. *cuspidata* (Wall. ex G. Don) Cif. (hereafter abbreviated as *O. europaea*), commonly known as African olive, is a multipurpose tree species found widely distributed in the forest [11,13]. The wood is used for fuel, fumigation (smoke baths), farm implements, house building and furniture, and the leaves are used for medicine. For example, the unique fragrance from the smoke of burnt *O. europaea* is used as a pleasant scent in homes, for flavoring traditional drinks, and as an insect repellent [14]. Negash [15] states that because of its economic and traditional benefits, the population of *O. europaea* is declining in Ethiopia due to overexploitation and needing in situ conservation at a national level [16–19]. However, there is limited knowledge about the harvesting rate of the species in Hugumburda forest. Accordingly, the main objectives of the study were: (1) to estimate the annual harvest of *O. europaea* in Hugumburda; (2) to identify the pattern in the annual harvesting of the species in relation to distance from the villages, slope, and elevation; and (3) to assess the socioeconomic importance of *O. europaea* for local households.

## 2. Materials and Methods

### 2.1. Study Area

Hugumburda National Forest Priority Area (12°36′ N, 39°31′ E) is situated in the southern part of Tigray Region, Ethiopia. The altitudinal range is 1860–2700 m a.s.l. (meters above sea level) [12]. Average daily temperatures are in the range of 14.6–22.4 °C, with a minimum of 8.8 °C in October and a maximum of 34.3 °C in June, and the average annual rainfall is 705–986 mm [13]. The forest was designated as a National Forest Priority Area in 1993 [11].

The forest is located ca. 630 km north of Addis Ababa, the capital of Ethiopia. There are four districts bordering the forest: Alamata, Endamehoni, Ofla, and Raya Azebo. The extraction of any resources within the forest except dead wood and cactus fruit is forbidden by law.

### 2.2. Data Collection

#### 2.2.1. Ecological Survey

We compiled a forest inventory to enable us to estimate the extent of the harvesting of *O. europaea* in Hugumurda Forest. Initially, a reconnaissance survey was performed to identify *O. europaea*-dominated areas of the forest. Then, 70 sample plots (20 m × 20 m) (Figure 1) were laid out in *O. europaea*-dominated areas in which all *O. europaea* stumps could be counted and their diameter at stump height (DSH) measured, in order to estimate the aboveground biomass of the wood that had been cut and removed from the forest. The plots were marked ca. 100 m apart along parallel transects placed perpendicular to three local terrain ridges, with each transect running from the top to the bottom of the ridge. The distance between neighboring transects was ca. 150 m. The time since harvest (hereafter referred to as stump age) of each stump was estimated by the freshness of exposed wood and coppices, in order to estimate the annual harvest rate. Stumps with freshly exposed wood and without coppices were estimated as one year old. The age of stumps with older exposed wood and small sprouts was estimated as two years old, and those with coppices and signs of decomposition were estimated to be more than two years old. We roughly determined the purpose of illegal harvesting on the basis of the stump diameters (i.e., DSHs). Local farmers and forest guards assisted us with stump age estimation and identification of the reason for cutting. Other information collected from each plot included slope and elevation measured at the center of each main plot with a clinometer and a handheld GPS respectively. By overlaying 70 plots in Google Earth software version 7.2 (Google, California, CA, USA), we were able to measure the distance from each sample plot to the nearest village, Hugumburda to see how the accessibility related to the harvesting rates. The Hugumburda village was the nearest village to all sample plots.

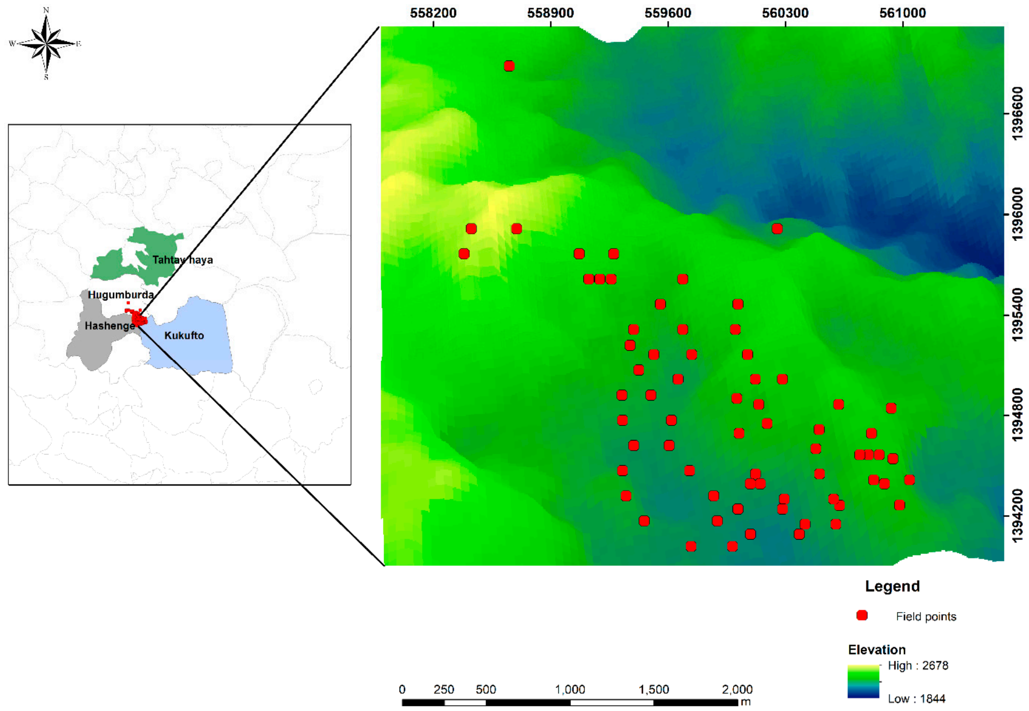


**Figure 1.** The sample plots in Hugumburda Forest in relation to the study villages, Hashenge, Kukufto, and Tahtay Haya.

2.2.2. Socioeconomic Survey

We conducted a socioeconomic survey in three villages to assess human activities relating to the harvesting of *O. europaea* in the reserve. Three villages, Kukufto, Hashenge, and Tahtay Haya, were selected from the three neighboring districts of Raya Azebo, Ofla, and Endamehoni, respectively, based on their proximity to the forest. In order to avoid sampling bias, we did not conduct a socioeconomic survey in Hugumburda village because some of the households lived within the forest. Representatives of 162 households and 54 respondents from each village were interviewed. Systematic stratified sampling was used to select households, with the aim of including both genders and different economic statuses, age classes, and educational backgrounds. A semi-structured questionnaire was developed and pre-tested twice. The survey was conducted from March to May 2016.

The questionnaire was designed to provide demographic information, such as gender, age, education, profession, job type, economic status, marital status, and different uses of *O. europaea* wood; frequency of using *O. europaea* wood; and places where the household obtained *O. europaea* wood for different purposes. The age of each respondent was classified into one of four age groups: 15–24 years, 25–44 years, 45–64 years, and 65+ years. The data were collected by conducting face-to-face personal interviews in the local language, Tigrigna.

In addition, direct preference ranking was done to identify the local community preference for plant species for fuel wood and traditional toothbrush uses. The names of common plants were listed and the respondents were divided into 16 groups, each with 9–10 respondents, and requested to rank their preferences for fuel wood and cleaning teeth use. After the ranking was completed, the scores for each species were counted and the preference list was compiled on the basis of the highest score.

Additionally, a fuel wood market survey was conducted to quantify the amount of *O. europaea* wood products being traded at the local markets. In addition, the market price for the same products in Mekelle, the capital of Tigray, was assessed for comparison. During the survey, 12 *O. europaea* wood sellers were found in two marketplaces, Shoko Majo and Kukufto, located in Endamehoni and Raya Azebo districts, respectively. Each marketplace was represented by six wood sellers and they were interviewed about the quantity of *O. europaea* wood and the price at the local market. In addition, the same fuel wood survey was conducted to five marketplaces (Aider, Adiha, Adihawsi, Lachi, and Ashirte shewuate) in Mekelle town. Seven *O. europaea* wood merchants from each of the markets, 35 in total, were interviewed. The amount of *O. europaea* wood traded in the fuel markets was quantified by weighing each bundle and converting the local unit of measurement (bundle of wood) into kilograms.

### *2.3. Data Analysis*

#### 2.3.1. Data Preparation

To determine the quantity of *O. europaea* wood harvested annually (hereafter called the harvesting rate), we summed the aboveground biomass of all *O. europaea* trees cut during the last year (i.e., stumps classified as one year old). The sum of individual tree aboveground biomass was divided by 0.04 to find the harvested biomass in kg $ha^{-1}$ $year^{-1}$ for each sample plot, since all sample plots were 400 $m^2$.

The aboveground biomass (AGB) of *O. europaea* wood harvested in Hugumburda forest was calculated using the allometric equation developed by Parent [20] for oven-dry biomass of *O. europaea* trees in Ethiopia:

$$\text{AGB (in kg)} = (0.6806 \times \text{DSH}) + (0.0422 \times (\text{DSH}^{2.7}), \quad (1)$$

where AGB = aboveground biomass of individual *O. europaea* tree (kg) and DSH = the diameter at stump height (cm). The estimated biomass did not include roots and foliage.

#### 2.3.2. Statistical Analysis

The ecological dataset was first subjected to exploratory analyses following Zuur et al. [21], to check for outliers and collinearity between candidate explanatory variables and to explore the relationships between the response and candidate explanatory variables. To avoid collinearity, we made a correlation matrix with correlation coefficients ($r$) for all possible pairs of candidate explanatory variables. Pearson correlation coefficients test were used for the continuous explanatory variables.

We used two different estimates of harvested amount (number of stumps and harvesting rate) because they were not strongly correlated (Pearson correlation: $r$ = 0.53, $p$ < 0.001. This is not so surprising, given that the diameter distribution of harvested *O. europaea* trees was quite variable. This means that for example 10 random samples of 10 harvested trees, would have a high among-samples variation in biomass. The two different estimates of harvested amount were influenced by different explanatory variables. By using only one of them, we would miss interesting patterns of association with the explanatory variables. Therefore, we chose to use both of them.

To determine whether there was a relationship between the harvesting rate of *O. europaea* (i.e., the quantity of *O. europaea* wood harvested from the forest annually) and the explanatory variables, we fitted a general linear model (GLM) with an identity link function, assuming a Gaussian distribution of errors. Explanatory variables included in the full model were elevation, slope, distance to nearest village, and the second power of each of these variables, to capture "humped-backed" relationships detected in the exploratory analyses.

To determine whether there was a relationship between the number of harvested stumps of *O. europaea* and the explanatory variables, we fitted a generalized linear model (GLM) with log link function, assuming a Poisson distribution of errors. However, this model was overdispersed (generalized Pearson statistic ($gPs$) = 4.01); therefore, we refitted the model with a negative binomial GLM ($gPs$ = 0.99). Explanatory variables included in the full model were elevation, slope, distance to nearest village, and the second power of each of these variables, to capture "humped-back" relationships detected in the exploratory analyses.

Initially, we did not consider number of stumps as a response variable because harvesting rate was calculated from the number of stumps. However, during data exploration, we found that number of stumps had a strong relationship with distance from the nearest village but harvesting rate did not have a similarly strong relationship. Therefore, we performed separate analyses for the two variables, assuming both variables as a response variable, to determine how harvesting rate and number of *O. europaea* stumps were related to slope, elevation, and distance to nearest village.

To determine whether the probability that a household harvested *O. europaea* wood directly from the forest ("yes" or "no") was influenced by the candidate explanatory variables sampled in the socioeconomic surveys (Table 1), we fitted a GLM, assuming a binomial distribution of errors and using the logit link function. Many of the candidate explanatory variables were strongly correlated (i.e., collinearity problem) and not significant to the response variable during the single variable model selection. Therefore, only explanatory variables that had a statistically significant influence ($p < 0.05$) on the response in the single variable models were included as explanatory variables in the full model. Among the candidate explanatory variables described in Table 1, only the variables "Use of *O. europaea* wood for fuel wood," "Villages," "Household head," and "Frequency of use of *O. europaea* wood for fumigating the home" were included as explanatory variables in the full model, with "Likelihood of harvesting *O. europaea* from Hugumburda forest" as a response variable. The other candidate variables were not included in the full model, either because they had no significant influence on the response variable in single-variable models ($p > 0.05$), or because they were strongly correlated ($r > 0.7$) with one or more of the explanatory variables (indicated in bold in Table 1). Polychoric correlation tests [22], i.e., tests of association between ordinal variables, were used to identify correlations between candidate categorical explanatory variables in the socioeconomic dataset: village; age class; family size; education level; household head; marital status; economic status; places to collect *O. europaea* wood for fuel wood, fumigation, and farm implements; use of *O. europaea* wood for fuel wood, fumigation, and farm implements; frequency of use of *O. europaea* wood for fumigation; and whether or not *O. europaea* trees were planted in the backyard (Table 1). In cases of correlation ($r > 0.7$) between two candidate variables, we selected the variable most strongly correlated with the response (i.e., the highest $r$-value) for inclusion in the full (most complex model), while at the same time avoiding collinearity with other variables.

**Table 1.** Description of response and candidate explanatory variables used in the model within the socioeconomic dataset. Only explanatory variables in bold were included in the full model explaining the Likelihood of harvesting *Olea europaea* (Wall. ex G. Don) Cif. from Hugumburda Forest. The other variables were not included in the full model, either because they had no significant influence on the response variable or because they were strongly correlated ($r > 0.7$) with one or more of the variables in bold.

| Variables | Description |
|---|---|
| **Response Variable** | |
| Likelihood of harvesting *O. europaea* from Hugumburda Forest | The probability that a household harvested *O. europaea* wood directly from the forest (yes or no) |
| Candidate explanatory variables: | |
| **Villages** | Hashenge, Kukufto, and Tahtay Haya (administrative units) |
| Age class | Age of the household head in years (15–24, 25–44, 45–64, or 64 + ) |
| Family size | Number of family members |
| Education level | Number of school years completed by the household head (0, 1–5, 6–10, 11–12, or 12 + ) |
| **Household head** | Male-headed or female-headed household |
| Marital status | Household situation with regard to whether household head is single, married, separated, divorced, or widowed |
| Economic status | Whether the household is poor, middle-income, or rich |
| **Use of *O. europaea* wood for fuel wood** | A household using *O. europaea* wood for fuel wood (yes or no) |
| Use of *O. europaea* wood for fumigation | A household using *O. europaea* wood for fumigation (yes or no) |
| Places obtaining *O. europaea* wood for fumigation | A household obtaining *O. europaea* wood for fumigation (from backyard, market or the forest) |

**Table 1.** *Cont.*

| Variables | Description |
| --- | --- |
| **Response Variable** | |
| **Frequency of use of *O. europaea* wood for fumigating the home** | The frequency of a household head using *O. europaea* wood to fumigate his or her own house (daily, every three days, once per week, or three times per week) |
| Use of *O. europaea* wood for farming implements | A household using *O. europaea* wood for farming implements (yes or no) |
| Places obtaining *O. europaea* wood for making farm implements | A household obtaining *O. europaea* wood for making farming implements (from backyard, market or the forest) |
| A household head planted *O. europaea* in his/her garden | A household that has planted an *O. europaea* tree (yes or no) |

For the generalized linear models, we carried out model selection by stepwise variable selection procedure, which retains or drops explanatory variables to produce a model that minimizes the Akaike information criterion (AIC) using the stepAIC function in the MASS package in R. The model was fitted using the package in R version 3.4.4 software (R Core Team, Vienna, Austria, 2018).

Responses collected during preference ranking were used to identify the plants that were most important for fuel wood and cleaning teeth from the woody species in the forest. The respondents' scores were counted and ranked from the highest to lowest. Descriptive statistical methods were used to summarize the data.

The fuel wood data collected from the market places were used to show the demand for *O. europaea* wood in the rural villages and big town such as Mekelle. Accordingly, the average price was estimated for each *O. europaea* wood bundle weighed from seven local merchants and 35 Mekelle town fuel wood merchants.

## 3. Results

### 3.1. Amount of *O. europaea* Wood Harvested

The stump survey revealed that the average annual *O. europaea* wood harvest rate was 430 kg/ha of the surveyed part of Hugumburda Forest. The 95% confidence interval for this estimate was between 250 kg/ha and 620 kg/ha. Given that the total forested area in the study area was 8103 ha, the total biomass of *O. europaea* wood harvested in the reserve during the study period was probably between 2000 and 5000 tons.

A frequency distribution plot of the diameter classes shows that the frequency of cutting *O. europaea* trees with small diameters (1–4 cm) was higher than for those in the large diameter classes (5–13 cm) (Figure 2). This might have been due to the high abundance of small *O. europaea* trees in Hugumburda forest.

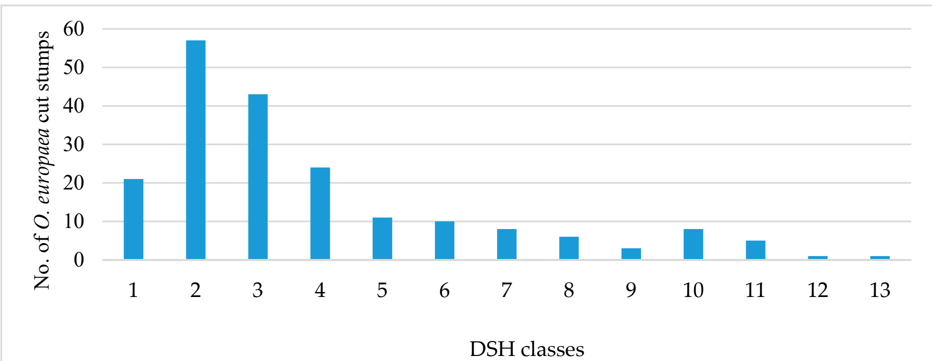


**Figure 2.** Number of *Olea europaea* (Wall. ex G. Don) Cif. stumps in different diameter classes in Hugumburda Forest. DHS class 1 = 0–2.9 cm; 2 = 3–5.9 cm; 3 = 6–8.9 cm; 4 = 9–11.9 cm; 5 = 12–14.9 cm; 6 = 13–17.9 cm; 7 = 18–20.9 cm; 8 = 21–23.9 cm; 9 = 24–26.9 cm; 10 = 27–29.9 cm; 11 = 30–32.9 cm; 12 = 33–35.9 cm; 13 = 36–38.9 cm.

### 3.2. Factors Influencing the Amount of O. europaea Harvested

The general linear model explained 11% of the variation in the harvesting rate of *O. europaea* (Table 2). Annual harvesting rate of *O. europaea* was positively related to elevation in the forest (Figure 3). For instance, the annual harvesting rate increased by 100 kg/ha when elevation increased 2300–2400 m a.s.l. This might have been due to the high abundance of *O. europaea* trees at higher altitudes (Table 2 and Figure 3).

**Table 2.** Factors influencing the harvesting rate of *Olea europaea* (Wall. ex G. Don) Cif. in Hugumburda dry Afromontane forest in northern Ethiopia. Also shown are the parameter estimates (β) and associated standard errors and *t*-values for a linear model of the relationship between *O. europaea* harvesting rate and the explanatory variables retained in the final model (Y = 0.423 + 0.262*x*, $R^2$ = 0.11).

| | β | SE | *t* | *p* |
|---|---|---|---|---|
| Intercept | 0.423 | 0.094 | 4.480 | <0.001 |
| Elevation (m a.s.l.) | 0.262 | 0.095 | 2.757 | <0.001 |

m a.s.l., meters above sea level.

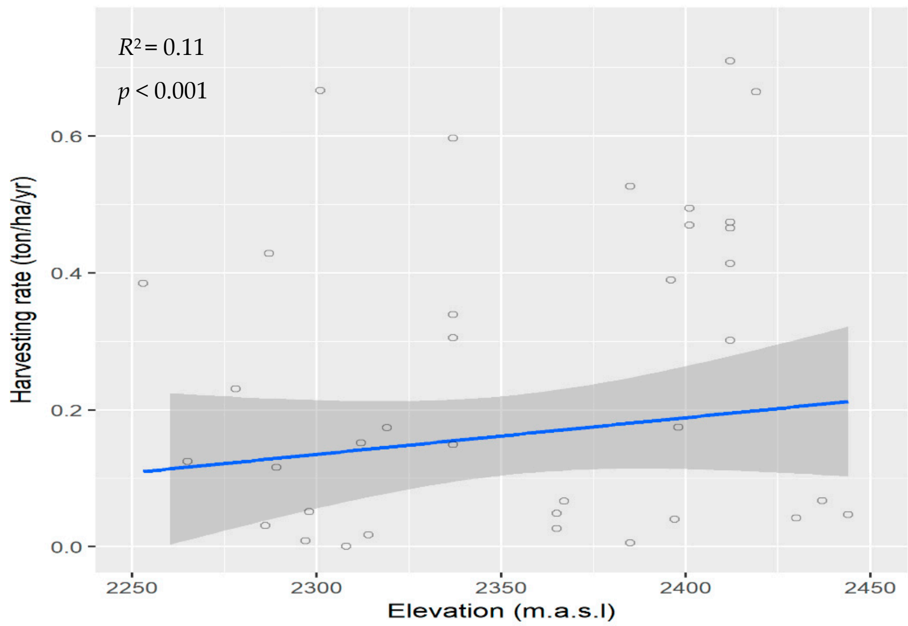


**Figure 3.** The relationship between harvesting rate of *Olea europaea* (Wall. ex G. Don) Cif. and elevation in Hugumburda dry. Afromontane forest in northern Ethiopia. The solid lines indicate the fitted lines and the shaded polygons denote the 95% confidence intervals. The grey circles show observed values. m a.s.l., meters above sea level.

The general linear model explained 17% of the variation in the number of *O. europaea* stumps. There was a "humped-back" relationship between the number of *O. europaea* stumps and distance from the nearest village (Table 3). For instance, the number of stumps increased when the distance from the nearest village increased from 1 km to 2 km. However, the number of stumps showed a decreasing trend when the distance increased from 2.5 km to 4 km (Figure 4).

**Table 3.** Factors influencing the number of *Olea europaea* (Wall. ex G. Don) Cif. stumps in Hugumburda dry Afromontane forest in northern Ethiopia. Also shown are the parameter estimates (β) and associated standard errors and *z*-values for the relationship between the number of *Olea europaea* stumps and other explanatory variables retained in the final model ($Y = 1.222 + 0.118x - 0.333x^2$, $R^2 = 0.17$).

| | β | SE | *z* | *p* |
|---|---|---|---|---|
| Intercept | 1.222 | 0.110 | 11.072 | <0.001 |
| Distance from the nearest village (km) | 0.118 | 0.119 | 0.987 | 0.324 |
| Distance to the nearest village ($km^2$) | −0.333 | 0.100 | −3.339 | <0.001 |

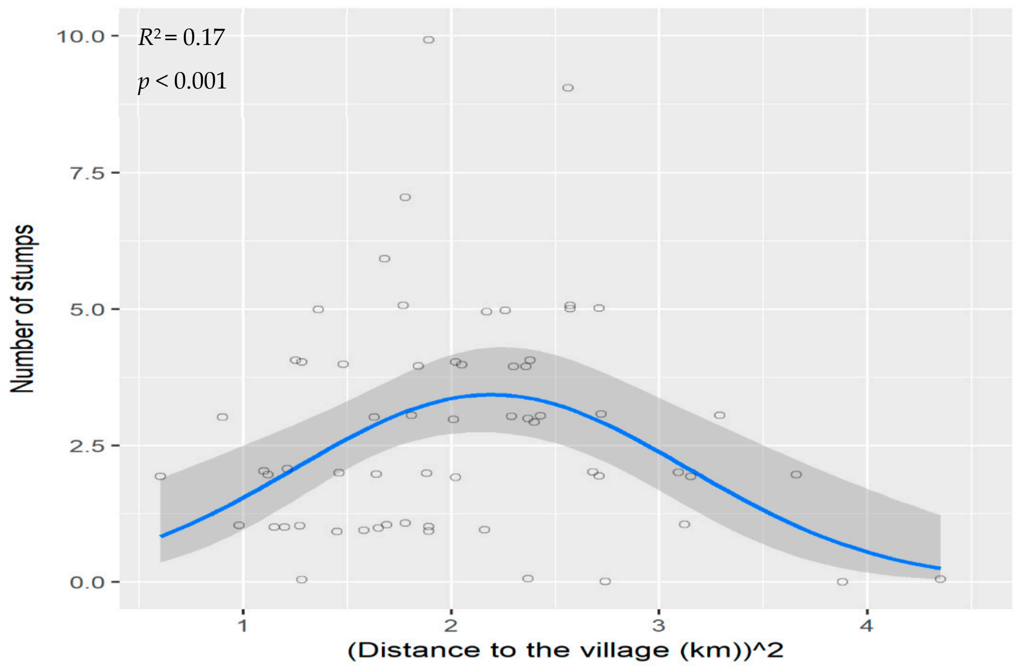


**Figure 4.** The relationship between the number of *Olea europaea* (Wall. ex G. Don) Cif. stumps and distance from the nearest village in Hugumburda dry Afromontane forest in northern Ethiopia. The solid lines indicate the fitted lines and the shaded polygons denote the 95% confidence intervals. The grey circles show observed values.

### *3.3. Household Consumption of O. europaea Wood*

The three case villages represented 54% (Kukufto), 28% (Hashenge) and 18% (Tahtay Haya) of the total number of households (7011) in those villages. The majority of respondents interviewed (96%) in the villages confirmed that fuel wood was their main source of energy (Table 4). According to the preference ranking of plant species, *Cadia purpurea* Willd. and *O. europaea* were the villagers' preference for fuel wood; only 3% of the respondents used cow dung, and only 1% used electricity.

In addition to fuel wood, the preference-ranking analysis was also conducted to rank the most common plant species used for oral hygiene (traditional toothbrush). During the interviews, seven of the most important plant species for fuel wood and six for cleaning teeth use were identified among 40 woody species from the forest. *O. europaea* and *Dodonaea viscosa* (L.f.) Benth. var. *angustifolia* were the main species preferred by the villagers (Table 5).

**Table 4.** Energy sources and plant species used for cooking (fuel wood) ranked by the respondents' preferences.

| Types of Energy | Preferred Species for Fuel Wood | No. of Respondents | Rank |
|---|---|---|---|
| Fuel wood | *Cadia purpurea* Willd. | 57 | 1 |
| | *O. europaea* (Wall. ex G. Don) Cif. | 51 | 2 |
| | *Carissa edulis* L. | 15 | 3 |
| | *Eucalyptus camaldulensis* Dehnh. | 9 | 4 |
| | *Dodonaea viscosa* (L.f.) Benth. var. *angustifolia* | 5 | 5 |
| | *Juniperus procera* Hochst. ex Endl. | 1 | 6 |
| | *Clerodendrum villosum* De Wild | 1 | 7 |
| | Others | 15 | – |
| Cow dung | | 5 | – |
| Electricity | | 2 | – |

**Table 5.** Respondents' total scores and ranking of the six plant species used for cleaning teeth.

| Species Used for Cleaning Teeth | Total Score | Percentage | Rank |
|---|---|---|---|
| *O. europaea* (Wall. ex G. Don) Cif. | 154 | 92.8 | 1 |
| *Dodonaea viscosa* (L.f.) Benth. | 57 | 34.3 | 2 |
| *Pittosporum viridiflorum* Sims | 15 | 9.0 | 3 |
| *Cardia purpurea* Willd. | 11 | 6.6 | 4 |
| *Euclea racemosa* subsp. *schimperi* A.DC. F. White | 6 | 3.6 | 5 |
| Others | 38 | 22.9 | 6 |

### *3.4. The Main Uses of O. europaea Wood*

The majority of respondents indicated that fuel wood, fumigation, and farm implements were the three main uses of *O. europaea* wood. For fuel wood, both the stem (80.7%) and branches (69.2%) were ranked as the main parts of the trees that were preferred and the leaves (3%) were the least preferred part. For fumigation, both the stem (90.3%) and the roots (74.1%) were the main preferred parts and the bark (0%) was not used at all. For making farm implements, branches (77.7%) were ranked as the main preferred part of *O. europaea*, the stem (50%) was the second most preferred part, and the least preferred part were the roots. When we asked respondents whether they used *O. europaea* wood for different purposes, the majority (83%) responded that they used it for fumigation, and almost as many (76%) said they used it for making farm implements.

In the local markets, 1 kg of *O. europaea* wood was sold at a price of 6.56 $\pm$ 1.92 Ethiopian Birr (ETB), yet in Mekelle town the price was 3.9 $\pm$ 0.51 ETB. The prices were converted from ETB to United States dollars (USD), using an exchange rate of 1 USD to 21.59 ETB (April 2016 exchange rate). Therefore, 100 kg of *O. europaea* wood at the local wood market was estimated as having a value of 30.89 $\pm$ 8.91 USD, which was more than the equivalent price per 100 kg at Mekelle town's wood market (17.94 $\pm$ 2.38 USD).

Both the geographical location of a household and its use of *O. europaea* for firewood affected the likelihood of the household's members harvesting and collecting *O. europaea* wood directly from the forest (Table 6 and Figure 5). There was a highlight probability of people living in Kukufto harvesting *O. europaea* from the forest compared with people from Tahtay Haya and Hashenge, and people from the Hashenge forest had the lowest probability of harvesting *O. europaea* from the forest. Households that used *O. europaea* for firewood were more likely to obtain the wood directly from the forests than were households that did not use it for firewood.

**Table 6.** The estimated likelihood *O. europaea* (Wall. ex G. Don) Cif. being harvested from Hugumburda Forest by people from different villages adjacent to the forest, based on results from a binary GLM (response: harvest versus non-harvest) with logit link function. GLM, General Linear Models. Also shown are the parameter estimates (β) and associated standard errors and *z*-values.

| | β | SE | *z* | *P* |
|---|---|---|---|---|
| Intercept (Hashenge) | −0.223 | 0.387 | −0.576 | 0.565 |
| Kukufto | 2.238 | 0.658 | 3.400 | 0.001 |
| Tahtay Haya | 0.803 | 0.511 | 1.570 | 0.116 |


**Figure 5.** The likelihood of *O. europaea* (Wall. ex G. Don) Cif. wood being harvested from the forest by the respondents living in the three villages adjacent to Hugumburda forest.

## 4. Discussion

We estimated that a quantity of 2000–5000 tons of *O. europaea* wood biomass was harvested from 8103 ha of Hugumburda Forest during 2016 (i.e., the study year). Since our sample plots were located in parts of the forest where the species was abundant, the actual removal might have tended towards the lower end of this interval. To our knowledge, no estimates of increment or yield of *O. europaea* in Hugumburda Forest have been made to date. However, the reported mean annual increment (MAI) of *O. europaea* in Desa'a dry Afromontane forest (a similar forest type to Hugumburda Forest, located in same region) is 1.083 $m^3$ $ha^{-1}$ [23]. If this estimate were applied to the forest area of Hugumburda, the total increment of *O. europaea* would be more than 8700 $m^3$ per year. Using the basic specific gravity of 0.72 [24], 8700 $m^3$ is equal to 6300 Mg of biomass. This indicates that removal is below the estimated increment and that the ongoing illegal harvest is not seriously degrading the population of *O. europaea* in the forest. However, this estimate is rather speculative. Based on the interviews, we found that the *O. europaea* wood harvested was used for different purposes, including farm implements, fuel wood, and fumigation. An ethnobotanical study conducted by Kidane et al. [13] revealed that *O. europaea* tree is a multipurpose species in the study area. According to previous studies, the hard and heavy wood is useful for farm implements [25]. In addition, many households use *O. europaea* wood for firewood or making charcoal because it burns slowly and has a high calorific value with little smoke [10,26]. The chemical components of wood and leaves [27,28] make the tree attractive for fumigation and cleaning teeth. The logs used for farm implements were medium-sized, whereas there was no size preference for fuel wood. By contrast, large logs were preferred for fumigation, possibly because of the villagers' belief that large *O. europaea* logs had more effective medicinal value than did small ones. However, we could not find any evidence of suggested log size for fumigation use in previous studies.

The *O. europaea* stump diameter distribution shows that small trees were cut more frequently than were large ones, and the reason could be the population dynamics of the species, as similar size distributions have been found in most non-regulated tree populations [29,30]. Therefore, the harvesting pattern might simply have been a result of natural availability. Another explanation could be that small trees were easier to cut with the tools available, and were therefore used for firewood [31]. During the interviews, we also noted that the local people did not have any special size preference regarding the species used for fuel wood. In addition, since the forest is at its secondary succession [12], perhaps any large trees in the reserve had been cut a long time ago.

The positive relationship between the harvesting rate and elevation may be due to the high abundance of the species at higher elevations. Kidane et al. [32] observed that the abundance of different tree species, including *O. europaea*, was higher at higher elevations in the same forest.

We found a positive relationship between the number of stumps and distance from the nearest village up to ca. 2.5 km, but for longer distances the relationship was weaker. This finding shows that most trees have been cut at intermediate distances (ca. 1.5–2.5 km) from the nearest village during recent years. According to Kidane et al. [13], sawmills were installed in the forest in the 1950s, and trees were harvested for commercial purposes. However, the decreasing number of stumps found beyond 3 km from the village probably related to transport economics, since *O. europaea* is heavy and transportation is very difficult, which often means that the wood has to be carried by hand.

Surprisingly, the market price for *O. europaea* wood in Mekelle was lower than in the villages around Hugumburda Forest, possibly due to high demand for the species by the local communities living around the forest [13]. It is probable that the *O. europaea* wood sold at the wood market in Mekelle comes from many sources, and competition among suppliers may help to keep the prices for the wood relatively low. In turn, this could increase the likelihood of illegal harvesting in forests.

Despite the existence of rules and regulations that prohibit the harvesting of *O. europaea* in Hugumburda Forest, local people continue using the wood regularly. This was particularly the case in Kukufto village, and the reason might be that most of the forest guards were from the village of Hashenge, which is near the forest. Thus, it was relatively easy for the guards to identify who among the people living in the closest villages had cut the trees, and the people were afraid of being caught. The people in the farthest village, Kukufto, might have had less fear about harvesting *O. europaea* wood in the forest because few forest guards were enrolled from their village. Furthermore, we observed that there were more *O. europaea* wood merchants in Kukufto than at Shoko Majo market because most of the forest guards were from Hashenge, and therefore they could be stricter towards those living in villages nearer to them than could other guards. This, in turn, may be a reason why we found a low probability of *O. europaea* wood being obtained directly from the forest by the villagers in Hashenge. It may be a good idea to recruit guards from all villages surrounding the reserve to make the forest guarding more secured. However, forest guards are employed to look after the forest reserve and ensure that illegal harvesting does not occur. Clearly, they have not been entirely effective in this respect, and this may be due to a lack of sufficient resources for patrolling or because guards are corrupt or unwilling to stop low-intensity tree cutting carried out by their own neighbors [33,34]. The level of patrolling necessary to stop all illegal harvesting may not be socially optimal [35]. Since the forest is at its secondary stage of development, which means it is dominated by small-sized woody species [13], we would not encourage any harvesting in the forest except for non-timber forest products. In addition, for an effective guarding system, we recommend that the forest administration should consider equal representation of guards from all surrounding villages.

## 5. Conclusions

Illegal harvesting of *O. europaea* wood was observed in Hugumburda Forest for three main uses, fuel wood, fumigation, and farm implements, likely because the local people did not have an alternative source. The positive relationship between the harvesting rate and elevation showed a high frequency of harvesting in the forest at higher altitudes, where *O. europaea* is abundant. The estimated value of *O. europaea* biomass harvested illegally does not seem to degrade the population of this tree species. We recommend the establishment of permanent sample plots in the forest reserve in order to monitor the increment of *O. europaea* as well as other tree species.

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## References

1. Friis, I. *Forests and Forest Trees of Northeast Tropical Africa: Their Natural Habitats and Distribution Patterns in Ethiopia, Djibouti and Somalia*; Her Majestry's Stationery Office: London, UK, 1992.
2. Bekele, T. *Vegetation Ecology of Remnant Afromontane Forests on the Central Plateau of Shewa, Ethiopia*; Opulus Press: Uppsala, Sweden, 1993.
3. Teketay, D. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production-population structures. *Trop. Ecol.* **2005**, *46*, 29–44.
4. Hawando, T. Desertification in Ethiopian Highlands. Available online: http://www.rala.is/rade/ralareport/Hawando.pdf (accessed on 14 August 2018).
5. Teketay, D. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: II. Forest disturbances and succession. *Trop. Ecol.* **2005**, *46*, 45–64.
6. Girma, A.; Mosandl, R.; Kateb, H.E.; Masresha, F. Restoration of degraded secondary forest with native species: A case study in the highland of Ethiopia. *Scand. J. For. Res.* **2010**, *25*, 86–91. [CrossRef]
7. Kituyi, E.; Marufu, L.; Huber, B.; Wandiga, S.O.; Jumba, I.O.; Andreae, M.O.; Helas, G. Biofuel consumption rates and patterns in Kenya. *Biomass Bioenergy* **2001**, *20*, 83–99. [CrossRef]
8. Njiti, C.F.; Kemcha, G.M. In Survey of Fuel Wood and Service Wood Production and Consumption in the Sudano-Sahelian Region of Central Africa: The Case of Garoua, Cameroon and Its Rural Environs. Available online: https://hal.archives-ouvertes.fr/file/index/docid/135780/filename/T222Njiti.pdf (accessed on 14 August 2018).
9. Teklehaimanot, Z.; Healey, J. Biodiversity Conservation in Ancient Church and Monastery Yards in Ethiopia. Available online: http://www.darwininitiative.org.uk/documents/10031/14005/10-031%20AR1%20-%20edited.pdf (accessed on 14 August 2018).
10. Gebreslassie, T.; Hagos, G.; Abraham, M. Assessing households' fuel wood tree species preference, the case of Desa'a afro alpine forest, Tigray. *Civ. Environ. Res.* **2014**, *6*, 48–51.
11. Woldemichael, L.K.; Bekele, T.; Nemomissa, S. Vegetation composition in Hugumbirda-Gratkhassu National Forest Priority Area, South Tigray. *Momona Ethiop. J. Sci.* **2010**, *2*, 27–48. [CrossRef]
12. Aynekulu, E. Forest Diversity in Fragmented Landscapes of Northern Ethiopia and Implications for Conservation. Ph.D. Thesis, Rheinschen Friedrich-Wilhems Universitat, Bonn, Germany, 2011.
13. Kidane, L.; Nemomissa, S.; Bekele, T. Human-forest interfaces in Hugumburda-Gratkhassu National Forest Priority Area, North-eastern Ethiopia. *J. Ethnobiol. Ethnomed.* **2018**, *14*, 17. [CrossRef] [PubMed]
14. Negash, L. *Indigenous Trees of Ethiopia: Biology, Uses and Propagation Techniques*; Department of Biology, Addis Ababa University: Addis Ababa, Ethiopia, 1995.
15. Negash, L. Vegetative propagation of the threatened African wild olive [*Olea europaea* L. subsp. *cuspidata* (Wall. ex DC.) Ciffieri]. *New For.* **2003**, *26*, 137–146. [CrossRef]
16. Viswanathan, T. Endangered tree species in Northern Ethiopia. *Environ. Conserv.* **1986**, *13*, 71–72. [CrossRef]
17. Negash, L. Successful vegetative propagation techniques for the threatened African pencil cedar (*Juniperus procera* Hoechst. ex Endl.). *For. Ecol. Manag.* **2002**, *161*, 53–64. [CrossRef]
18. Aynekulu, E.; Denich, M.; Tsegaye, D. Regeneration Response of *Juniperus procera* and *Olea europaea* subsp *cuspidata* to exclosure in a dry Afromontane forest in northern Ethiopia. *Mt. Res. Dev.* **2009**, *29*, 143–152. [CrossRef]

19. CBD Convention on Biological Diversity (CBD) Ethiopia's 4th Country Report. Available online: https://www.cbd.int/doc/world/et/et-nr-04-en.pdf (accessed on 14 August 2018).
20. Parent, G. Manual for woody biomass inventory. In *Woody Biomass Inventory and Strategic Planning Project*; Ministry of Agriculture: Addis Ababa, Ethiopia, 2000.
21. Zuur, A.F.; Ieno, E.N.; Elphick, C.S. A protocol for data exploration to avoid common statistical problems. *Methods Ecol. Evol.* **2010**, *1*, 3–14. [CrossRef]
22. Ekström, J. A Generalized Definition of the Polychoric Correlation Coefficient. 2011. Available online: https://escholarship.org/uc/item/583610fv (accessed on 14 August 2018).
23. Gebreslassie, T.; Gebreslassie, H. Current status and future prospect of *Olea europaea* and *Juniperu procera* on Desa'a Afro Alpine forest, North Ethiopia. *J. Nat. Sci. Res.* **2014**, *4*, 62–65.
24. Meier, E. Wood!: Identifying and Using Hundreds of Woods Worldwide. Wood Database, 2015. Available online: https://www.amazon.com/Identifying-Using-Hundreds-Worldwide-2015-10-10/dp/B01FGP9964 (accessed on 14 August 2018).
25. Kassa, A.; Konrad, H.; Geburek, T. Mating pattern and pollen dispersal in the wild olive tree (*Olea europaea* subsp *cuspidata*). *Tree Genet. Genomes* **2018**, *14*, 3. [CrossRef]
26. Wubet, T.; Kottke, I.; Teketay, D.; Oberwinkler, F. Mycorrhizal status of indigenous trees in dry Afromontane forests of Ethiopia. *For. Ecol. Manag.* **2003**, *179*, 387–399. [CrossRef]
27. Long, H.S.; Tilney, P.M.; van Wyk, B.E. The ethnobotany and pharmacognosy of *Olea europaea* subsp *africana* (Oleaceae). *South Afr. J. Bot.* **2010**, *76*, 324–331. [CrossRef]
28. Flemmig, J.; Kuchta, K.; Arnhold, J.; Rauwald, H.W. *Olea europaea* leaf (Ph.Eur.) extract as well as several of its isolated phenolics inhibit the gout-related enzyme xanthine oxidase. *Phytomedicine* **2011**, *18*, 561–566. [CrossRef] [PubMed]
29. Leak, W.B. The J-shaped probability distribution. *For. Sci.* **1965**, *11*, 405–409.
30. Westphal, C.; Tremer, N.; von Oheimb, G.; Hansen, J.; von Gadow, K.; Härdtle, W. Is the reverse J-shaped diameter distribution universally applicable in European virgin beech forests? *For. Ecol. Manag.* **2006**, *223*, 75–83. [CrossRef]
31. Leach, G.; Mearns, R. *Beyond the Woodfuel Crisis: People, Land and Trees in Africa*; Routledge: London, UK, 2013.
32. Kidane, L.; Nemomissa, S.; Woldu, Z. The effects of disturbance on the population structure and regeneration potential of five dominant woody species–in Hugumburda-Gratkhassu National Forest Priority Area, North-eastern Ethiopia. *Afr. J. Ecol.* **2016**, *54*, 20–28. [CrossRef]
33. Teye, J.K. Corruption and illegal logging in Ghana. *Int. Dev. Plan. Rev.* **2013**, *35*, 1–19. [CrossRef]
34. Lee, J.-H.; Sigmund, K.; Dieckmann, U.; Iwasa, Y. Games of corruption: How to suppress illegal logging. *J. Theor. Biol.* **2015**, *367*, 1–13. [CrossRef] [PubMed]
35. Hofstad, O. A theoretical analysis of illegal wood harvesting as predation–With two Ugandan illustrations. *Scand. For. Econ.* **2008**, *42*, 441–452.