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Dragon's blood tree – Threatened by overmaturity, not by extinction: Dynamics of a *Dracaena cinnabari* woodland in the mountains of Soqatra

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ABSTRACT

Age determination of tropical trees, and monocotyledons in general, is not an easy task. Representatives of the *Dracaena* genus have survived in woodlands on dry margins of the Tethys tropical forest since the Tertiary Period. Here we present analyses of *Dracaena cinnabari* (DC) stand dynamics via direct and indirect methods of age determination. The direct method has taken advantage of historical photographs of DC mountain woodlands from Soqatra during an Austrian scientific expedition in 1899 by comparing these with the woodland stage in 2004. A decline in the number of tree individuals is obvious, but considering the little that is known about dynamics of DC woodland, one cannot simply state that such decline means forest destruction. The results from this direct method are compared to an indirect mathematical method of age determination using data from 2003. Indirect age determination values differed only about 6.5% from those obtained with the direct method, indicating that the indirect methodology is quite precise.

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1. Introduction

Soqatra Island (12°19'–12°42' N latitude and 53°18'–54°32' E longitude) (see Fig. 1) is unique in its high biodiversity and high number of endemics (37% of plants - Miller et al., 2004), which is the result of a long-term separation from the African continent. The prehistoric origin of local plants and their degree of endemism usher the island into the society of one of the most environmentally significant spots on Earth. The Soqatra Archipelago was declared a UNESCO Biosphere Reserve in 2003, inscribed among Natural properties on UNESCO's World Heritage List in 2008, and designated as one of the 'Global 200' priority natural habitats by WWF.

Endemic *Dracaena cinnabari* groves greatly contribute to the biodiversity value of the island. This plant (further abbreviated as DC) is a flagship tree that dominates the landscape character of Soqatra, with a natural occurrence ranging from 250 masl. to the highest parts of the mountains (i.e., third to fifth altitudinal vegetation zones according to Habrova (2004)).

Most *Dracaena* species grow as shrubs or geophytes; only six species (*D. cinnabari*, *Dracaena serrulata*, *Dracaena ombet*, *Dracaena schizantha*, *Dracaena draco*, and *Dracaena tamaranae*) have the growth habit of trees (Marrero et al., 1998). These species are considered to be remnants of the Mio-Pliocene Laurasian subtropical forests, now almost extinct because of the climate changes of the late Pliocene that caused the

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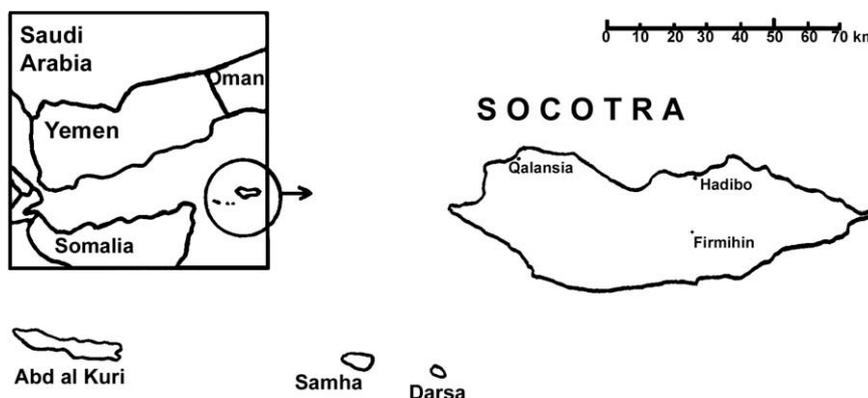


Fig. 1 – Geographical location of Soqatra Island.

desertification of North Africa (Quézel, 1978; Mies, 1996). In the past, this unique ecosystem was present over large areas of the former Tethys. It is an example of two major biogeographical disjunctions between East and West Africa, being of Tethyan origin according to fossil and paleoclimatic data. According to pollen analyses, extinct *Dracaena* species have been identified throughout the Mediterranean region (Tunex, France) into Bohemia and Southern Russia (Gwynne, 1968; Saporta, 1873; Van Campo and Sivak, 1976).

D. cinnabari is very well adapted to arid tropical conditions of the island, but, despite these long-term adaptations, present tree populations do have evident unbalanced age structure, discontinuous woodland patches, and a lack of natural regeneration. The DC forest on Soqatra represents one of the oldest Earth forest ecosystems (Miller and Cope, 1996) and it was presumably present over larger areas of the island in the past. Remnants of this unique woodland are in the Hageher Mountains (declared as the National Park) and adjacent limestone plateaux in east central Soqatra, where the tree often forms monospecific stands. The most preserved DC stands mainly occur in the inaccessible localities. In general, DC seedlings are rarely seen due to the intense effects of livestock, except among steep slopes of some wadis or mountain regions. According to an investigation of land-cover classification by Kral and Pavlis (2006), DC occupies three land-cover classes “*Dracaena cinnabari* forest”, “*Dracaena cinnabari* woodland” and “Mountain forests”.

The species is an evergreen tree with a typical umbrella-shaped crown due to a ‘dracoid’ ramification (Adolt and Pavlis, 2004) of branches. *Dracaena* species are exceptional among monocots because of their capacity for secondary thickening of stems and roots. Due to the absence of annual rings, the age of *Dracaena* trees can only be determined with considerable difficulty comparing to wide range of classical methods from boreal biomes.

The age of *Dracaena* trees has generally been clouded by overestimation, i.e., by Humboldt (1814) who hypothesized that a huge *D. draco* with 15 m stem girth from Orotava, Tenerife was several thousand years old. A more probable average was estimated to be up to 700 years old by Byström (1960). However, later observations by Symon (1974) and Magdefrau (1975) brought both a precise record of the age of cultivated trees as well as the first clues to determine ageing. Neverthe-

less, only one authentic study (Adolt and Pavlis, 2004) on the ageing of natural populations of *Dracaena* tree species has been published. This study was based on an indirect method reflecting relationship between the number of flowering periods and the actual age of a specimen. Specific branching of arborescent *Dracaenas* is characterized by markedly swollen branches segregated individually by narrowed ‘sausage-shape’ sections (see Fig. 5). These obviously relate to the growth rhythm of a tree and correspond to one period of flowering. According to this method, DC reaches an age up to 650 years.

The present paper deals with following three objectives in an effort to elucidate DC population dynamics: (1) to analyse changes in a DC grove between the years 1899 and 2004 with the aid of photograph interpretation (*direct method* of population analyses), (2) to verify if an *indirect method* of population structure analyses is applicable – i.e., model of population development based on architectural age, and (3) to compare results of direct and indirect method in order to precise model calibration.

2. Materials and methods

2.1. Field measurement

Long-term (1999–2007) scientific attention paid to *D. cinnabari* specimens throughout Soqatra by a Mendel University team has brought together records on phenology, habitat features, species composition, and space and age structure of DC populations.

In 1899, an expedition led by Prof. Kossmat (Wettstein, 1906) took photographs in the Skant mountain (Hageher Mts. range), the highest part of Soqatra. After rediscovery of these photographs in the Vienna museum archive, the authors were inspired to find the locality photographed 100 years ago as this allowed evaluation of the DC stand dynamics over the course of known time series. Determining the exact localization of the Austrian expedition photograph from Skant was not an easy task. Difficulties related to hard terrain, weather conditions and unreliable maps of the area led to many unsuccessful attempts from 2001. However, we finally succeeded in April 2004 and identified the peak of Djebel Dried as the site from where the original picture was shot in

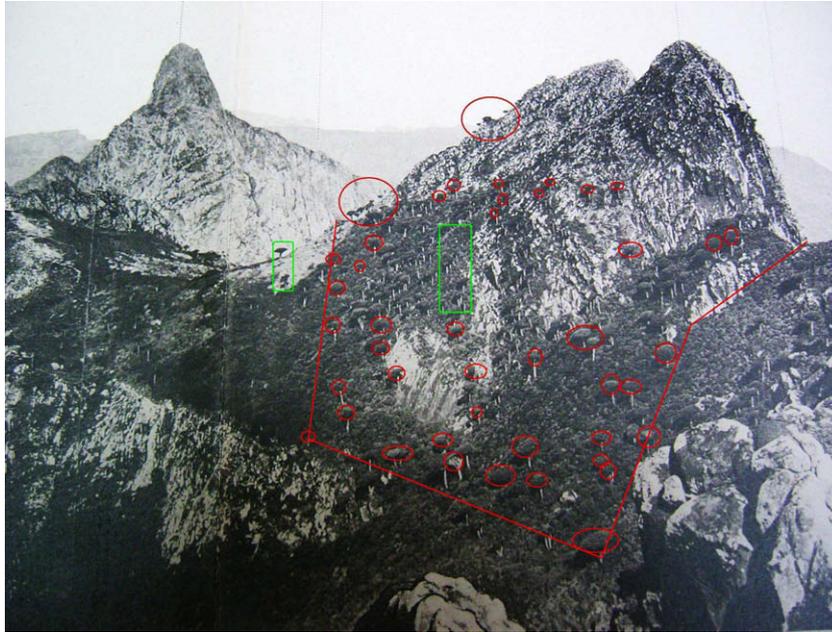


Fig. 2 – Photo taken from the hill “Djebel Dried” by an Austrian expedition in 1899 (Wettstein, 1906; Kossmat, 1907). Small red circles indicate tree individuals which are identifiable also in 2004; green polygons indicate DC tree groups that are not present in 2004; two big red circles indicate larger DC groups also present in 2004.

1899. New photographs were then taken there by digital camera.

Actual population structure at Skant was observed on three research plots of irregular shape – according to the presence of DC trees in three of the nearest hills (Shaar, Mashaniq, Momheir located among $12^{\circ}34'30''$ – $12^{\circ}34'50''$ N, $54^{\circ}01'30''$ – $54^{\circ}01'45''$ E). The plot topographies were described by slope inclination and exposition, altitude and soil type. The follow-

ing characteristics were measured for each of the trees inside the sample plot: (1) localization of the individual tree, (2) total height, (3) height of stem, (4) circumference of stem in breast height, (5) diameter of crown, (6) number of branch sections (see explanation above and Fig. 5), (7) number of leaf rosettes on crown periphery, and (8) number of paniculate inflorescences on periphery of crown. Since the terrain was steep and rocky, only 86 individual trees were recorded.

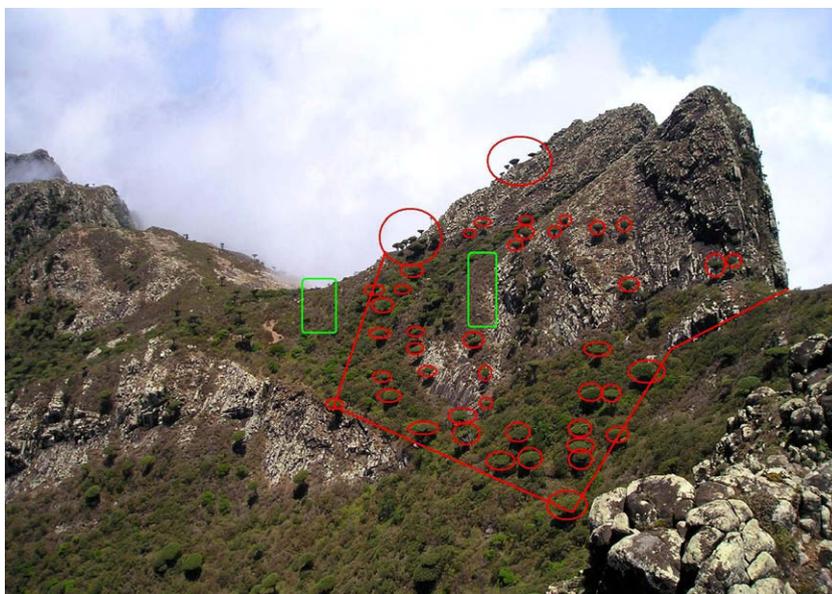


Fig. 3 – Photo taken from “Djebel Dried” in 2004 (author M. Culek). Small red circles indicate clearly identifiable trees that have survived from 1899; green polygons delineate clearings without DC that were present in 1899; two big red circles indicate large DC groups that were present in 1899.

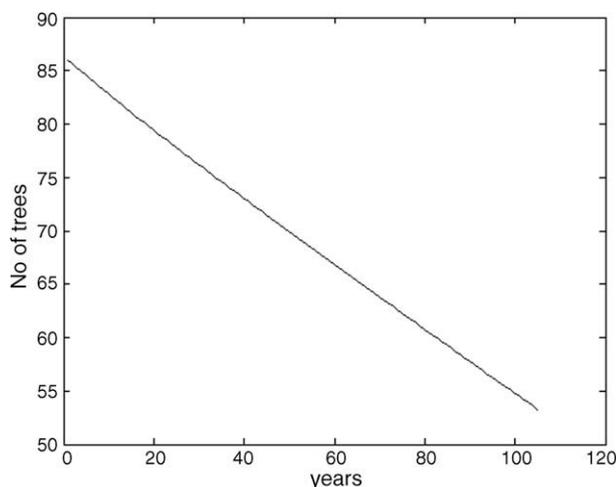


Fig. 4 – Graph expressing the decrease in the number of trees during 105 years, determined by multiplying the matrix data by the vector data from Table 1.



Fig. 5 – Specific branching of arborescent *Dracaenas* is characterized by markedly swollen branches segregated individually by narrowed ‘sausage-shape’ sections that are the basis of the architectural age method.

2.2. Data processing

The *direct method* involves assessing forest dynamics by repeated observations in time, done here by using the two available photographs (dated 1899 and 2004). Since the different photographic techniques did not allow for acquisition of exactly equivalent pictures, the comparison remained rather

complicated. Therefore, the first and crucial task related to identifying reliable terrain points where contours of the sample plot could be established. Within the area of the sample plot, the total number of *D. cinnabari* trees was determined. Further, the total area of DC crowns was determined by a planimetric method. This method was more practical and preferable when compared with the initially considered image analysis by the Ecognition program, which could be rather helpful for larger areas. The crown cover area has been expressed in relative terms (%) and not absolutely (m^2) due to the different photographic techniques and unknown surface of the sample plot.

Since repeated observation of forest stand dynamics is a time-consuming task, *indirect methods* that are based on architectural age and statistical analyses (Hallé et al., 1978) can be more suitable for age determination of monocotyledon trees. Previously verified tree ages obtained by these indirect methods (Adolt and Pavlis, 2004) were used to determine the population dynamics of DC in the mountains of the Skant area. Based on data from the whole island (not only from Skant, as a huge amount of data is needed), values of probability indicated that a tree dies out once it has a certain number of branch sections (Table 1). Populations of measured DC were divided into 16 categories: seeds, seedlings, immature plants (prior to first flower), and 13 categories of branching for mature trees (every category included two branch sections each, i.e., 1–2 sections, 3–4, 5–6, ... 25 and more). The number of trees in a particular category provided the vector of a population. The age of one branch section was adopted from a previous study (Adolt and Pavlis, 2004), and it reached about 19 years.

In order to construct a model of population development in the following years in accordance with methods in Caswell (2000), it was necessary to compile a generally applicable matrix. The matrix (Table 1) was constructed of values for the probability of dying out within a given age category and the value of the average age of one section of a branch. The values along a diagonal give the probability that a plant will persist in the same category during one year. Values one line below provide the probability of transition to the next category (e.g., in trees already coming into flower, the number gives the probability of flowering) and a missing value to the sum of 1 is the probability that a plant in the given category will die out during the given year. After multiplying the matrix by a particular vector (i.e., by the actual number of trees in particular categories) we obtain the population development model that can be depicted by the diagram in Fig. 4.

3. Results

Using the *direct method*, the number of DC trees declined by 44.22% from 199 trees in the original 1899 photograph to only 111 individuals in 2004. Nevertheless, differences in daylight conditions of the exposed photographs resulted in illuminated stems (morning sun) that were fully visible on the photo from 1899, whereas stems on the photo from 2004 were not very clear (noon sun shade of tree crowns). Thus, on the latter photo, it was more difficult to recognize individual trees growing in closed groups and it is possible that the real num-

Table 1 – Matrix indicating the probability of persisting a tree within branch section category (for the detail explanation please see the third paragraph of the Data Processing chapter). The vector on the right side sets factual number of trees fallen into each category for a given “number of branch sections”.

	0	1–2	3–4	5–6	7–8	9–10	11–12	13–14	15–16	17–18	19–20	21–22	23–24	25+	Vector
0	0.988235	0	0	0	0	0	0	0	0	0	0	0	0	0	3
1–2	0.011765	0.973684	0	0	0	0	0	0	0	0	0	0	0	0	5
3–4	0	0.026316	0.971775	0	0	0	0	0	0	0	0	0	0	0	7
5–6	0	0	0.026264	0.972061	0	0	0	0	0	0	0	0	0	0	13
7–8	0	0	0	0.026272	0.97125	0	0	0	0	0	0	0	0	0	11
9–10	0	0	0	0	0.02625	0.972511	0	0	0	0	0	0	0	0	19
11–12	0	0	0	0	0	0.026284	0.96975	0	0	0	0	0	0	0	11
13–14	0	0	0	0	0	0	0.026209	0.968224	0	0	0	0	0	0	2
15–16	0	0	0	0	0	0	0	0.026168	0.968012	0	0	0	0	0	6
17–18	0	0	0	0	0	0	0	0	0.026162	0.966194	0	0	0	0	4
19–20	0	0	0	0	0	0	0	0	0	0.026113	0.963542	0	0	0	0
21–22	0	0	0	0	0	0	0	0	0	0	0.947129	0	0	0	2
23–24	0	0	0	0	0	0	0	0	0	0	0.025598	0.942703	0	0	2
25+	0	0	0	0	0	0	0	0	0	0	0	0.025478	0.958833	0	1

ber of DC trees in 2004 was slightly higher. Nevertheless, the absence of trees from younger age classes is evident in the 2004 photo. This is a general problem for the majority of the island that has been caused by overgrazing, which does not allow for development of a new generation. Despite the longevity of the DC species, this absence of a new generation may lead to a gradual die-back of the population.

From the photograph comparison, data can also be gleaned for relative DC crown cover projection over the sample plot area. Crown cover projection decreased from 8.211% for the total sample plot area in 1899 to only 6.654% in 2004. This represents an 18.961% decrease in crown projection over the past 105 years on a sample plot area. A final detailed comparison of both photographs indicates obvious clear-patches on the 2004 photo where absolute disappearance of the DC trees has occurred. These patches are marked by green polygons in Figs. 2 and 3. Such small clearings were probably caused by water erosion during rainstorms, which regularly occur in the mountains and sometimes reach destructive intensity. For example, in 2006, total precipitation on the Firmihin locality, where the Czech team installed an automatic measuring meteorological station, reached up to 168 mm in 26 h (Habrova, 2007).

Comparison of the data processed by direct observation with data processed by the indirect methodology from a nearby locality in Skant (86 trees), revealed only slightly different results. The diagram in Fig. 4 projects a model of population development for the forest stand in 2108 and supposes that, from the original number of 86 DC tree individuals, only 53 trees will remain. Therefore a decrease will be 37.79%. The model is valid under conditions of continued intensive grazing, limiting the regeneration of DC trees. The model does not consider natural or artificial woodland regeneration, accidental climatic deviations (e.g., many-year of drought) or natural disasters.

Generally, the difference in DC “mono-coenosis” after 105 years between the direct stand observation method (44.22%) and indirect modelling method (37.79%) is quite low. Despite the fact that this difference can be considered insignificant and that the proposed indirect method is very accurate, several affecting factors that were not considered in the model should be mentioned:

- the model depicted by Fig. 4 does not only include tree survey data of the mountain DC trees, but it also includes DC data from lower parts;
- the locality of repeated photographs and the locality of the 86 tree measurement are ca 300 m apart;
- there may be effects of external factors occurring over a larger (century scale) time flow not considered here.

After almost a decade of the field-work on the island, forest ecologists can already conclude that most of the DC tree stands occur in a so-called stage of optimum (mature forest and old trees) or are already in the stage of disintegration (higher presence of old & dead trees). The disintegration stage is indicated by a high proportion of robust trees with high fruiting capacity (seeds germinate and seedlings grow quite well under controlled conditions) having low stand tree crown cover. The reason of general absence of young age classes is

related to low survival capacity of DC seedlings in the open area (see Adolt and Pavlis, 2004). Therefore, the overall population structure can be approximated by the Gaussian curve and not by an exponential one (see vector of the matrix – Table 1).

4. Discussion

Issues discussed below accompany the broader context of the DC phenotype and ecotope features, its woodland structure as well as touching on peculiarities of its coexistence with transhuman pastoralists.

Through increasing our understanding of the growth habits, experienced field researchers can confirm that the mountain population is probably of a different ecotype than the population from lower parts of the island. Some authors (Mies and Beyhl, 1996), after reviewing the plant material, have even mentioned sorting mountain *Dracaenas* into multiple taxonomical groups (species, subspecies) if differences between generative organs are verified. The mountain ecotype is characterised by smaller dimensions of stem (height, girth), crown and, usually, larger branch sections. The most significant difference is the branching habit; *Dracaena* from lower parts ramify rather uniformly with branches of about 20–30 cm, have crowns that are quite dense and have potentially important differences in flowering intervals. Conversely, mountain *Dracaenas* sometimes have much longer branches (around 40–50 cm), the crowns are rather scarce and flowering intervals seem to be different. However, the mountain population is scarce and is located in areas that are mainly inaccessible, such that obtaining a sufficient amount of data to create a generally valid matrix for mountain *Dracaenas* is very time-consuming (if possible at all).

The description of DC forest or woodland appearance can provide important contextual information (see definition of forest/woodland e.g., FAO, 2001).

Although certain age uniformity of most of the DC stands is remarkable, there is an interesting exception related to the high rate of occurrence of the youngest trees and seedlings on steep and extreme cliffs (in all altitudes of DC occurrence). This small-scale success of the DC reproductive strategy may be consequently related to either a more favourable moisture regime for seed germination inside stone pockets of those cliffs or to habitat inaccessibility by grazing animals (Van Uytvanck et al., 2008). Although little is known of the dynamics of DC stands and oscillation of their tree number in a long-term scale, however, it is apparently not rational to blame climate change theory (i.e., Attorre et al., 2007) as the main cause of DC population over-maturity. It is evident that the stage of disintegration in these forests lasts for a very long time, and, for our study, began over 100 years ago (long-term field-work of by the Czech team started in 1999). Accordingly, there is stronger evidence for the hypothesis of a sudden mass regeneration in favourable short “wetter” periods interrupting the standard long-lasting semi-arid weather pattern. However, it is still difficult to judge whether this sudden mass recovery wave was caused by favourable climatic conditions or if it follows a decline of the livestock population, i.e., recurrent animal-unfavourable deficiency of water and

feed (Liddle et al., 2006). This DC reproduction strategy is somewhat similar to the forest reproduction pace of natural monocoenotic overmature spruce forest in the boreal zone, which regenerates over large areas following a zero event (Oldeman, 1983) caused by wind, fire or bark-beetle attack. Moreover, such a presumption of the species regeneration course is supported by the very uniform age structure of DC populations on most of the optimum habitats of Soqotra.

DC woodland importance can be seen not only from the perspective of world nature conservation community demand, but also linked to traditional sustainable ecosystem management lasting for millennia. This would include dragon’s blood resin tapping, forage for goats and a local source of fuel-wood. During the last decade, the value of the island’s natural beauty for eco-tourism has also risen substantially.

At present, with an expanding human population on the island (estimates range between 40,000 and 80,000 people), traditional natural resource management methods balanced within the population of 10,000 people (Elie, 2006) are no longer followed. In order to achieve realistic protection (Burgess et al., 2007; McDonald et al., 2008) of the slowly vanishing flagship DC species, the world nature conservation community should first perform detailed surveys of *D. cinnabari* occurrence at the scale of the individual tree, since high-tech media are available – e.g., Quick Bird satellite images of high resolution. With regard to particular measures for direct preservation of the unique dragon forest of Soqotra, there is still enough time to support practical experiments that may involve: (1) participation of the motivated indigenous community in out-planting of seedlings (e.g. Vesik et al., 2008), (2) immediate protection by fencing against livestock, and (3) watering of seedlings in the open landscape. However, at the island scale it will be necessary to concentrate extensive funds to back either protection of naturally regenerated seedlings or tree nursery production and consequent out-planting.

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