








Article

The Conservation Status and Population Mapping of the Endangered *Dracaena serrulata* in the Dhofar Mountains, Oman

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Abstract: Populations of *Dracaena serrulata* are disappearing at an alarming rate in the Arabian Peninsula. They are being destroyed by herders who use the leaves as fodder for camels, goats, and sheep during the dry season. Up until now, precise information about the current distribution and population status of *D. serrulata* in Oman have not been published. To fill this gap, the main aim of this work was to map the species distribution in the Dhofar Mountains (Oman) and to define the conservation and health status of the populations. Three isolated sub-populations of the study species were defined and mapped: the Jabal Samhan, Jabal al Qara, and Jabal al Qamar sub-populations. *Dracaena serrulata* occupies an area of 227 km² in the Dhofar Mountains. More than 43,000 trees were counted, and 2387 trees were inventoried in total. The Jabal Samhan sub-population is an example of an extensively damaged population with 59% of the trees recorded as dead and only 21% healthy trees. Populations in the western portions of the Dhofar Mountains, Jabal al Qamar, and Jabal al Qara are comparatively abundant stands of healthy trees with a higher proportion of seedlings. The health of trees is strongly influenced by accessibility and precipitation provided by the southwest summer monsoon: the healthy individuals predominate on the steep terrain along the seaward facing cliffs.

Keywords: *Dracaena serrulata*; Dhofar Mountains; health status; Oman; occurrence; threat

1. Introduction

Dracaena Vand. ex L. (Asparagaceae) [1,2] is taxonomically classified among the terrestrial monocotyledons [3]. There are 60–100 species in the genus *Dracaena*, of these, relatively few have a tree growth form, and these are commonly known as Dragon trees including *D. serrulata* Baker [4].

Marrero et al. [5] specifically described six arborescent *Dracaena* species (*Dracaena cinnabari* Balf.f., *D. draco* L., *D. tamaranae* A. Marrero, R. S. Almeida et M. González-Martín, *D. ombet* Heuglin ex Kotschy&Peyr., *D. schizantha* Baker, and *D. serrulata* Baker) as making up the dragon tree group.

The arborescent dragon tree species are found not only in the Arabian Peninsula, Africa, and nearby islands (Canary, Madeira, Cape Verde, and Socotra Islands), but also as far afield as Southeast Asia [6,7] and one from the Neotropics [8]. All members of the dragon tree group appear in areas with seasonally arid climates where the average annual precipitation is 200–500 mm and the mean annual temperatures are 18–20 °C [5,9]. The dragon trees are well adapted to capture horizontal precipitation [10–12] and some authors have connected their distribution with seasonal cloud forests [5,13–18].

Dragon trees exhibit a biogeographical disjunction, regarded by Adolt and Pavlis [9] as ‘a relict representation of the Mio-Pliocene Laurasian subtropical flora’. Bramwell [19] included the species of the dragon tree group among the important elements of the much older Rand Flora, which existed in the southwestern region of South Africa during the Paleocene. According to Denk et al. [20] contemporary, semi-desert dragon trees may have originated from a western Eurasian mesic lineage that had evolved xeromorphic characteristics by the Miocene. The replacement of a savannah-woodland belt in the Sahara region with desert in the late Miocene [20] potentially caused the modern disjunct distribution of many Rand Flora elements including dragon tree species.

Thus, dragon tree species are considered tertiary relicts and most of them are endemic due to long-term isolation. The current distribution of individual species is scattered with small, fragmented, and isolated populations with unbalanced age structures, where often the young developmental stages are missing. For example, dragon’s blood tree (*Dracaena cinnabari*), endemic to Socotra Island, occupies only 5% of its potential habitats [21] and over 100 years of normal/typical regeneration is missing [1,2]. The reasons for population decline are overgrazing [11,17,18,21,22] and ecosystem aridification [19]. These effects have been intensified by global climate change in the last decade [21].

There are a limited number of studies on other dragon tree species that focus on their distribution and population status. *Dracaena ombet* in Gebel Elba NP (Egypt) was investigated by Kamel et al. [23] and in the Tigray Highlands (Ethiopia) by Aynekulu et al. [16]. The current occurrence of *D. tamaranae* was described by Almeida Pérez [24] and *D. draco* by Almeida Pérez [25]. The Asian species, *D. cambodiana* in Hainan Island (China), was investigated by Zheng et al. [26] and *D. jayniana* by Wilkin et al. [6]. Only a general occurrence description of *D. draco* subsp. *caboverdeana* has been published [27]. Adolt et al. [28] described the population structure of *D. cinnabari* on Firmihin (Socotra Island) using a statistical inventory approach.

Dracaena serrulata Baker (Arabian Dragon Tree) is closely related to *D. cinnabari* [29]. *D. serrulata* has a robust short stem with a slightly dense crown. The younger trees do not branch, but later, the trunk is repeatedly sympodially branched, forming a smaller umbrella crown. The tree reaches heights of 2 to 8 m. The length of the leaves varies from 30 to 60 cm and their width is between 2 and 3.5 cm. Its fruit is a large spherical berry up to 1 cm in diameter [30]. *D. serrulata* has a scattered distribution along the southwestern edge of the Arabian Peninsula, especially in the hills of southern Medina and the El Asir mountains in Saudi Arabia. It also is present in the foothills of Yemen and on the northern slopes of Dhofar, southern Oman. According to Lavranos [30], there are three geographically isolated subspecies: *D. serrulata* subsp. *serrulata* occurs in Yemen, subsp. *mccoyorum* in Saudi Arabia, and subsp. *dhofaricum* in Oman. According to the World List of Monocotyledons [8] the populations in Saudi Arabia belong to *D. ombet* subsp. *ombet*.

In southern Oman, *D. serrulata* grows at elevations between 800–1400 m along the steep escarpment slopes of the Dhofar Mountains. From June to September each year, the area comes under the influence of the southwest monsoon, when an upwelling of cold water off the coast rapidly cools the moist winds to dew point, causing dense fog to form against the seaward-facing escarpment. Due to the dense cloud cover, the temperature drops, and relative humidity reaches 90–97%. Fog can extend up to 250 km along the escarpment and up to 50 km inland [31]. The combination of topography and temperature inversion creates stable, moist conditions for three to four months, with persistent dense

cloud clinging to the seaward slopes [32]. The vegetation of the escarpment is dominated by a narrow band of deciduous trees and shrubs skirting the coastal mountains from southern Oman into eastern Yemen. This narrow band of desert cloud oasis is one of the most diverse ecosystems of the Arabian Peninsula [33], and includes a large number of rare and endemic plant species. This fragile ecosystem is strongly dependent on the interaction between climate, topography, and vegetation.

D. serrulata is a rare and endangered species [4] found in the xerophilic zone where *Acacia-Commiphora* dominates [5]. The populations of *D. serrulata* are disappearing at an alarming rate in the Arabian Peninsula, where they are destroyed by herders who use the leaves as fodder for camels, goats, and sheep during the dry season. This has become more intense in recent decades. The stems and branches are also cut for beehive production [30]. This species is missing natural regeneration among most of its populations and appears to be on the brink of extinction [30]. Accordingly, it is listed on the International Union for Conservation of Nature (IUCN) Red List as an Endangered Species [34].

Precise information about the current distribution and the population status of *D. serrulata* in Oman is lacking. To fill this gap, the main aim of our work is to map the whole population of *D. serrulata* in the Dhofar Mountains and to define the conservation and health status of selected accessible parts of the population. Specifically, we describe two separate, concurrent field studies to map and assess the population size, distribution, health, and threats regarding *D. serrulata*. The first study was undertaken in 2018 by researchers from the Oman Botanic Garden and the Anglo Omani Society. The main aim was to analyze and describe the population size and distribution of *D. serrulata* in the Dhofar Mountains. The second study was undertaken between 2017–2018 by researchers from Mendel University in Brno and from University College London. The main aim of this project was to analyze the health status of the population using an inventory of separated subpopulations of *D. serrulata*. Using the results of these studies, we then assessed the IUCN national threat assessment of *Dracaena serrulata*.

2. Material and Methods

2.1. Population Size and Distribution

In January 2018, the population size and distribution of *D. serrulata* was investigated across the Dhofar Mountains including Jabal al Qamar, Jabal al Qara, and Jabal Samhan. A total of 225 viewpoints were strategically selected according to accessibility and in order to represent a variety of topologies (escarpments, wadis, plateaus, etc.) across the species range. At each point, the total number of trees within the view-shed were counted (Table 1). In difficult to access locations, binoculars were used to support counting. All viewpoints were recorded on a Garmin etrex 20× handheld device for the Global Navigation Satellite System (GNSS). Viewshed maps were generated using ArcGIS (ESRI, Redlands, California, United States) after the fieldwork in order to calculate the total surveyed area and inferences were made about the overall distribution and population density. Trees were recorded as juvenile, mature (Figure 1), or standing dead (no rosettes visible).

Table 1. Observation points and recorded trees.

	Total Survey Points	Total Survey Area (km ²)	Total Living Trees	Total Dead Trees	Total Juvenile Trees	Total
Jabal al Qamar	89	42	18,077	1021	1102	20,200
Jabal al Qara	50	24	14,502	1050	1475	17,027
Jabal Samhan	86	66	6041	261	154	6456

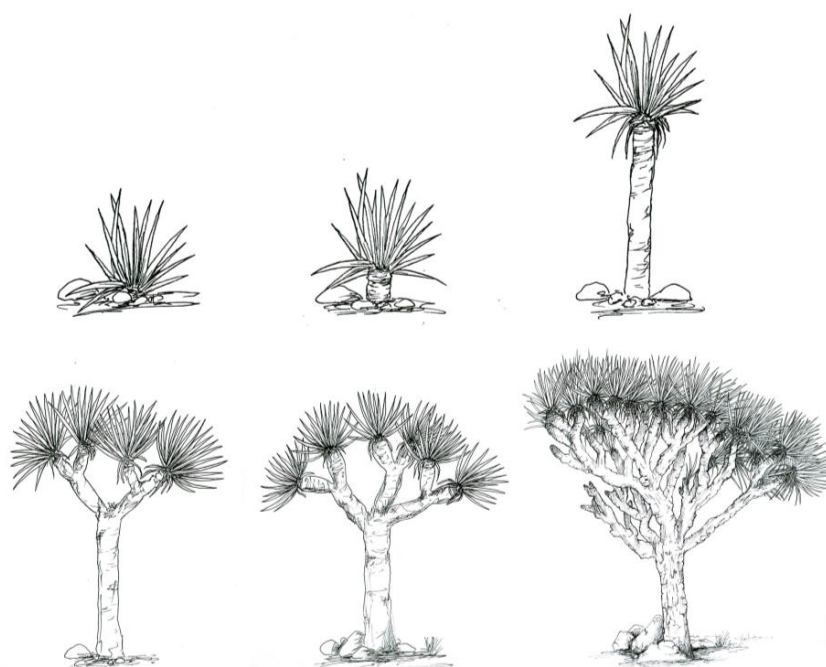


Figure 1. Schematic diagram of juvenile and mature trees according to Maděra et al. [30]. Trees in the **(top)** row are classified as juvenile; they have a single rosette and no trunk or a single rosette on an unbranched trunk. Trees in the **(bottom)** row are classified as mature; they possess at least one lateral branch.

2.2. Health Status of the Population

In the period between May 2017 and March 2018, the whole area of the Dhofar Mountains was explored to map and define the health status of the population of *Dracaena serrulata*. Most of the trees are distributed on difficult to access cliffs, canyon walls, or high ridges. Such localities were mapped visually from the surrounding areas. Individual trees growing in accessible localities were mapped and inventoried using a GPS locator connected to a web mapping server. To enhance the efficiency of the inventory process, the mobile application Collector for ArcGIS (ESRI, Redlands, CA, USA) was connected with the predefined mapping server and all the field data were synchronized continuously using the cloud service of ArcGIS Online (ESRI, Redlands, CA, USA).

A complex inventory of the population of *Dracaena serrulata* was created on the upper plateau of Jabal Samhan. Within the Jabal al Qamar subpopulation, three accessible groups of trees were inventoried. The inventory process collected the following data: position, health status expressed by ratio of damaged/undamaged rosettes in the crown, age expressed as the number of branch sections, and the stem diameter. Age estimation of trees is complicated due to the lack of studies on this issue. The age evaluation depends on the number of branch sections, so we are able to indirectly express the ontogenetic stage of the tree by the number of branch sections, even though we do not know the exact age of the tree (see Figure 1). A model of crown age estimation based on a number of branch sections was developed for *Dracaena cinnabari* [35]. However, such a model needs the probability of the flowering of leaf rosettes as input data because new branch sections start to form with leaf rosette blooming [9]. Thus, the duration of growth of one branch section is expressed by time lasting between two flowering events. This information is still missing for *Dracaena serrulata*, and, therefore, age estimates could be developed.

A dataset of field records was processed using ArcGIS software version 10.7.1. (ESRI, Redlands, CA, USA) software and evaluated statistically using Statistica software version 13 (TIBCO Software Inc., Palo Alto, CA, USA) to analyze the geomorphological conditions of the habitats, and to study the health status of inventoried parts of the population.

The dataset of the recorded trees was analytically overlaid with the data of the digital terrain model and its geomorphometric derivatives of slope and curvature of terrain. Surface data with the spatial resolution of 5 m were retrieved from the National Survey Authority in Oman. We obtained values of altitude and slope using spatial extraction of data. Slope values for each damage class were compared based on a 95% confidence interval of the mean. The k-sample Anderson–Darling test [36] was used for the comparison of a probability distribution of diameter at breast height (DBH) and the number of branch sections in each population. The Kolmogorov–Smirnov test was used for pairwise comparison. *P*-value was adjusted by Bonferroni corrections to counteract the multiple comparison problem, where type II errors increased. The level of significance per comparison was calculated as the desired level of significance divided by a number of comparisons.

2.3. National Threat Assessment of *Dracaena serrulata* according to International Union for Conservation of Nature (IUCN)

Using the field data, the extent of occurrence (EOO) and area of occupancy (AOO) were calculated using the geospatial conservation assessment tool GeoCat. GeoCAT [37] provides a tool to collate primary biodiversity data for application of the IUCN Red List assessment systems and provides baselines in the threat status of species from which changes in status can be monitored over time. The GeoCat outputs were used to complete an IUCN Red List Assessment. The assessment was undertaken at the national level, following the guidelines for IUCN national assessments [37].

3. Results

3.1. Population Size and Distribution

During the population census of *D. serrulata* from the Dhofar Mountains—Jabal al Qamar, Jabal al Qara, and Jabal Samhan—43,683 trees including juvenile, mature, and standing dead trees were recorded in 2018 (see Table 1 and Figure 2).

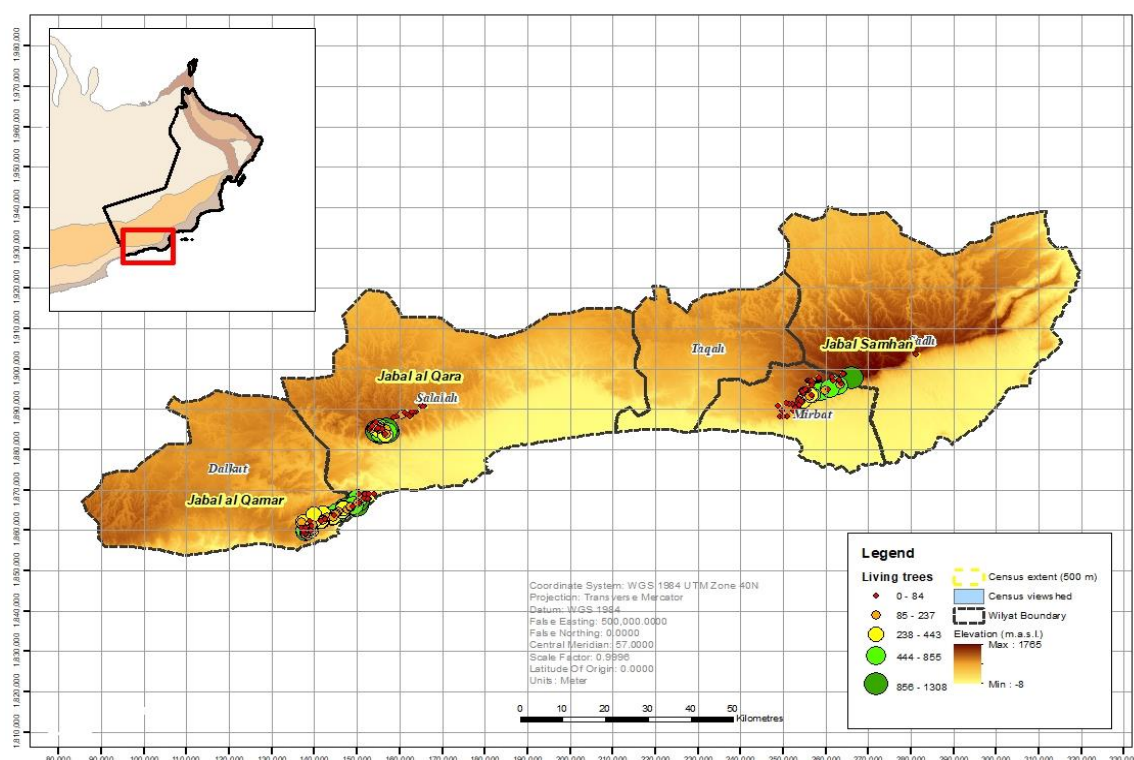


Figure 2. The overall distribution of *Dracaena serrulata* across the Dhofar Mountains including Jabal al Qamar, Jabal al Qara, and Jabal Samhan as recorded in the project census, January 2018.

The highest concentration of trees is located in Jabal al Qamar and Jabal al Qara (see Figures 3 and 4). Those populations are also significantly younger than those in the Jabal Samhan population, which accounted for just 20% of the total trees (see Figure 5).

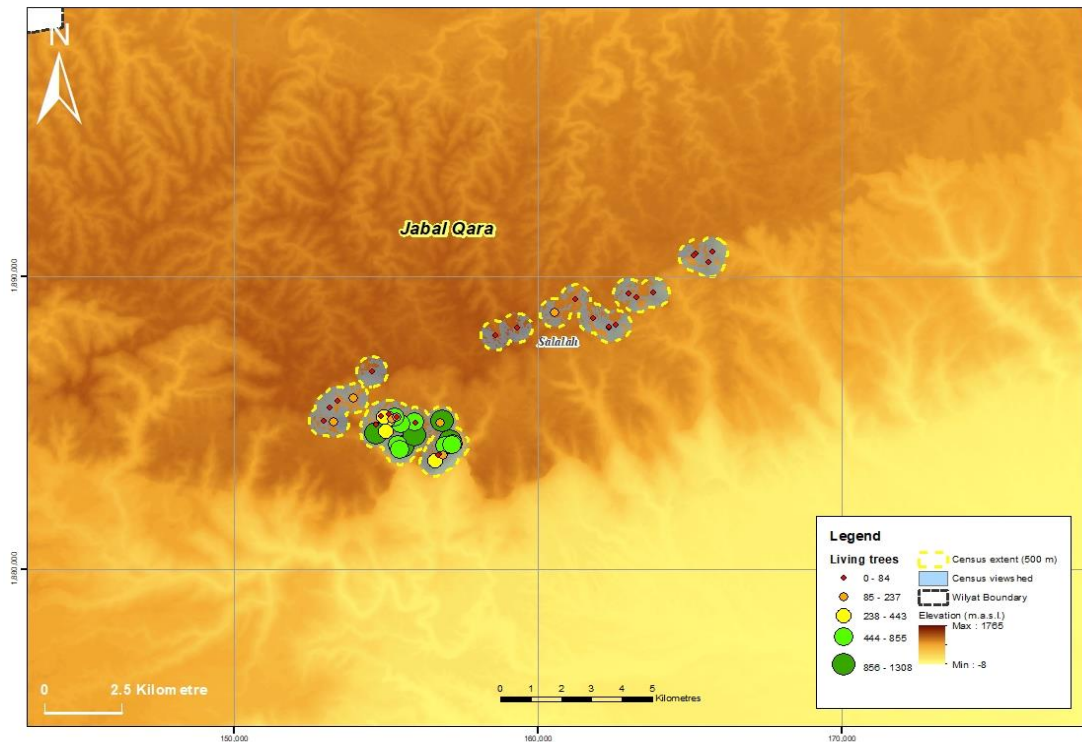


Figure 3. Distribution of census survey points, viewshed areas (depicted in blue within the dashed yellow lines), and total tree numbers on Jabal al Qara, southern Oman, January 2018.

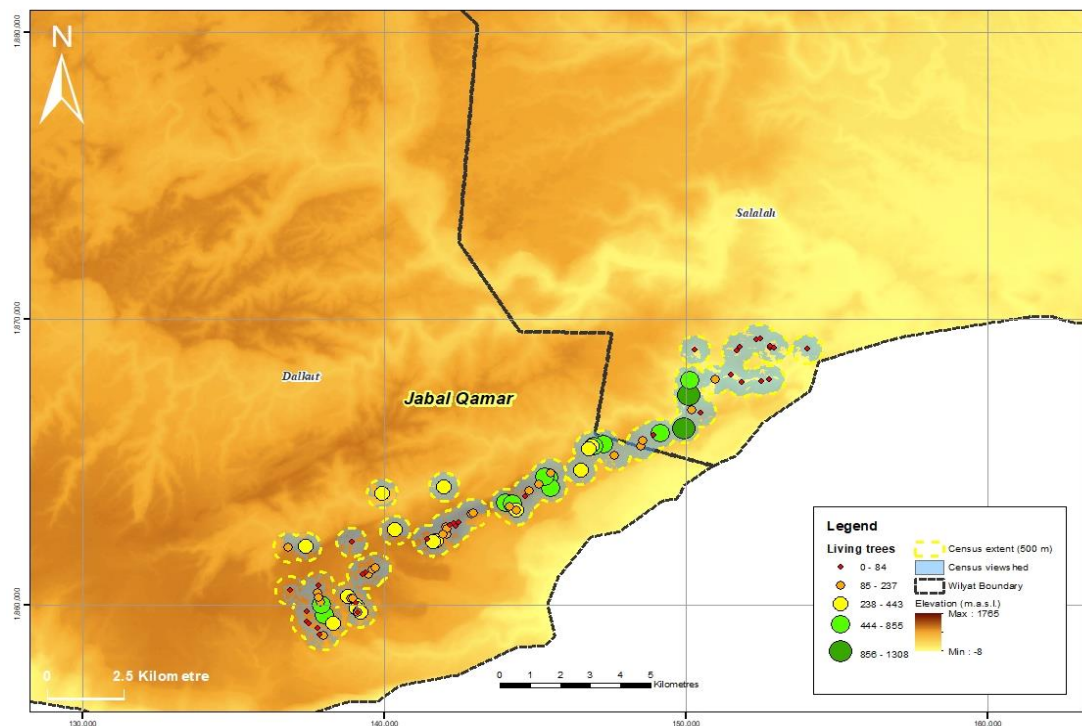


Figure 4. Distribution of census survey points, viewshed areas (depicted in blue within the dashed yellow lines), and total tree numbers on Jabal al Qamar, southern Oman, January 2018.

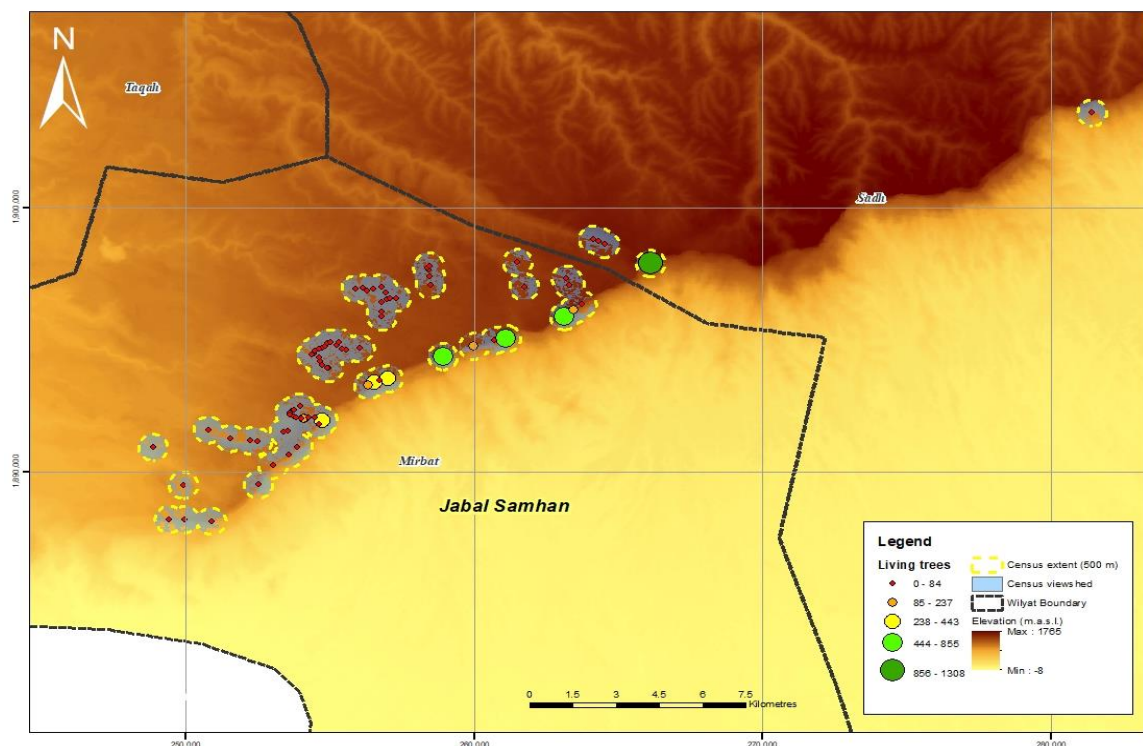


Figure 5. Distribution of census survey points, viewshed areas (depicted in blue within the dashed yellow lines), and total tree numbers on Jabal Samhan, southern Oman, January 2018.

3.2. Health Status of the Population

Three isolated populations of the studied species were defined and mapped (see Figure 2). The Jabal al Qamar and Jabal al Qara populations were confined largely to north-facing, inaccessible slopes at an average altitude of 815 m a.s.l. for the recorded trees, with a minimum altitude of 659 m a.s.l. and maximum of 1082 m a.s.l. However, the maximum altitude of visually recorded trees was an altitude above 1200 m a.s.l. The total area of confirmed occurrence at the Jabal al Qamar and Al Qara populations was 14,300 ha. The Jabal Samhan population occupies the steep cliffs and a small portion of the upper plateau. The average altitude of recorded trees was 1160 m a.s.l., with the minimum altitude 1075 m a.s.l. and a maximum of 1579 m a.s.l.: no trees were observed above this altitude. The total area of confirmed occurrence of the studied species in Jabal Samhan was 8400 ha.

Within the complex inventory of the upper plateau of Jabal Samhan, 1835 individual trees were recorded and measured. Of these, 386 were healthy trees, 366 were damaged trees, and 1083 were dead trees (Figure 6). The average age as described by the number of branch sections (BS) was 3.4 BS, with a maximum of 22 BS, and minimum 0 BS. According to these values, Jabal Samhan is considered to be a young population. The age structure is described in Figure 7.

Of Jabal al Qamar's population, 552 individual trees were recorded and measured: 308 were healthy trees, 131 were damaged trees, and 113 were dead trees (Figure 8a,b). The average age described by the number of branch segments was 2.8 BS, with a maximum of 22 BS, and minimum of 0 BS. According to these values, we can consider the population to be young. The age structure is described in Figure 7.

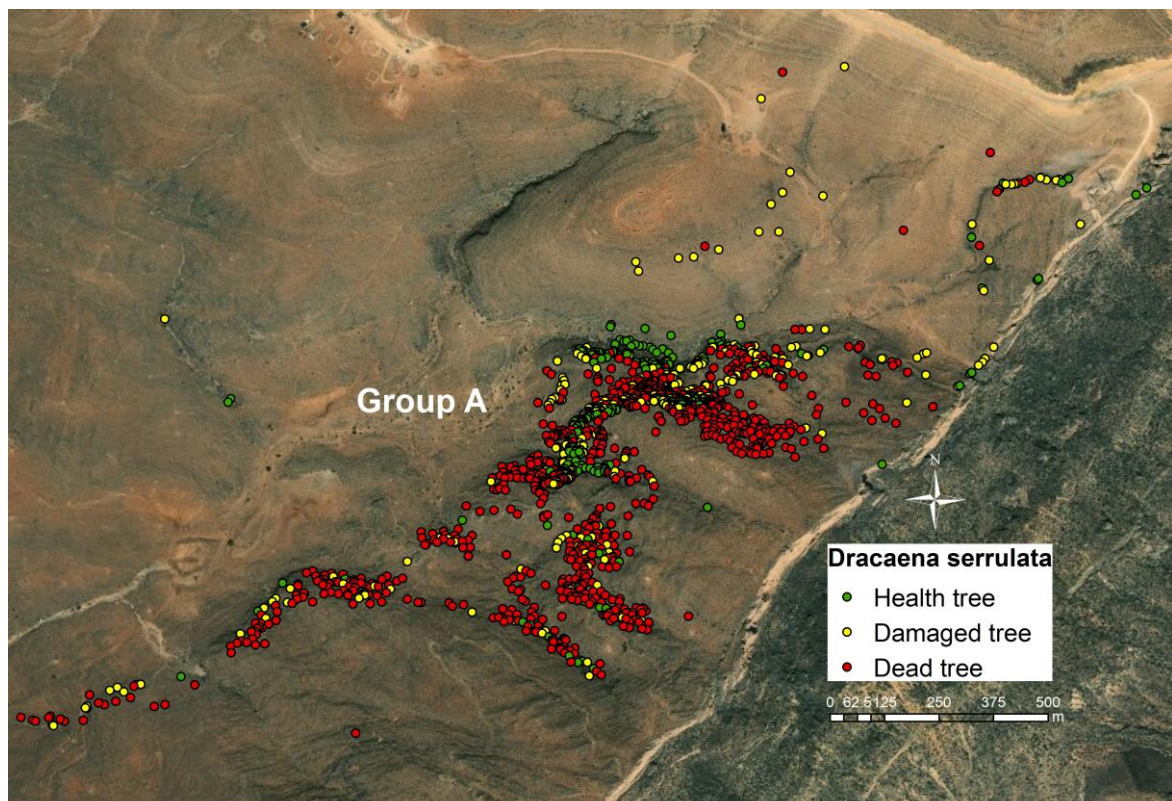


Figure 6. Inventory of *Dracaena serrulata* at the upper plateau of Jabal Samhan. Group A in the analysis. Background: ESRI base maps (Redlands, CA, USA).

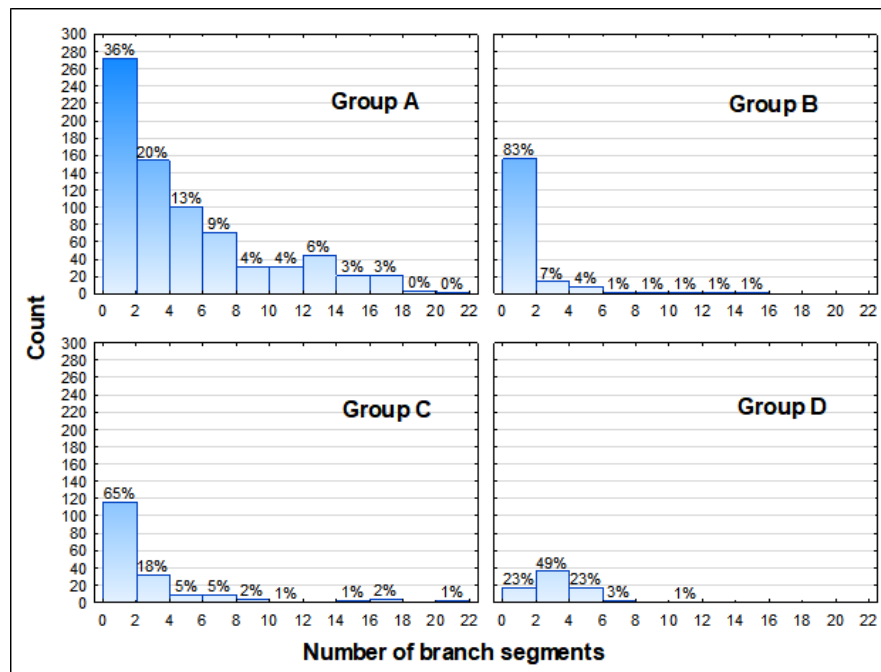


Figure 7. Histograms of the age structure of inventoried groups described by the number of branch sections. Group A is the Jabal Samhan population, B and C are populations located at the eastern parts of Jabal al Qamar, and group D is located at the western part of Jabal al Qamar.

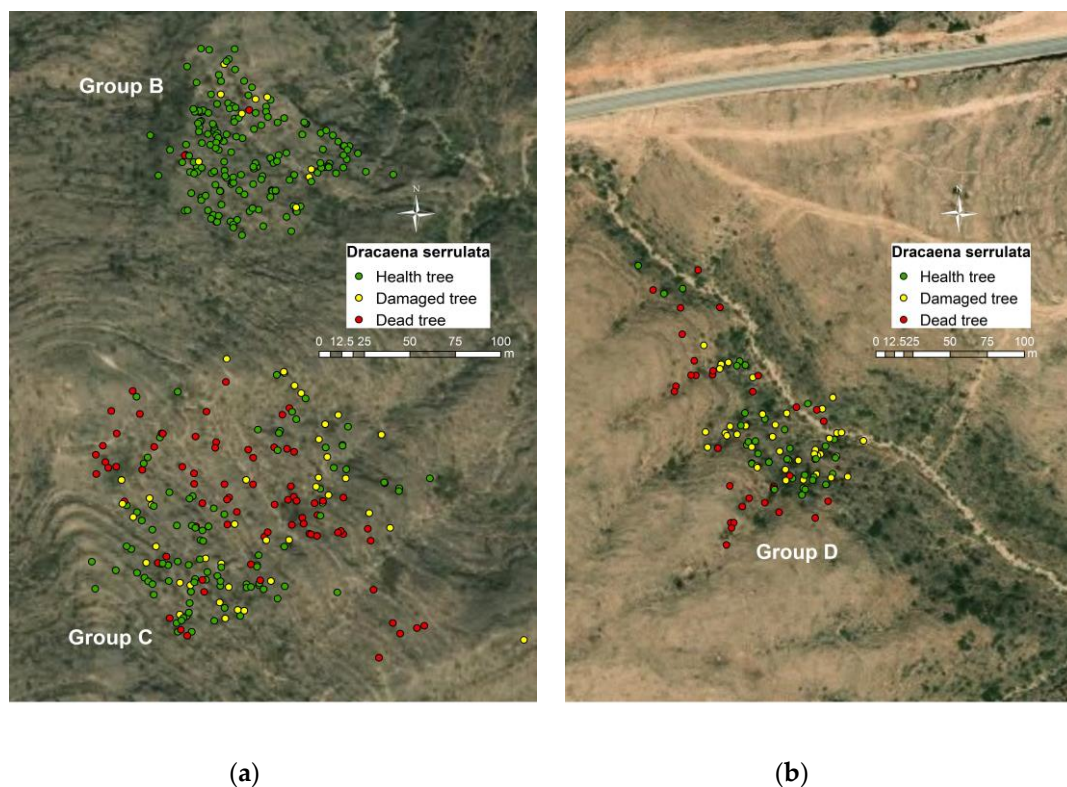


Figure 8. (a) Inventory of groups B and C at the eastern part of Jabal al Qamar. (b) Inventory of group D at the west part of Jabal al Qamar. Background: ESRI basemaps (Redlands, CA, USA).

To analyze and compare the structure and health status of the inventoried groups of trees, the whole dataset was separated into four groups according to geographical location. Group A was the Jabal Samhan population (Figure 6), groups B and C were populations located at the eastern parts of Jabal al Qamar at the southern oriented slopes of the western part of the Dhofar mountains (see Figure 8a), and group D is the population in the western part of Jabal al Qamar situated in several shallow canyons at a higher plateau of the west part of the Dhofar Mountains (see Figure 8b).

According to Figure 9, based on DBH, more adult trees and a higher number of branch segments occur in the Jabal Samhan population compared to the other populations (Figure 7). The distributions of DBH differed significantly across the four populations (K-sample Anderson–Darling, $p < 0.05$). Pairwise Kolmogorov–Smirnov tests revealed that the distribution of DBHs did not differ between populations A and D or between populations C and D ($p > 0.0083$; adjusted by Bonferroni corrections). However, they did differ between A and B, A and C or B, and C, B, and D.

The distributions of the number of branch segments differed significantly across the four populations (K-sample Anderson–Darling, $p < 0.05$). Pairwise Kolmogorov–Smirnov tests revealed that the distribution of branch sections differed between all inventoried population ($p > 0.0083$; adjusted by Bonferroni corrections). According to the visual interpretation of Figure 7, smallest differences are between groups B and C. The Jabal Samhan population contained the oldest trees of the inventoried groups, but Group D was the oldest overall. Groups B and C were younger than A and D.

There was a significant difference in the health status of the studied populations (Figure 10 a,b). Group A was the most damaged, and group B was the healthiest. Based on 95% confidence intervals of means, there was no difference between groups C and D in the percentage of undamaged rosettes. Group A had the lowest and group B had the highest percentage of undamaged rosettes.

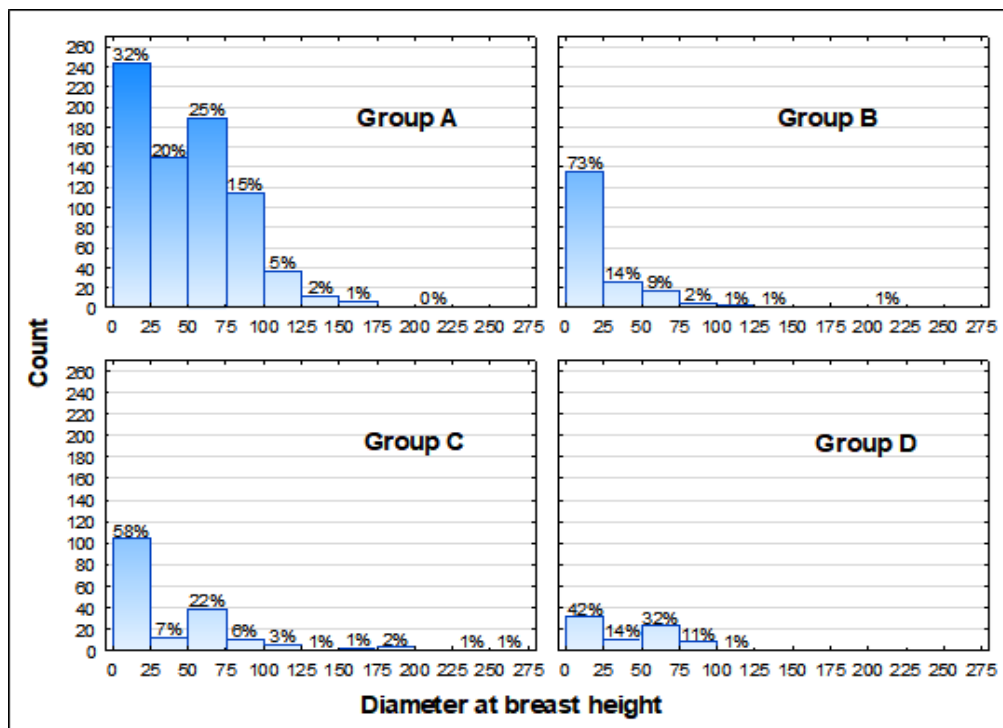


Figure 9. Histograms of diameter at breast height (DBH) structure of the inventoried groups. Group A is the Jabal Samhan population, B and C are populations located at the eastern parts of Jabal al Qamar, and group D is located at the western part of Jabal al Qamar.

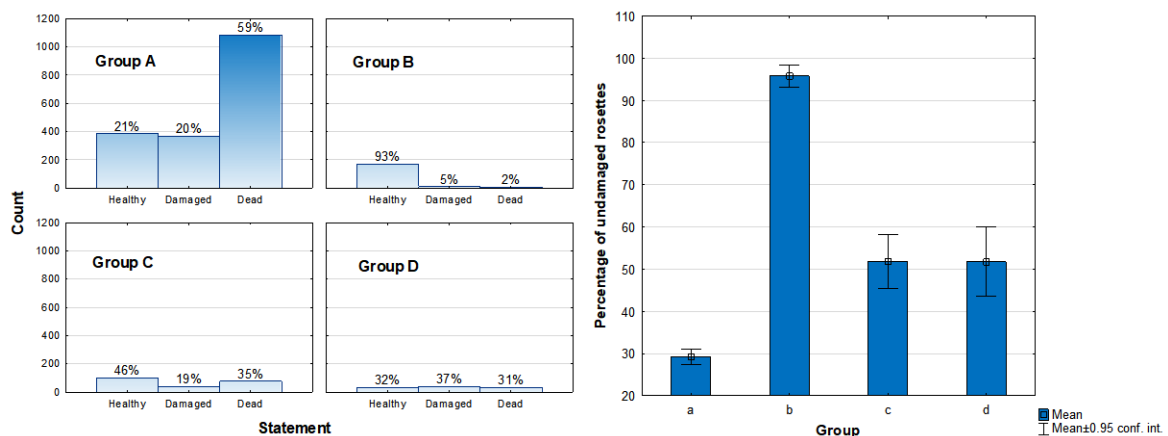


Figure 10. (a) The health status of inventoried groups of trees (left). (b) Percentage range of undamaged rosettes in crowns of the inventoried groups (right). Group A is the Jabal Samhan population, B and C are populations located at the eastern parts of Jabal al Qamar, and group D is located at the western part of Jabal al Qamar.

To verify the hypothesis that the grazing and cutting of leaves is the main reason for the poor health status of populations, inaccessibility, due to the steepness of the terrain, as a determining factor in the health status of trees was analyzed. All the inventoried populations were intensively damaged by the grazing and cutting of rosettes, which are used as fodder for camels. Most of the dead and damaged trees were located on flat accessible plots, whereas healthy individuals were located on steep cliffs and canyon walls (Figure 11).

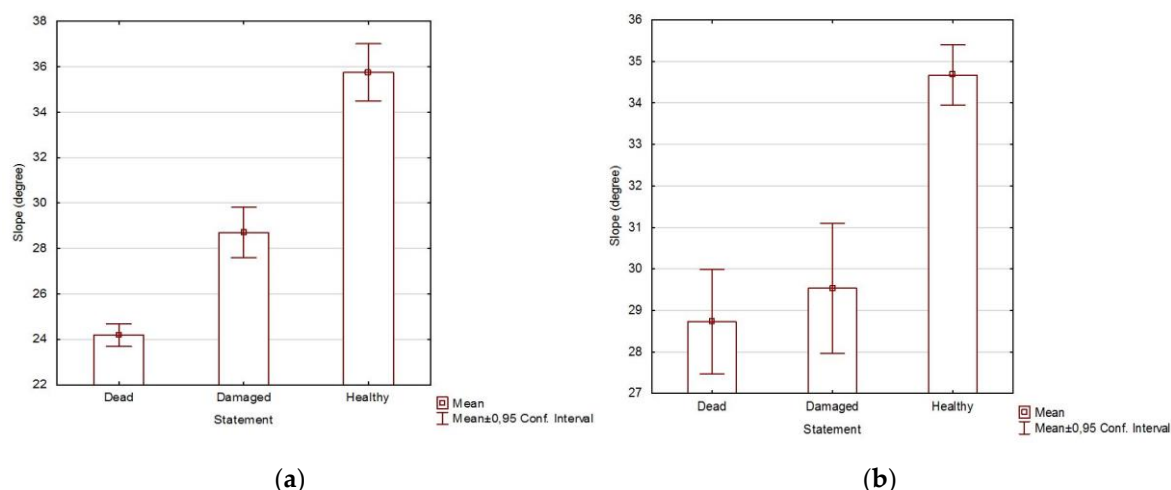


Figure 11. Relation of the slope of terrain and health status of trees in Jabal Samhan population (a) and Jabal al Qamar/Qara population (b).

3.3. IUCN National Assessment of *Dracaena Serrulata*

The extent of occurrence (EOO) for *D. serrulata* in the Dhofar Mountains is 2301 km² and the area of occupancy (AOO) is 220 km². *Dracaena serrulata* was categorized under Criterion B of the IUCN Red List Threat Status. The EOO is a <5000 km² threshold, therefore, *D. serrulata* qualifies under category Endangered (B1). The AOO is a <500 km² threshold, which qualifies under category Endangered (B2). *D. serrulata* in Oman is Endangered B1 ab (iii,v)+2ab (iii,v), where the details are outlined below:

B1—Extent of occurrence (EOO) <5000 km²

- (a) Number of locations ≤5 (locations the threats on the taxon).
- (b) Continuing decline inferred in (iii) extent and/or quality of habitat, (v) number of mature individuals.

B2—Area of occupancy <500 km²

- (a) Number of locations ≤5 (locations the threats on the taxon).
- (b) Continuing decline inferred in (iii) extent and/or quality of habitat, (v) number of mature individuals.

4. Discussion

Few studies have provided detailed population inventories for dragon tree species. As a result, there is a lack of knowledge regarding the total area of distribution for these often-endangered trees. The only previous population evaluation for *Dracaena serrulata* was by Lawranos [30], who claims that this species is on the brink of extinction. Our results show that *D. serrulata* in the Dhofar Mountains in Oman occupies an area of 227 km², more than that found for most other dragon tree species. Král and Pavliš [38] estimated the total occurrence for *D. cinnabari*, a species endemic to Socotra Island, was 72.3 km², comprising 62.0 km² of woodlands, 2.3 km² of forests, and 8.0 km² of mixed vegetation [39]. Kamel et al. [23] estimated that *D. ombet* in Gebel Elba National Park (Egypt) occupied an area of 1327 km². Approximately 10 populations of *D. jayniana* were found by Wilkin et al. [6] with a calculated area of occupancy of 32 km².

In a detailed inventory of *Dracaena ombet*, occurring on the highest slopes of Gebel Elba National Park in Egypt [23], a total of 353 trees were recorded, of which only 161 (46%) were alive, only 96 (27%) healthy, and only 1% young, indicating not only a low regeneration rate, but also poor overall population health. Almeida Pérez [24] found 86 trees of *Dracaena tamaranae* on Grand Canaria (Canary

Islands), of which 10 trees were dead, one old, 12 mature, and 63 juvenile. A statistical inventory approach was used by Adolt et al. [28] for the *Dracaena cinnabari* forest in Firmihin (Socotra, Yemen) on an area of 6.48 km². A total of 66,054 trees were estimated according to the model, of which 545 trees were dead and 8177 trees were less than 100 years old. All of the above-mentioned authors reported no natural regeneration except in inaccessible locations.

We estimate that the abundance of *Dracaena serrulata* in the Dhofar Mountains exceeds 50,000 trees. The highest numbers were found on the steep wadi slopes and seaward facing cliffs in Jabal Al Qara and Jabal Al Qamar with a reduction in numbers toward Jabal Samhan. The presence of healthy trees and seedlings were confined predominantly to the steep, inaccessible cliffs, and wadis. This is likely to relate to the inability of browsing animals to access the trees, resulting in a significant reduction in grazing intensity. Habrova et al. [40] observed a similar population structure for *Dracaena cinnabari* on the mountain slopes of Socotra and postulated that the existence of seedlings was due to the presence of a more favorable moisture regime for germination, created by the sheltered cracks and soil pockets formed in the rock surfaces. Habrova et al. [40] further postulated that the presence of seedlings was possibly a result of ‘sudden mass regeneration’ brought on by short ‘wetter’ periods that punctuate the more typical long periods of aridity: a reproductive strategy observed in many xerophytic trees. According to Miller and Morris [41], the flowering of *D. serrulata* in Dhofar is not an annual event and only heavy rains could cause the trees to flower. This was observed in 2019 when botanists from the Oman Botanic Garden (OBG) on field work in Dhofar observed and collected large quantities of *D. serrulata* seeds for inclusion in their seed bank. The production of flower spikes in 2019 may be attributed to the two severe cyclones in 2018. The Dhofar area was inundated by Cyclone Mekunu in May and Cyclone Luban in October 2018. In a 24-h period, Mekunu discharged 617 mm of rainwater, resulting in extensive and prolonged flooding across the entire Dhofar region. Despite multiple field trips to Dhofar by the OBG in the period between 2009 and 2018, flowers or seeds were observed very rarely and in small numbers only. It is difficult to ascertain if this ‘sudden mass regeneration’ episode was a direct result of the rains in 2018. The possibility is worthy of consideration.

The presence of seedlings is not exceptional in the Dhofar Mountains and compared with the other *Dracaena* species, it is a sign of less intensive grazing. On the other hand, the cutting of leaf rosettes and grazing by camels were recognized as a main negative influence in *D. serrulata* in contrast with *Dracaena cinnabari* from Socotra, where this practice is not used. According to the field survey done in 2018, a similar decline of numbers of *Dracaena ombet* in the Tigray region (Ethiopia) was visible.

Both populations, *D. cinnabari* in Socotra and *D. serrulata* in the Dhofar Mountains, differed substantially in their age structure. Populations of *D. cinnabari* were older; the abundance of mature trees was higher, whereas in relative terms, the populations of *D. serrulata* contained a lower presence of mature trees and a higher presence of trees in the younger age classes. This difference might be caused by the cutting of leaf rosettes or grazing of camels on older trees, which appears to be having a significant impact on tree mortality, following a number of consecutive years of this practice. These practices and their impacts require further investigation. The absence of goat grazing in the Dhofar Mountains enables natural regeneration (at least in some places) whereas on Socotra Island, the overgrazing has been the main factor affecting natural regeneration for decades if not centuries [28].

The limited number of studies focused on the population status and structure of dragon trees clearly indicate the high level of threat facing these iconic species. Overgrazing [1,3,35], aridification [14,23], global climate change [21], long-term climate oscillation [42], cutting of leaves [22,30], dragon’s blood harvesting [13], and to some extent mine extraction and road construction [4] are mentioned as key factors of dragon tree population decline.

The precipitation and cooling effect provided by the summer monsoon is a driving force for the unique and diverse vegetation of the Dhofar Mountains [32,43–45]. The areas most affected by the summer monsoon are the southwest facing slopes of the Dhofar Mountains, particularly the escarpment cliffs on Jabal al Qara and al Qamar. The effect diminishes eastward, having less of an impact on Jabal Samhan, particularly at high altitude. However, the plant communities do receive some benefit from

the ambient cooling effect during the summer months [32]. *Dracaena* trees are nebulophytes: their narrow leaves, arranged in dense rosettes, can capture horizontal moisture from fog and direct it to their succulent woody organs to be stored for later use. Nadezhdina, Nadezhdin [11] demonstrated that *D. cinnabari* and *D. draco* are able to channel atmospheric moisture through their leaf axils to stem tissues and suggested that this means of water absorption provides an alternative mechanism of water uptake, which is particularly important for plants in foggy, arid regions. Oral history reports from Socotra suggest that *D. cinnabari* does best in areas that experience what is locally called *ilihil di horf*, that is, mist, low cloud, or drizzle during the monsoon. To the local people, the presence of the tree is a natural indicator of this microclimate [13].

No long-term data exist for the geographical extent or annual duration of the summer monsoon in Dhofar. Local people claim the monsoon has contracted and has become less intense in recent decades. Despite the absence of quantitative data, it is worth considering whether the putative contraction in the monsoon is having a negative impact on the distribution and regeneration of *D. serrulata*, particularly along its eastern extent on Jabal Samhan, where the monsoon is weakest. Future contractions in the summer monsoon would very likely put further pressure on this already stressed species.

Population decline, fragmentation, and isolation of dragon tree populations could cause a demographic and genetic bottleneck effect [26]. Kamel et al. [23] suggested that 80% of *D. ombet* populations in Gebel Elba may soon be extinct. Severe decline has also been documented for the rest of the *D. ombet* distribution in NE Africa [16]. Attore et al. [21] estimated that dragon tree now occupies only 5% of its potential habitat on Socotra Island. The population decline and over-maturing of populations of *D. cinnabari* were also considered by Habrová et al. [40]. For *D. draco*, Almeida Pérez [25] documents the previous larger occurrence of trees according to toponyms. This dragon tree population decline has been predicted to continue, so that, for example, the dragon tree density on a permanent plot at Firmihin (Socotra) has been projected to decrease by 36% over the years 2010 to 2110 [46]. Such declines, leading to small, isolated populations put these species at risk of inbreeding and local extirpation [47].

Indeed, four species from the dragon tree group (*D. cinnabari*, *D. draco*, *D. ombet*, and *D. serrulata*) are listed in the International Union for Conservation of Nature Red List [34] as globally threatened. Similarly, both *D. draco* and *D. tamaranae* appear on the Red List of endangered species in Spain [48], with the latter as critically endangered. Additionally, Wilkin et al. [6] described the endemic *D. jayniana* of Thailand as endangered, and Zheng et al. [26] assessed the *D. cambodiana* on Hainan Island (China) as endangered.

5. Conclusions

This is the first detailed population mapping and inventory of *D. serrulata* in the Dhofar Mountains in southern Oman. It provides important baseline data relating to the species distribution and the potential threats to the species' long-term survival. Trees on Jabal Samhan appear to be severely degraded, with large amounts of dead and damaged trees reported. Healthy trees are largely confined to the steep, inaccessible slopes of the seaward facing cliffs where grazing by camels does not occur and favorable conditions for seed recruitment are present. Jabal Al Qara and Jabal Al Qamar, southwest of Jabal Samhan, support healthier stands of *D. serrulata*, although trees are also confined predominantly to wadi slopes and steep coastal cliffs. All trees are likely to benefit from the precipitation and shade provided by the summer monsoon, the effect of which diminishes eastward along Jabal Samhan.

This work suggests there are a number of threats facing *D. serrulata* in southern Oman: (1) climate change, specifically a reduction in duration and intensity of the summer monsoon, resulting in increased aridity; (2) over-grazing, resulting in the direct removal of *D. serrulata* seedlings or the removal of surrounding vegetation, vital for providing protective shading for germination and establishment; (3) the cutting of leaf rosettes as fodder for livestock during periods of drought; and (4) habitat loss through road construction and mining, although this particular threat was not observed during this work and is unlikely to directly impact the inaccessible coastal slopes.

A number of conservation steps are suggested: (1) carry out high-resolution satellite mapping of tree distribution to determine the full extent of the populations; (2) immediately protect intact sites, in particular sites on Jabal al Qara and Jabal al Qamar, which may be valuable refugia in the future; (3) elevate the importance of *D. serrulata* conservation, promoting it as a flagship species and an umbrella for broader conservation concerns; (4) establish a long-term management program on fixed sites; and (5) continue to establish an exsitu conservation collection at Oman Botanic Garden through the collection and banking of seed and the cultivation and showcasing of living collections.

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