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First Age-Estimation Model for *Dracaena ombet* and *Dracaena draco* subsp. *caboverdeana*

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Abstract: Research Highlights: The first model for crown age estimation was developed for *Dracaena ombet* Heuglin ex Kotschy and Peyr. and *D. draco* subsp. *caboverdeana* Marrero Rodr. and R. Almeida. Background and Objectives: *Dracaena* species are monocotyledon trees without annual tree rings. Most arborescent dragon tree species are endangered; thus, it is important to determine the age structures of these populations for proper conservation management strategies, and for modelling of population trends. For these reasons, it is necessary to develop a methodology of crown age estimation. Materials and Methods: Field data were collected in the Desa'a Forest (Ethiopia) and in Santo Antão (Cape Verde Islands). Trees within each age class, as expressed by the number of branch orders, were measured. The diameter at breast height, tree height, stem height, number of branch orders, number of all leaf rosettes and number of flowering leaf rosettes within the crown were recorded for each sampled tree. The flowering probabilities were counted as input data for the model used. Results: The duration of the interval between flowering events was 5.23 years for *D. ombet* and 4.94 years for *D. draco* subsp. *caboverdeana*. The crown of the oldest tree of *D. ombet* with 18 branch orders was estimated to be 94.2 years old, and the crown of the oldest tree of *D. draco* subsp. *caboverdeana* with 22 branch orders was estimated to be 108.6 years old.

Keywords: dragon trees; Desa'a Forest; Santo Antão; Cape Verde Islands; Cabo Verde; tree age modelling; monocotyledon tree

1. Introduction

The genus *Dracaena* is classified in the family Asparagaceae subfamily Nolinoideae [1,2]. The genus *Dracaena* is composed of 60–100 species [3]. Most of the *Dracaena* species grow as shrubs or geophytes. Only a few species have arborescent forms. The arborescent species of *Dracaena* are classified as the dragon tree group, formed by *Dracaena ombet* Heuglin ex Kotschy and Peyr. from eastern Africa, *D. cinnabari* Balf.f. from Socotra, *D. serrulata* Baker from southwestern Arabia, *D. draco* L., *D. draco* subsp. *caboverdeana* Marrero Rodr. and R. Almeida and *D. tamaranae* A. Marrero, R. S. Almeida and M. González-Martín from the Macaronesian islands, *D. draco* subsp. *ajgal* Benabid and Cuzin from Morocco, *D. schizantha* Baker and *D. ellenbeckiana* Engl. from northeastern and eastern tropical Africa, *D. jayniana* Wilkin and Suksathan and *D. kaweesakii* Wilkin and Suksathan from Thailand, *D. cambodiana* Pierre ex Gag- nep., and *D. yuccifolia* Ridl., *D. cochinchinensis* (Lour.) S. C. Chen from Southeast Asia and the Pacific islands [4,5].

Dragon trees are long-lived and slowly maturing species [6]. Typical for dragon trees is their sympodial branching, during which, each branch order is created from a sleeping lateral bud growing up after an apical leaf rosette blooms and therefore, the terminal bud dies [5]. In this manner, dragon trees form their typical umbrella-shaped crowns (Figure 1). The foliage consists of sword-shaped leaves arranged in the apical rosettes. The leaves are scleromorphic, densely tufted, dark green and elongated [7]. Mature dragon trees reach heights of up to 20 m (*Dracaena draco*) [8].

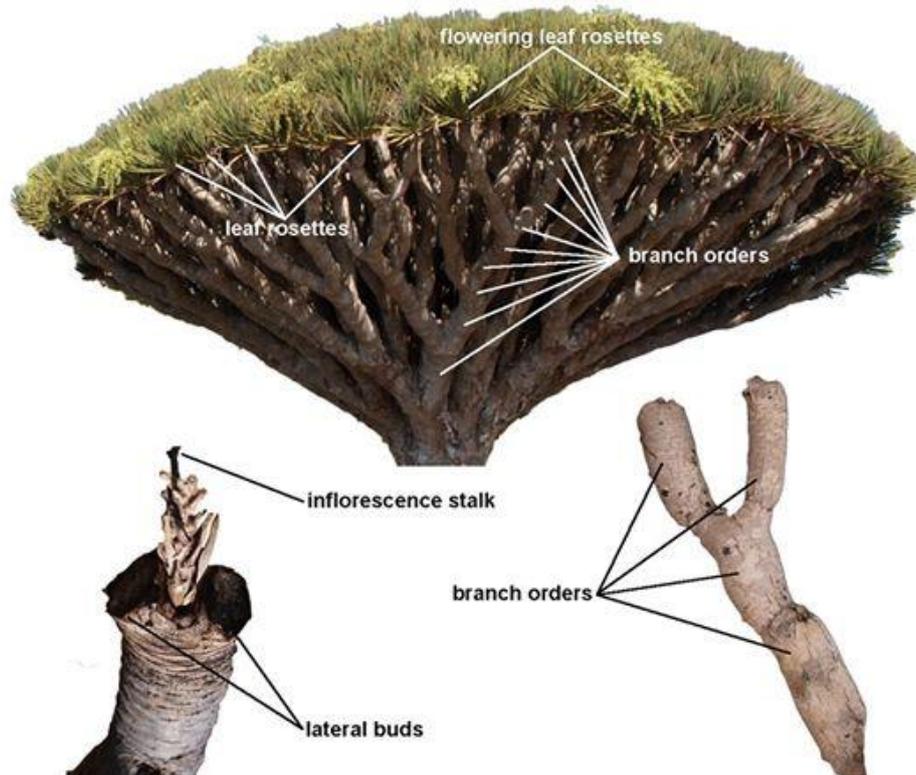


Figure 1. Umbrella-shaped crown exhibits characteristic sympodial branching. Branches are composed from sections-orders. A branch order begins after a terminal bud dies due to a flowering event. Then, a lateral bud(s) begins growing. This growth terminates after the next flowering event, and a new branch order is established. The duration of growth for one branch order is terminated by two following flowering events. The flowering probability of any leaf rosette is expressed as the ratio of flowering leaf rosettes and all leaf rosettes within the tree crown.

The highest measured *D. ombet* tree is 8 m high [9], and its typical height is approximately 5 m. *D. ombet* has a densely packed crown with straight leaves that are approximately 5 cm wide and 1 m long. The trunk is grey, smooth and forked. Similar to the leaves, the flowers occur only at the ends of the youngest branches. The white or light pink flowers are small (1 cm in diameter) and have spherical fleshy berries each containing one small (5 mm diameter) seed [10]. This species is found in the dry sub-humid areas, bushlands and woodlands on mountain slopes and cliffs at elevations of 450–1450 m, and generally at 1000–1800 m [10]. *D. ombet* occurs in Egypt, Sudan, Eritrea, Djibouti, Ethiopia, Somalia and Saudi Arabia [11]. Information regarding *D. ombet* populations is limited. The current results of population studies indicate that *D. ombet* has become a strongly endangered species. Kamel et al. [10] measured 353 trees, however only 46% (161 individuals) were alive and only 27% (96 individuals) were healthy in Gebel Elba NP (Egypt). Similarly, Elnoby et al. [12] recorded a total of 1450 *D. ombet* trees in southeastern Egypt, only 870 were alive, and 580 trees were dead, representing approximately 40% mortality. The population of *D. ombet* in the Desa'a Forest (Tigray highlands, Ethiopia) is confined

to a small area of shallow soil along the escarpment [13]. In northern Sudan, the only population of *D. ombet* in the country has vanished [14].

Dracaena draco occurs in northwest Africa—Madeira, the Canary Islands, the Cape Verde Islands and in southern Morocco [8]; however, wild populations are extremely rare and in Madeira they have recently become extinct [15]. Three subspecies of *Dracaena draco* are mentioned by Marrero and Almeida Pérez [16]: *D. draco* subsp. *draco* from the Canary Islands, *D. draco* subsp. *caboverdeana* from the Cape Verde Islands and *D. draco* subsp. *ajgal* from Morocco. They differ from each other in colour, shape and number of leaves, trunk heights and the size of the fruits. The typical height for *D. draco* subsp. *caboverdeana* is up to 4–6 (8) m and, with a shorter stout trunk, 1–2 (3) m. The crown is wide and dense with linear ensiform leaves up to 110 cm long with a blue-grey or glaucous colour. The inflorescences are conical-globular and can be up to 100 cm long. Flowers are greenish-white or (exceptionally) an off-white-cream colour with green or green-yellowish stamens and the fruits are fleshy with spherical seeds [16]. Currently, natural populations are found on the islands of Santo Antão, São Nicolau and Fogo; on the other islands, this species is only cultivated in urban areas [17].

Dragon trees currently face a number of threats related to both human and natural influences. One of the most important influences is the missing or limited natural regeneration of the overwhelming majority species within the dragon tree group that is caused by overgrazing and increasing drought [5–7, 9,10,12,18–25]. The populations are over-mature with an unbalanced age structure [26]. The increasing population declines have led to the inclusion of *Dracaena cinnabari*, *D. tamaranae*, *D. draco*, *D. ombet* and *D. serrulata* in the International Union for Conservation of Nature Red list of globally endangered species. *D. draco* is listed as Vulnerable and *D. ombet* is listed as Endangered [27]. Knowledge of the age structures of the wild populations of *D. ombet* and *D. draco* subsp. *caboverdeana* is necessary for rescue programmes and for conservation projects that are of great importance [5,6].

The arborescent members of the *Dracaena* genus do not form annual tree rings; therefore, the age estimations of the trees cannot be based on tree ring counts. It is necessary to use some allometric relationship, where one variable has a measured relationship to the age. Pütter [28] first used the relationship between the duration of the flowering period and the characteristic branching of dragon trees for age estimation (see Figure 1). New approaches are based on linear relationships between the duration of the flowering period and the number of branch orders, as described by Adolt and Pavliš [12]. Adolt et al. [29] used an improved method of age estimation by logistic regression on an example of *Dracaena cinnabari*. The aim of our study is to calibrate the method published by Adolt et al. [29] for estimating the age of new species of dragon trees: *D. ombet* and *D. draco* subsp. *caboverdeana*, based on the hypothesis that this methodology is suitable not only for *D. cinnabari* but also for our investigated species.

2. Materials and Methods

2.1. Study Area

The data for *D. ombet* were collected in the Tigray region (northern Ethiopia) in the Desa'a Forest (Figure 2). The Desa'a Forest is located on the border of the Tigray and Afar regions on the escarpment of the Great Rift Valley. The gentle to steep scarps form climatic buffer zones between the Tigray highlands and the Afar lowlands. The altitude ranges from 1500 m in the lowlands to 2500 m in the highlands. The Desa'a Forest, a national forest priority area, is drier than the rest of the Tigray region. In the rainiest months (July and August), precipitation ranges from 116.3 to 230 mm [30]. The total mean annual precipitation is less than 1000 mm [13]. The minimum temperature varies from 7.5 °C to 19.3 °C, and the maximum temperature ranges from 22.6 °C to 33.4 °C [30]. The Desa'a Forest is predominantly formed on Enticho sandstone and crystalline Precambrian basement rocks [31,32]. The dominant plants are *Juniperus procera* and *Olea europaea* subsp. *cuspidata*, forming a dry, evergreen Afromontane forest, typical for the Desa'a Forest [13,33]. According to the IUCN [27], the Desa'a Forest is an important habitat for the endangered *D. ombet* [13].

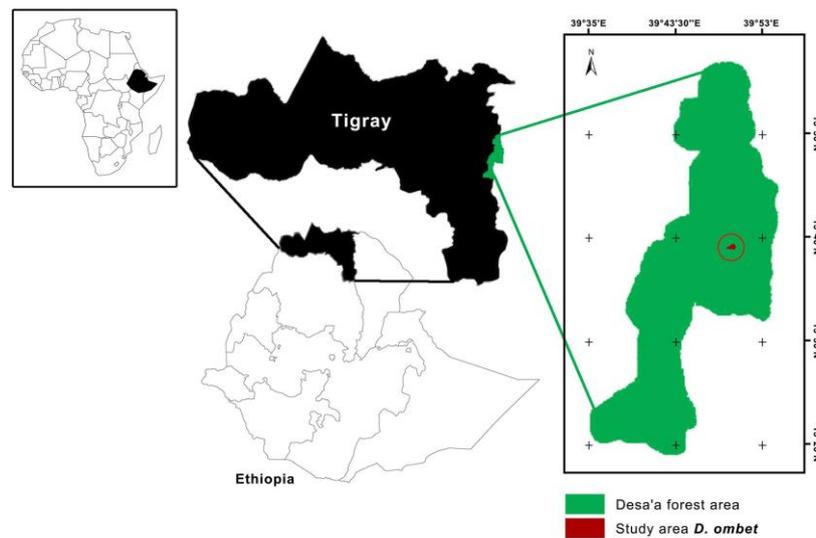


Figure 2. The study area of *Dracaena ombet* (Northern Ethiopia).

The study area is located at an altitude of 1700 m a.s.l. The climatological characteristics were interpolated according to Hijmans et al. [34] for each sample tree position and were then averaged, as included in Table 1. The total mean annual precipitation reaches 599 mm, and the mean annual temperature reaches 21.1 °C. *D. ombet* occurs in communities with *Acacia etbaica* from 1400 to 1800 m a.s.l. on sloped terrain with rock outcrops and prefers shallow soils [13].

Table 1. Climatological characteristics for the *D. ombet* (Do) *D. draco* subsp. *caboverdeana* (Dd) localities under study, according to Hijmans et al. [34].

	Mean Annual Temperature (°C)	Max Temperature of Warmest Month (°C)	Min Temperature of Coldest Month (°C)	Mean Annual Precipitation (mm)	Precipitation of Wettest Month (mm)	Precipitation of Driest Month (mm)
Do	21.1	31.6	10.3	599	146	21
Dd	17.4	22.1	12.9	314.7	99.5	0

The study area of *D. caboverdeana* is located in Santo Antão (Figure 3), which is one of ten of the Cape Verde Islands. The Cape Verde archipelago is located in the central eastern Atlantic and is 600 km west of Senegal on the African coast. The archipelago is situated in the African-Sahelian climatic region with a tropical oceanic climate. The annual precipitation ranges from 80 to 300 mm on the coast and up to 1200–1600 mm in the highlands [35,36]. The Intertropical Convergence Zone causes a rainy season with monsoon rains [37]. The rainy season alternates with a dry season that brings Harmattan winds with Saharan dust, thereby increasing evapotranspiration [38]. However, the northeast winds are humid and bring additional water sources in the form of fog, mist and dew to the highlands [39].

Santo Antão is the most western and most northern point of Cape Verde and is the second largest island. The Santo Antão landscape is formed by plateaus, valleys and high peaks (the highest mountain is 1979 m high). Santo Antão is the only island in the Cape Verde Archipelago in which there are permanent watercourses during the whole year [40]. The mean climatological characteristics for the study area [34] at 815–1270 m a.s.l. are shown in Table 1.

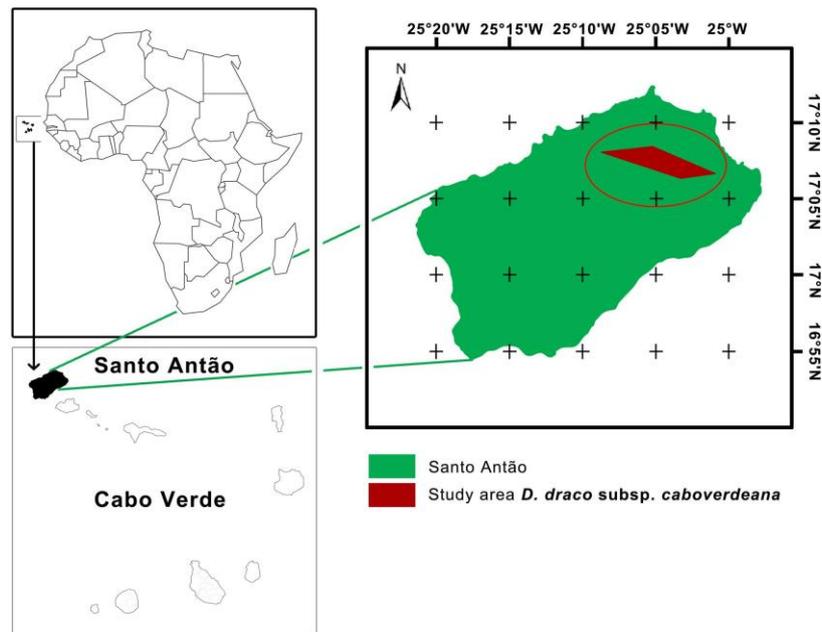


Figure 3. The study area of *D. draco* subsp. *caboverdeana* (Cabo Verde).

2.2. Data Collection

Input data for the age estimation model were obtained from trees of different ontogenetic stages (109 *D. ombet* individuals and 82 *D. draco* subsp. *caboverdeana* individuals). The measurements were conducted in May 2017 for *D. ombet* and in November 2018 for *D. draco* subsp. *caboverdeana*. The diameters at breast height (DBHs), tree heights, stem heights, numbers of branch orders, numbers of all leaf rosettes and the numbers of flowering leaf rosettes within the crown were recorded for each measured tree. Trees of both species were placed into classes based on the number of branch orders (Table 2). The total number of measured *D. ombet* individuals ranged from 2 to 10 in the classes. A low number of individuals occurred in a class with more than 15 branch orders. The occurrence of trees with more than 15 branch orders was rare, and trees with more than 19 branch orders were completely missing in the study area. The inaccessible terrain of the study area prevented measurement of some *D. draco* subsp. *caboverdeana* trees. The total population on the island is rather small, comprising only a few hundred trees. Due to the steep inaccessible slopes and presence of a fog, it was not possible to determine required characteristics in all founded individuals and thus, the set of fully measured individuals was reduced. Thus, the non-abundant population and its unavailability caused differences in the representation of individuals measured in the classes. The total number of *D. draco* subsp. *caboverdeana* individuals ranged from 0 to 24 within the classes, of which there were 22 in total (the maximum observed number of branch orders was 22 in the largest trees). However, classes 10, 13 and 19 contained no trees.

Table 2. Numbers of sampled trees within classes expressed by the number of branch orders.

Number of Branch Order	Number of Trees <i>D. ombet</i>	Number of Trees <i>D. caboverdeana</i>
1	7	24
2	7	8
3	6	7
4	6	1
5	8	4
6	7	1
7	6	4
8	8	3
9	10	1
10	7	0
11	6	3
12	7	3
13	6	0
14	6	1
15	4	4
16	3	2
17	3	3
18	2	1
19	0	6
20	0	0
21	0	3
22	0	3
Total number	109	82

2.3. Crown Age Calculation

A crown age estimation model was established for both species studied separately based on the methodology described by Adolt et al. [29]. This methodology is based on the calculation of the flowering probability by logistic regression (generalised linear model, [41,42]), the reciprocal value of which corresponds to the length of the interval between two flowering events [29]. The flowering probability is calculated based on the ratio between flowering rosettes to the total number of rosettes within the crown, see Figure 1.

As the flowering probability may not have a constant value across crown ages [29], we tested whether the probability varied depending on the number of branch orders (branch orders are closely related with crown age). Therefore, we tried to explain the flowering probability (response variable) by the number of branch orders (explanatory variable) using logistic regression (see Equation (1)), where Pf is probability of flowering, β_0 is the intercept value, β_1 is the coefficient estimate of the explanatory variable, and X1 is the explanatory variable—number of branching orders.

$$Pf = \beta_0 + \beta_1 \times X1 \quad (1)$$

Finally, the crown age estimation (A_c) was calculated according to Adolt et al. [29] using Equation (2):

$$A_c = O_n \times [1 + e^{-(\beta_0 + \beta_1 \times X1)}] \quad (2)$$

where O_n represents the number of branch orders and β_0 , $\beta_1 \times X1$ are the components obtained by logistic regression in Equation (1).

If the flowering probability does not depend on the mean number of branch orders, i.e., the parameter β_1 in Equation (1) is not significant, we used the simplified version of the crown age estimation (Equation (3)) according to Adolt et al. [29] instead of Equation (2). This version omits

values of $\beta_1 \times X_1$ and works only with intercept value— β_0 which represents mean value of flowering probability calculated by Equation (1).

$$A_c = O \times [1 + e^{-(\beta_0)}] \quad (3)$$

3. Results

The relationships between flowering probability and the number of branch orders show a constant or very slight trend that the leaf rosettes bloom more often with increasing crown age (Figure 4). However, this relationship in both species is not significant (generalized linear models, $p > 0.05$, see Table 3).

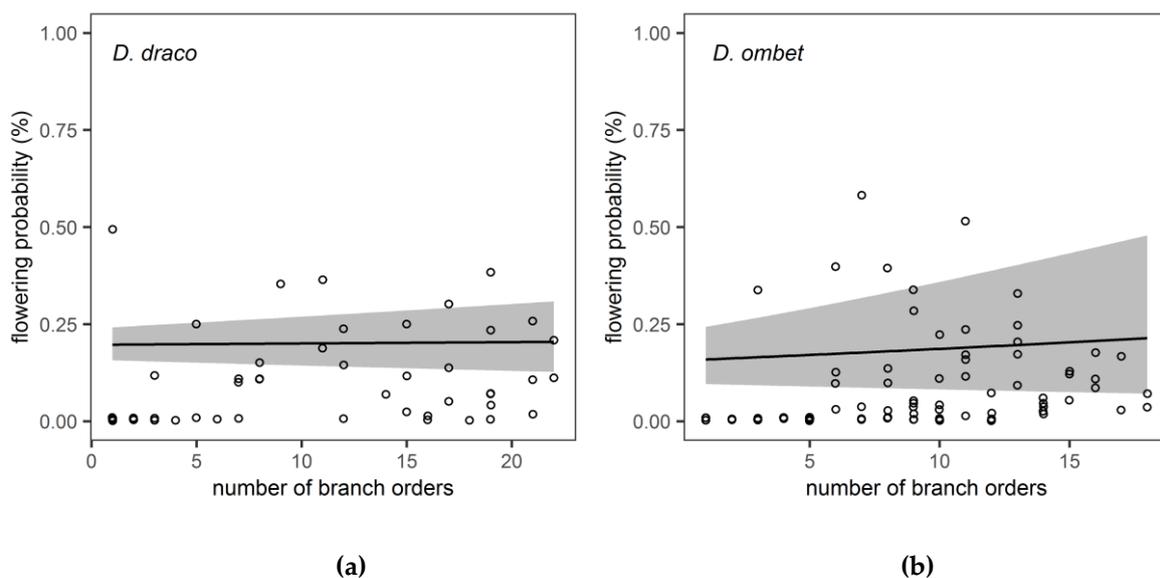


Figure 4. Relationships between the flowering probabilities and numbers of branch orders for (a) *D. ombet* and (b) for *D. draco* subsp. *caboverdeana*. The lines represent the modelled values (generalised linear models), the grey areas are within the 95% confidence interval. The small circles represent the observed values.

Table 3. The results of logistic regression models for both *D. draco* and *D. ombet* showing coefficients (Coeff.) estimates, t values and p values.

	Coefficients	Coeff. Estimate	t Value	p -Value
<i>D. draco</i>	Intercept (β_0)	−1.405075	−6.191	<0.001
	Branch orders (β_1)	0.002147	0.162	0.872
<i>D. ombet</i>	Intercept (β_0)	−1.68578	−6.961	<0.001
	Branch orders (β_1)	0.02132	1.068	0.288

Thus, we were required to use the mean value of the flowering probability for age modelling, i.e., the duration of the interval between flowering events, namely, 5.23 years for *D. ombet* and 4.94 years for *D. draco* subsp. *caboverdeana*.

The final age estimations based on Equation (2) for both investigated dragon tree species (absolute values) are shown in Table 4. The crown of the oldest *D. ombet* tree, with 18 branch orders, is estimated to be 94.2 years old and the crown of the oldest *D. draco* subsp. *caboverdeana* tree, with 22 branch orders, is estimated to be 108.6 years old.

Table 4. Modelled age of the crowns of *D. ombet* and *D. draco* subsp. *caboverdeana* according to the number of branch orders.

Number of Branch Order	Age of <i>D. ombet</i>	Age of <i>D. draco</i> subsp. <i>caboverdeana</i>
1	5.2	4.9
2	10.5	9.9
3	15.7	14.8
4	20.9	19.7
5	26.2	24.7
6	31.4	29.6
7	36.6	34.6
8	41.9	39.5
9	47.1	44.4
10	52.3	49.3
11	57.5	54.3
12	62.8	59.2
13	68.0	64.2
14	73.2	69.1
15	78.5	74.1
16	83.7	79.0
17	88.9	83.9
18	94.2	88.9
19	-	93.8
20	-	98.7
21	-	103.7
22	-	108.6

4. Discussion

4.1. Comparisons with Age Estimations of Other Dragon Tree Species

The first age estimation for dragon trees was conducted for *Dracaena draco*, and a very large specimen from Orotava (Tenerife, Canary Islands), by Humboldt [43], Christ [44] and Schenck [45] was estimated to be several thousand years old. Pütter [28] made the first estimation and noticed the relationship between the duration of the flowering period and the characteristic branching and used these factors for his age estimation. He substantially decreased his age estimation of the very large specimen from Orotava to 575 years and also stated that the ages of all other trees on Tenerife did not exceed 300 years. Currently, the oldest dragon tree is located in Icod, and its age was estimated by Mägdefrau [46] to be 365 years.

To express the age structure of the population of *D. cinnabari* on Socotra Island, Adolt and Pavliš [5] developed an indirect model of age estimation for this species based on a linear relationship between the duration of the flowering period and the branching events. The results obtained by these researchers show that the tree ages ranged from 30 to 530 years. More recently, Adolt et al. [29] published a new indirect model which considers that the flowering period lasts longer for younger trees and is shorter for older trees. The resulting crown age estimates are highly similar to the previous model, and the crown of a tree with 30 branch orders should be 500 years old.

For other species of dragon trees, except for the two mentioned above, there is no published information about age estimation. Only Zheng et al. [47] inferred from stem diameters ranging from 50 to 120 cm, that the individuals of *Dracaena cambodiana* are several hundred years old.

Our findings, namely, 94.2 years for *D. ombet* and 108.6 years for *D. draco* subsp. *caboverdeana*, are substantially lower than estimations for *D. cinnabari* [5,29] and for *Dracaena draco* subsp. *draco* [28,46]. This finding is observed partially because the investigated species have fewer branch orders. An appropriate crown age for a *Dracaena cinnabari* tree with 18 branch orders according to Adolt et al.'s [29] model is 367 years, and for 22 branch orders, the crown age from this model is 419 years. This model was developed for populations growing in the highlands near 700 m a.s.l.

Adolt et al. [29] also published a model for populations growing in the mountains near 1400 m a.s.l. This model shows comparable results, namely, 114 years for crown of trees with 18 branch orders and 140 years for crown of trees with 22 orders.

Usama [48] carried out a field survey of *D. ombet* in the Erkowit Mountains (Sudan), divided the trees into five DBH classes, and estimated the age of each class. This researcher estimated the age of the largest trees with DBHs from 80 to 100 cm as 100 years. Although the researcher did not explain any methodology for the age estimations, these results are not in contrast with our model. However, the DBH of our largest tree is only 50 cm. Unfortunately, Usama did not count the number of branch orders in his dataset.

Our model is focused only on crown age estimation, currently there has not been any indirect model developed for juvenile dragon trees' age estimation before the first blooming of the tree, after which the crown starts to form. Only very sparse information was published from direct observation of few individuals. Annual stem height increment varied from 2 [6] to 10 cm [5] for *D. cinnabari*. For a few cultivated specimens of *D. draco*, the juvenile period until first branching lasted 9–25 years [49–51].

4.2. Effects of Environmental Conditions

The differences in dragon tree growth and their associated ages could be attributed to different evolutionary histories of individual dragon tree species [2] or, more probably, by different environmental conditions in the areas of distribution of individual species and their populations.

The duration of one flowering period (i.e., the time between two flowering events when one branch order develops) plays a key role in dragon tree's crown age estimations. Adolt et al. [29] developed a model that showed a changing duration of the flowering period during tree ontogeny in the drier highland conditions (e.g., from 28 years for the first branch order to 9 years for the 30th branch order) and a constant duration of the flowering period (6.5 years) in the more humid conditions of the mountains. This finding means that with increasing precipitation amounts (both vertical and horizontal), the tree growth seems to be faster and more constant; thus, the crown ages with the same number of branch orders are lower.

The growth pattern of our investigated species is very similar to that of *Dracaena cinnabari* in the mountains of Socotra Island. The duration of the flowering period was also found to be constant and lasts 5.23 years for *D. ombet* and 4.94 for *D. draco* subsp. *caboverdeana*.

Information regarding the duration of the flowering periods among different species of dragon trees is very sparse. Magdefrau [46] mentioned the duration of the flowering period for *Dracaena draco* subsp. *draco* as being from 11 to 17 years and Pütter [28] presented a range of 14.2 to 22.3 years by using long-term direct observations of a few trees on Tenerife Island.

The study areas of both investigated species are at higher elevations, namely, 1700 m a.s.l. for *D. ombet* and 815–1270 m a.s.l. for *D. draco* subsp. *caboverdeana*. Additionally, the mountain model from Socotra comes from 1400 m a.s.l. [29]. Unfortunately, there are no available local climate measurements from those localities with investigated dragon tree occurrences. Only sparse climate data have been published from broader areas.

In the Desa'a Forest, the precipitation ranges from 116.3 to 230 mm in the rainiest months (July and August) [30] and the total mean annual precipitation is less than 1000 mm [13]. However, according to Marrero et al. [8], the annual average rainfall of the vegetation zone with *D. ombet* occurrences is 200 mm. Using an interpolation published by Hijmans et al. [34], the total mean annual precipitation for the *D. ombet* locality reaches 599 mm.

The mean annual precipitation ranges from 80 to 300 mm on the coast and can reach 1200–1600 mm at the highest elevations on Santo Antão Island [35,36]. However, according to the interpolation [34], the total mean annual precipitation for the *D. draco* subsp. *caboverdeana* locality is only 314.7 mm. This value is less than for *D. ombet* because individual trees of *D. draco* subsp. *caboverdeana* were distributed at lower altitudes.

For comparison, the mean annual precipitation on Socotra Island is 216 mm [52], but measurements were carried out at lower altitudes in this case. Madéra et al. [6] mentioned 543 mm at 705 m a.s.l. and Marrero et al. [8] mentioned a 400 mm mean annual precipitation amount for a *D. cinnabari* zone on Socotra Island. In Dhofar (Oman), where forests with *D. serrulata* occur, the mean annual precipitation is as high as 250 mm [53].

Marrero et al. [8] considered the *D. tamaranae* growing on Gran Canaria Island to be more xeric species than the *D. draco* on Tenerife, the Cape Verde Islands or in Morocco. The most xeric species in warm environments are *D. serrulata* and *D. ombet*. In contrast, *D. cinnabari* is the most mesophilic species [8]. The arborescent Dracaenas are spread across semiarid to arid areas because the mean annual temperatures for their areas of distribution are approximately 18 to 20 °C [8] and the potential evapotranspiration far exceeds the amount of available precipitation.

Both study areas (and also Socotra and Dhofar) belong to a unique ecosystem, a semiarid seasonal cloud forest, that is adapted to harvesting the not-negligible additional water from clouds and fog in the form of horizontal precipitation [13,39,52,53] as compensation of deficient rainfall.

The annual horizontal precipitation in Dhofar was modelled for forests and showed values ranging from 165 to 246 mm [54] and reached 11.5 mm per day on average during the summer monsoon from July to September 2005 [55]. The horizontal precipitation captured by nets varied from 0.18 to 10 mm per day during the summer monsoon from July to September 2004 and totalled up to 357–567 mm in Diksam (Socotra Island) [52]. A similar value for the mean horizontal precipitation, 10 mm per day, was published by Marzol et al. [56] for two localities with potential occurrences of *D. draco*: Boutmezguida (Morocco) and Anaga (Tenerife Island), and they measured 3163 mm and 2541 mm respectively, of total annual horizontal precipitation, which was 2 to 4 times more than the rainfall.

It is clear that dragon trees strongly depend more on horizontal precipitation than on vertical precipitation. Fog and clouds bring available water for the long periods of the monsoon that last a few months, while rainfall usually only arrives in a few events during the year. Dragon trees are notably well-adapted for the purpose of mist and drizzle collection from fog and clouds by having long ensiform leaves arranged in leaf rosettes [15,57,58] and the ability of direct water absorption by the leaves [59–61]. Thus, the growth speed of dragon trees strongly depends on the altitude as well as the fog and clouds' occurrence.

We did not test longitude as a possible factor influencing the flowering probability. Some dragon tree species are endemic with only a small area of distribution like *D. draco* subsp. *caboverdeana*, endemic taxon of Cape Verde Islands. *D. ombet* has a larger area of distribution, where a longitudinal effect could be observed, but we have no opportunity to study more localities than this in Ethiopia. Also, the populations of *D. ombet* are mostly very small, not abundant, with unbalanced age structure and prevailing occurrence of mature and senescent specimens [10,12–14,25,48], which would not allow taking representative samples within all age classes for proper statistical analyses.

4.3. Suggestions for Future Research

The accuracy of each model depends on the quality of the input data. For the model published by Adolt et al. [29], the most important input data were (1) the number of all peripheral leaf rosettes and (2) the number of only the flowering rosettes to express the flowering probability. This approach could cause errors because all leaf rosettes in the crown were not counted. The flowering probabilities calculated using all leaf rosettes could be different and more representative than those calculated only from the peripheral rosettes. Therefore, we counted all leaf rosettes within the crown for the crown age estimations of the two dragon tree species that we studied.

Another possible error could be caused by the seasonality of flowering. According to our experiences from Socotra Island, dragon's blood trees (*D. cinnabari*) bloom with different intensities within the year. This potential source of error can be eliminated only by long-term observations. Thus, we suggest for verification and improvement of our model, establishing long-term monitoring [49,62] where direct measurements of more individual sample trees (located by geographical coordinates

and tagged in the field) from different age classes be conducted and that following characteristics be recorded: the radial increment of the stems at breast height, the numbers of all leaf rosettes within the crown and the numbers of all flowering rosettes. We also recommend, as did Adolt et al. [29], tagging of individual leaf rosettes within the crown of the trees of different age and direct observations of the time until flowering for a sufficient number of leaf rosettes.

Regarding the radial increment, the monitoring of which we recommend, only sparse data have been published from repeated measurements of a few individual trees of *D. draco* [28,46,50,51]. These studies have mentioned annual increments of stem diameter from 0.2 to 2.0 cm, but these values were mostly from the largest and oldest trees from cultivated trees in artificial conditions. Such sparse data do not reflect the natural variability and are not useful for statistical analyses.

Our results filled the gap in dragon trees' crown age estimations which were carried out only for *Dracaena draco* subsp. *draco* [28,46,50,51] and *D. cinnabari* [5,29]. The ages of *D. draco* subsp. *draco* were estimated only for a small set of individuals, which did not allow for creation of a statistical model. A statistically sound methodology for indirect crown age estimation model formulation and parameterisation [29] was only developed for *D. cinnabari*. Additionally, for biodiversity conservation management strategies of the other arborescent dragon tree species, such as *D. tamaranae*, *D. serrulata* [8] and the Asian species [47,63,64], it is important to know the age structure of their populations.

Knowledge of the age population structures is of possible use for predicting future population developments, as was shown for *D. cinnabari* on Socotra Island [18,22,26]. We recommend the prediction of future population developments for both investigated species to create a time framework for conservation management measures. However, a proper population inventory [26,62] is still missing as input data for predictive population modelling [18,26].

5. Conclusions

Our hypothesis, that the methodology, so far published only for one species *D. cinnabari*, is possible to use also for the other arborescent *Dracaena* species, was confirmed. The first model of crown age estimation was developed for *Dracaena ombet* from the Desa'a Forest (Ethiopia) and for *D. draco* subsp. *caboverdeana* from Santo Antão (Cabo Verde Islands). This model can be used to express the crown age structures of populations of these endangered species for proper conservation management strategies and for predicting future population developments. However, the methodology has some weaknesses as we discussed above, that are a challenge for future research.

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