MENDELOVA UNIVERZITA V BRNĚ

Lesnická a dřevařská fakulta

Ústav lesnické botaniky, dendrologie a geobiocenologie

Ekologická studie dračince rumělkového (*Dracaena cinnabari*) na lokalitách Firmihin a Skand, ostrov Sokotra

DISERTAČNÍ PRÁCE

2016

Ing. Bc. Irena Hubálková

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Poděkování

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Práce vznikla za podpory těchto projektů: IGA 37/2012 *Morfologicko-anatomická studie dračince rumělkového (Draceana cinnabari Balf.)* [projekt Interní grantové agentury Mendelovy univerzity v Brně] a *Podpora drobných zemědělců a zemědělského vzdělávání na ostrově Sokotra* [projekt České rozvojové agentury; identifikační č. 08/2012/01, 08/2013/01, 08/2014/01].

ABSTRAKT

V této práci jsou předloženy výsledky výzkumu sub-populací dračince rumělkového (*Dracaena cinnabari* Balf.fil), endemické rostliny jemenského ostrova Sokotra. Práce sestává ze souboru čtyř vědeckých článků, které jsou přijaty, publikovány nebo předloženy k recenznímu řízení v recenzovaných a impaktovaných odborných časopisech. První článek predikuje vývoj sub-populace druhu na lokalitě Firmihin, kde se provedla podrobná inventarizace stromů na hektarové zkusné ploše a na základě již zjištěných poznatků o přirůstání dračinců na Firmihinu byla vytvořena simulace růstu stromů a následné mortality v časovém horizontu 100 let. Druhý článek je zaměřen na problematiku růstové dynamiky sazenic pěstovaných ex situ v kontrolovaných podmínkách, kdy se během dvou let pravidelně měřily přírůsty nadzemní části u sta sazenic z Firmihinu a ze Skandu. Následně se vyhodnotily rozdíly v růstové dynamice a mortalitě obou skupin sazenic pěstovaných ex situ. Třetí článek se rovněž týká obnovy dračince rumělkového a řeší možnost regenerace in situ v oplocenkách na plató Shibehon a u školy Oam al-Cora, kde tým Mendelovy univerzity v Brně v roce 2006 vysadil stovky sazenic a dlouhodobě monitoruje jejich růstovou dynamiku a mortalitu. Čtvrtý článek se týká studia anatomie sekundárně tloustnoucích částí rostliny. Ze 70 trvalých mikropreparátů byla analýzou obrazu zjištěna plocha xylému, floému, parenchymu a lumen cév v kořenu, stonku a větvi. Hodnoty se vyhodnotily, vzájemně porovnaly a graficky interpretovaly.

Klíčová slova: *Dracaena cinnabari*, populační dynamika, růstová dynamika, sekundární tloustnutí

ABSTRACT

The results of *Dracaena* sub-populations research are submitted in this dissertation. Dragon´s Blood Tree is an endemic plant species growing on the Socotra Island. The thesis contains four scientific papers published or submitted for review in journals with impact factor and in peer-reviewed journal. The first article predicts sub-population dynamics on Firmihin where the ha sample plot inventory was carried out. Tree growth and mortality simulation has been created using a time horizon of 100 years. The second article is focused on growth dynamics of seedlings growing ex situ under controlled conditions. One hundred plants from Firmihin and Skand have been measured once a week for two years. The differences in growth dynamics and mortality for both groups of young plants in ex situ were evaluated. The third article also relates to Dragon's Blood Tree regeneration and deals with a possibility of in-situ regeneration in the fenced area on Shibehon Plateau compared to Oam al-Cora school grounds. The team from Mendel University in Brno planted hundreds of seedlings in 2006, ever since the monitoring of growth dynamics and mortality continues. The fourth article deals with anatomy of secondary thickening plant organs. Xylem, phloem, parenchyma and vessels area of root, stem and branch was determined using 70 permanent microscope slides and processed by image analysis. The results were evaluated, compared and graphically interpreted.

Keywords: *Dracaena cinnabari*, population dynamics, growth dynamics, secondary thickening

Obsah

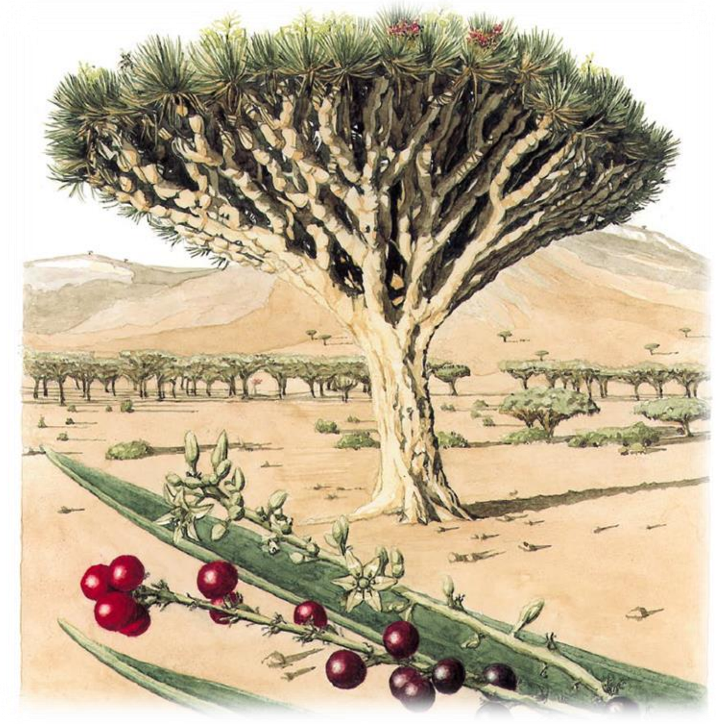
1. ÚVOD

Endemická rostlina dračinec rumělkový, známá také jako „strom dračí krve“, je symbolem a významným vlajkovým druhem jemenského ostrova Sokotra. Jedná se o druhotně tloustnoucí, jednoděložnou rostlinu, pocházející z období třetihor. Reliktní populace na Sokotře patří k nejstarším na Zemi (Attore, 2007; Culek, 2013; Maděra a kol. 2011). Druh byl pojmenován podle mízy specifické červenohnědé barvy, která se označuje jako „dračí krev“ nebo také „cinnabar“ (Miller a Morris, 1988). Její výjimečné účinky popisují už Balfour (1882b), Milburn (1984) nebo Naumkin (1993), podle nichž místní obyvatelé mízu používali v léčitelství jako antiseptikum nebo jako barvivo. Autoři uvádějí, že již od středověku byla dračí krev ceněným obchodním artiklem a vyvážela se do celého světa včetně Říma a dalších evropských států, kde se s ní lakovaly hudební nástroje včetně legendárních Stradivariho houslí. Autoři rovněž popisují, jak římští gladiátoři používali „cinnabar“ jako koagulant pro úpravu vody a všelék na žaludeční potíže a horečky.

Dračinec rumělkový se stromovým habitem významně liší od většiny druhů z rodu *Dracaena*, pro které jsou na základě způsobu uchování meristematických pletiv během nepříznivých období charakteristické odlišné strategie růstu a vývoje. Dominantními životními formami jsou nanofanerofyty a geofyty, pouze šest druhů včetně dračince rumělkového lze považovat za makrofanerofyty (Habrová a kol. 2009). Druh je adaptovaný na aridní až semiaridní klima ovlivněné oceánským podnebím, které panuje na ostrově (Jeník a Pavliš, 2011). Vyjma období monzunů jsou jediným zdrojem vláhy pouze horizontální srážky v podobě mlh a rosy (Miller a Morris, 2004; Scholte a De Geest, 2010).

Unikátní přírodní ekosystémy a impozantní krajinné scenérie Sokotry odpradávna lákaly badatele i turisty z celého světa. Zájem o přírodní bohatství a vysoká biodiverzita ostrova vedly k vyhlášení Sokotry biosférickou rezervací UNESCO v roce 2003 a zařazení na Seznam světového přírodního dědictví UNESCO v roce 2005 (Cheung a DeVantier, 2006; Scholte a kol. 2011). Od 90. let 20. století se ostrov zpřístupnil vědcům a cestovatelům. Od roku 1999 se na záchraně ohroženého endemitu podílí i výzkumný tým z Lesnické a dřevařské fakulty Mendelovy univerzity v Brně s cílem zajistit trvale udržitelný rozvoj, tj. zlepšování životní úrovně místních obyvatel při zachování přírodních hodnot a biologické rozmanitosti.

Studie dokazují, že dračince pokrývaly v minulosti mnohem větší území ostrova a tvořily dominantní složku vegetace (Attore a kol. 2007). Současný výskyt je vázán na vyšší polohy ostrova, pro něž je typická kondenzace vodních par (Adolt a kol. 2012; Brown a Mies, 2012; Habrová a kol. 2009; Král a Pavliš, 2006; Petroncini, 2001). Zbylé sub-populace jsou přestárlé a postupně odumírají (Adolt a Pavliš, 2004; Mies, 2001; Miller a Morris, 2004). Zásadním problémem je absence přirozené obnovy, převažují dospělí a přestárlí jedinci. Se zmlazením se lze setkat pouze na nepřístupných místech v horských polohách. Příčin tohoto fenoménu je zřejmě několik a mezi vědci se o nich vedou diskuse. Hlavním důvodem je pravděpodobně intenzivní spásání přemnoženými kozami (Hubálková, 2011; Miller a Morris, 2004). Attore a kol. (2007) problém přisuzuje globálním klimatickým změnám, především suchu. Za příčinu lze tedy považovat synergický efekt intenzivního spásání a aridizace klimatu (Brown a Mies, 2012). Postupné řídnutí a ústup stromovitých dračinců může mít do budoucna fatální dopad na rostlinnou diverzitu ostrova. Ochrana zbylých subpopulací je nezbytná pro zachování jedinečného charakteru krajiny Sokotry.



Obr. 1 Kresba habitu dračince, květenství a plodenství (autor M. Langman, 2012)

2. CÍL PRÁCE

Disertační práce s názvem „Ekologická studie dračince rumělkového (*Dracaena cinnabari*) na lokalitách Firmihin a Skand, ostrov Sokotra“ je svým obsahem zaměřena na dvě největší izolované sub-populace dračince rumělkového na ostrově.

Různé tematické celky spojuje společný cíl, kterým je zjišťování nových a ověřování současných poznatků z oblastí anatomie a morfologie druhu a jeho interakcí s prostředím. Součástí práce je predikce vývoje a růstové dynamiky ve stanoveném časovém horizontu, včetně návrhu obnovy dračincových porostů.

Byly stanoveny dílčí cíle, na jejichž základě je možné předpovědět vývoj populací dračince při stávajících podmínkách prostředí a při dosavadním managementu ochrany. S tímto záměrem souvisí posouzení regeneračního potenciálu druhu včetně adaptační schopnosti rostliny.

Jednotlivé dílčí cíle:

1. Predikovat vývoj sub-populace dračince rumělkového na lokalitě Firmihin v časovém horizontu 100 let.
2. Porovnat růstovou dynamiku skupin sazenic dračince rumělkového z lokalit Firmihin a Skand ex situ jako způsob uchování a ochrany genofondu obou sub-populací.
3. Vyhodnotit růstovou dynamiku skupin sazenic dračince rumělkového in situ jako způsob uchování a ochrany genofondu.
4. Popsat anatomickou stavbu druhotně tloustnoucích částí dračince rumělkového a vyhodnotit rozdíly mezi jednotlivými rostlinnými orgány (kořen – kmen – větev), posouzení z pohledu ontogenetického vývoje i ekofyziologické adaptace na prostředí.

Výše uvedené cíle byly dosaženy prostřednictvím řady metodologických postupů zahrnujících terénní mapování, odběry vzorků a zpracování vzorků v Dendrochronologické laboratoři Ústavu nauky o dřevě na Lesnické a dřevařské fakultě Mendelovy univerzity v Brně (Vichrová a kol. 2011). Měření parametrů mikroskopických struktur bylo provedeno pomocí analytického zpracování obrazu v Biometrické laboratoři Ústavu hospodářské úpravy lesa na Lesnické a dřevařské fakultě Mendelovy univerzity v Brně.

Modely zkusných ploch byly vytvořeny ve vizualizačním systému SVS (McGaughey, 2002). Následovalo statistické zpracování a interpretace dat (Cleveland a kol. 1992; R Core Team, 2013; Wickham, 2009). Metody jsou podrobně popsány v jednotlivých článcích.

3. STRUKTURA PRÁCE

Disertační práce je předložena formou kompendia čtyř článků, které byly opublikovány nebo přijaty v impaktovaných nebo recenzovaných odborných periodikách (viz Tab. 1). Texty jsou publikovány v anglickém jazyce. Ostatní kapitoly jsou v českém jazyce a jsou řazeny následovně: Úvod, Cíl práce, Struktura práce, Teoretické aspekty studované problematiky, Celkový závěr, Přílohy a Souhrnné Summary psané v anglickém jazyce. Způsob zpracování textu jako souboru uveřejněných a do tisku přijatých publikací je moderní formou disertační práce. Publikace byly vydány v mezinárodních časopisech, kde byly podrobeny procesu externího recenzování peer-review, což zaručuje kvalitu a hodnocení několika nezávislými recenzenty.

Publikace vznikaly postupně a jejich úroveň koresponduje s vývojem autora, jeho vědeckým a odborným vyjadřováním, utříděním poznatků studiem vědeckých prací s obdobnou tématikou i získáním zkušeností během terénního mapování na Sokotře, kde se realita mnohdy lišila od předem naplánovaných záměrů.

1. První článek „***Prediction of Dragon's Blood Tree (Dracaena cinnabari Balf. f.) Stand Sample Density on Socotra Island***“ predikuje vývoj sub-populace dračince rumělkového na lokalitě Firmihin jako na jediném místě na ostrově, kde se díky specifickému tvaru reliéfu dochoval zapojený porost (Brown a Mies, 2012; Miller a Morris, 2004). Provedla se podrobná inventarizace stromů na zkusné ploše o velikosti 1 ha a na základě již zjištěných poznatků o přirůstání dračinců na Firmihinu (Adolt a Pavliš, 2004; Habrová a kol. 2009) byla vytvořena modelová simulace růstu stromů a následné mortality v časovém horizontu 100 let. Článek byl publikován v roce 2011 v periodiku Journal of Landscape Ecology.

2. Druhý článek „***Growth dynamics of Dracaena cinnabari under controlled conditions as the most effective way to protect endangered species***“ je zaměřen na problematiku růstové dynamiky sazenic dračince rumělkového, pěstovaných ex situ v kontrolovaných podmínkách na Lesnické a dřevařské fakultě Mendelovy univerzity v Brně. Jednalo se o projekt, během něhož se pravidelně jednou týdně po dobu dvou let měřily přírůsty

nadzemní části u sta sazenic z Firmihinu a ze Skandu. Obě lokality charakterizují specifické stanovištní podmínky a niance v habitu dračinců (Brown a Mies, 2012). Ostrá (2014) však vyvrátila hypotézu genetické variability obou sub-populací. Zároveň s rozdíly v růstové dynamice obou skupin rostlin pěstovaných ex situ se zkoumala reakce sazenic na odlišné klimatické podmínky střední Evropy, jako je například vliv světla během střídání ročních období. Článek byl přijat v roce 2015 v periodiku Saudi Journal of Biological Sciences.

3. Třetí článek „***Growth dynamics of artificial afforestation of endangered, endemic Dracaena cinnabari in situ on Socotra Island***“ se rovněž týká možností obnovy dračince rumělkového. Na rozdíl od předchozí publikace řeší možnost regenerace in situ, a to na plató Shibehon, kde tým Mendelovy univerzity v Brně založil v roce 2006 oplocenku o výměře 1 ha. Do oplocenky vysadil 715 tří až pětiletých sazenic a v roce 2009 zde nainstaloval automatizovanou klimatologickou stanici. Kolektiv autorů ve studii souhrnně publikuje výsledky hodnocení růstové dynamiky v závislosti na specifických podmínkách dané lokality. Výsledky z Shibehonu porovnává s výsledky z oplocené zahrady 30 km vzdálené školy Oam al-Cora, kde v roce 2006 tým rovněž realizoval výsadbu dračincových sazenic. Obě lokality jsou svým způsobem jedinečné a vzájemně porovnatelné, protože díky oplocení a pravidelné kontrole místními obyvateli je zabráněno okusu kozami. Článek byl podán v roce 2016 do periodika Conservation Biology.

4. Čtvrtý článek „***Preliminary anatomical study on secondary thickening parts of endemic Dracaena cinnabari Balf.fil. from the Socotra Island***“ řeší velmi málo studované téma anatomie sekundárně tloustnoucích částí této jednoděložné rostliny. Celkem 15 vzorků kořene, kmene a větve pochází z čerstvého vývratu z plató Firmihin. Ze 70 trvalých mikropreparátů byla analýzou obrazu zjištěna plocha xylému, floému a parenchymu. Zároveň se změřila plocha lumenu cév. Hodnoty se vzájemně porovnaly a posoudily z pohledu ontogenetického vývoje a ekofyziologické adaptace na podmínky prostředí. Článek byl podán v roce 2016 do periodika Wood Research.

U všech publikací je autorka uvedena jako jeden z hlavních autorů (Tab. 1). Zásadním způsobem se podílela na veškerých aktivitách, včetně sběru vzorků, zpracování a vyhodnocení dat a jejich interpretaci. U tří ze čtyř studií je hlavní autorkou a má stěžejní podíl na jejich tvorbě. U článku „Growth dynamics of *Dracaena cinnabari* under controlled conditions as the most effective way to protect endangered species“ byla analýza dat významnou mírou realizována Ing. Danielem Volaříkem, Ph.D. U článku „Preliminary anatomical study on secondary thickening parts of endemic *Dracaena cinnabari* Balf.fil. from the Socotra Island“ se na analýze dat významnou měrou podíleli RNDr. Pavel Mazal, Ph.D. a RNDr. Martin Duchoslav, Ph.D. U článku „Growth dynamics of artificial afforestation of endangered, endemic *Dracaena cinnabari* in situ on Socotra Island“ je autorka uvedena jako jeden z hlavních autorů. Podílela se na terénním sběru dat, na psaní manuscriptu a jeho revizi (viz Tab. 1)

Tab. 1 Seznam publikací zařazených do disertační práce

NÁZEV	**TYP**	**PERIODIKUM**	**STAV, ROK**	**AUTORSKÝ PODÍL**
Prediction of Dragon's Blood Tree (*Dracaena cinnabari* Balf.) Stand Sample Density on Socotra Island	článek v recenzovaném časopise	Journal of Landscape Ecology (2011), Vol: 4 / No. 2	vydaný, 2011	Hubálková, I. (100 %)
Growth dynamics of *Dracaena cinnabari* under controlled conditions as the most effective way to protect endangered species	článek ve vědeckém časopise s impakt faktorem	Saudi Journal of Biological Sciences, doi:10.1016/j.sjbs.2015.09.011	v tisku, 2015	Hubálková, I. (70 %); Maděra, P.; Volařík, D.
Growth dynamics of artificial afforestation of endangered, endemic *Dracaena cinnabari* in situ on Socotra Island	článek ve vědeckém časopise s impakt faktorem	Conservation Biology	v recenz. řízení, 2016	Maděra, P.; Habrová, H.; Šenfeldr, M.; Hubálková, I. (20 %); Lvončík, S.; Ehrenbergerová, L.; Roth, M.; Nadězdina, N.; Němec, P.; Rosenthal, J.; Pavliš, J.
Preliminary anatomical study on secondary thickening parts of endemic *Dracaena cinnabari* Balf.fil. from the Socotra Island	článek ve vědeckém časopise s impakt faktorem	Wood Research	v recenz. řízení, 2016	Hubálková, I. (70 %); Duchoslav, M.; Houška, J.; Kubíček, J.; Mazal, P.; Pavliš, J.; Pohořalý, J.; Vichrová, G.

4. TEORETICKÉ ASPEKTY STUDOVANÉ PROBLEMATIKY

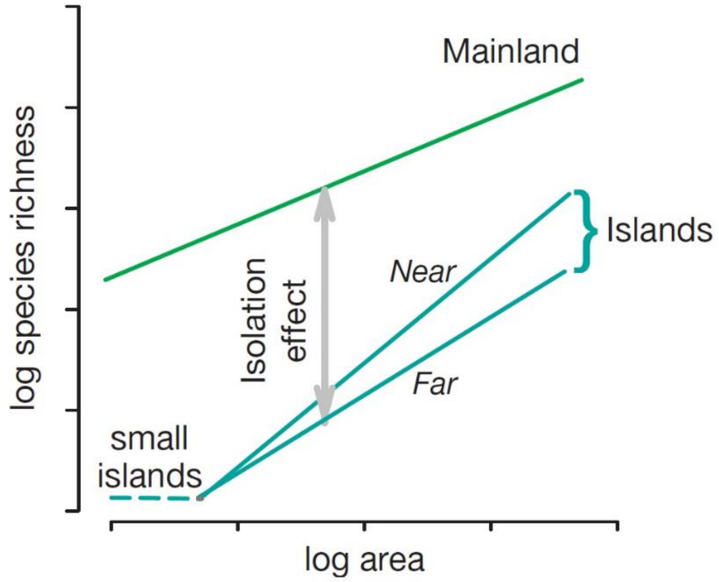
4.1 OSTROVNÍ EKOLOGIE

4.1.1 Teorie ostrovní biogeografie

Autoři Stuessy a Ono (2008) ve své publikaci o proměnlivosti a evoluci ostrovní vegetace trefně považují ostrovy v oceánech za jedny z nejzajímavějších ekosystémů na Zemi a zároveň jedny z nejvhodnějších míst k pochopení zákonitostí biologické rozmanitosti.

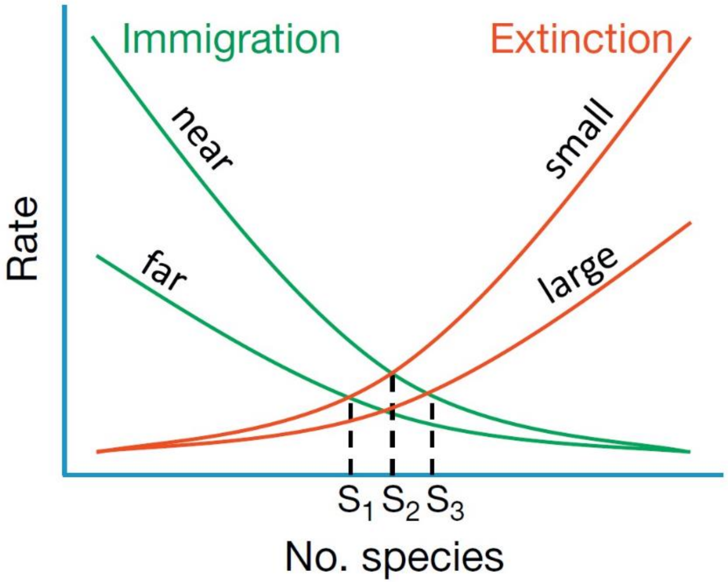
Díky izolovanosti se biodiverzita ostrovů výrazně liší od biodiverzity pevniny, a to i v případě podobných fyzicko-geografických podmínek prostředí (Guo, 2015). Simberloff (1974) uvádí, že až 5 % celkové plochy Země pokrývají ostrovy a souostroví.

V roce 1967 představili autoři R. MacArthur a E. O. Wilson teorii, která umožňovala charakterizovat a predikovat chování ostrovních společenstev (Warren a kol. 2014). Jejich teorie se opírala o tři základní charakteristiky izolovaných biot: vztah mezi počtem druhů na ostrově a velikostí ostrova (species-area relationship), vztah mezi počtem druhů na ostrově a izolovaností ostrova (species-isolation relationship) a o obměnu druhů (species turnover) (Masarykova univerzita, 2016; Warren a kol. 2014). Jak je patrné z Obr. 2, pro ostrovy je charakteristická strmější křivka 'velikost území-počet' druhů než pro pevninu.



Obr. 2 Teorie ostrovní biogeografie zohledňující velikost území a míru izolovanosti ostrova (vzdálenost od pevniny). Krátká přerušovaná linie znázorňuje malý ostrov s absencí vhodných biotopů. (Lomolino a kol. 2006 In Guo, 2015)

Teorie vycházející z předpokladu, že počet druhů na ostrově je určen dynamickou rovnováhou mezi imigrací a extinkcí, je znázorněna na Obr. 3.



Obr. 3 Rovnovážná teorie ostrovní biogeografie. Průsečíky S_1, S_2 a S_3 představují stabilní rovnováhu ostrovů různé velikosti a vzdálenosti od pevniny. V případě zvýšení nebo poklesu počtu druhů z S_2 na S_1 nebo S_3 se stav vrátí do rovnováhy (Guo, 2015).

Rovnovážná teorie MacArthura a Wilsona upozornila nejen na to, že populace opravdu vymírají, ale hlavně na to, že znalost dynamiky vymírání a kolonizace je důležitá pro pochopení interakcí jednotlivých složek životního prostředí (Storch, 2000). V textu Masarykovy univerzity (2016) je uvedeno, že křivka imigrace klesá z maximální hodnoty, kdy se na ostrově nevyskytuje žádný druh (všechny příchozí druhy jsou tedy nové a zvyšují tak počet druhů na ostrově), až k hodnotě nulové, kdy se na ostrově vyskytují všechny druhy, přítomné ve zdrojové oblasti či oblastech (žádný příchozí druh již tedy nezvýší počet druhů na ostrově). Křivka extinkce stoupá z nulové hodnoty, kdy se na ostrově nevyskytují žádné druhy, k maximu, kdy je ostrov zaplněn druhy ze zdrojového území (může vymizet maximální počet druhů). Obměna druhů v území je pak určována tvarem obou křivek (Obr. 3). Guo (2015) dodává, že na rozdíl od grafické interpretace, jsou křivky imigrace a extinkce s největší pravděpodobností protisměrně asymetrické a jejich pozice a tvary se mohou napříč ostrovy i taxony významně lišit. Guo (2015) a Masarykova univerzita (2016) upozorňují, že model na Obr. 3 nezohledňuje druhovou bohatost daného území tak jako model na Obr. 2, ale ukazuje a předvídá pouze celkový počet druhů, který se na ostrově vyskytuje.

Extinkce druhů se tedy teoreticky zvyšuje se stoupajícím počtem druhů. Jak glosuje Pâslaru (2014), velikosti populací budou na menších ostrovech nižší, proto je na nich pravděpodobně extinkce rychlejší.

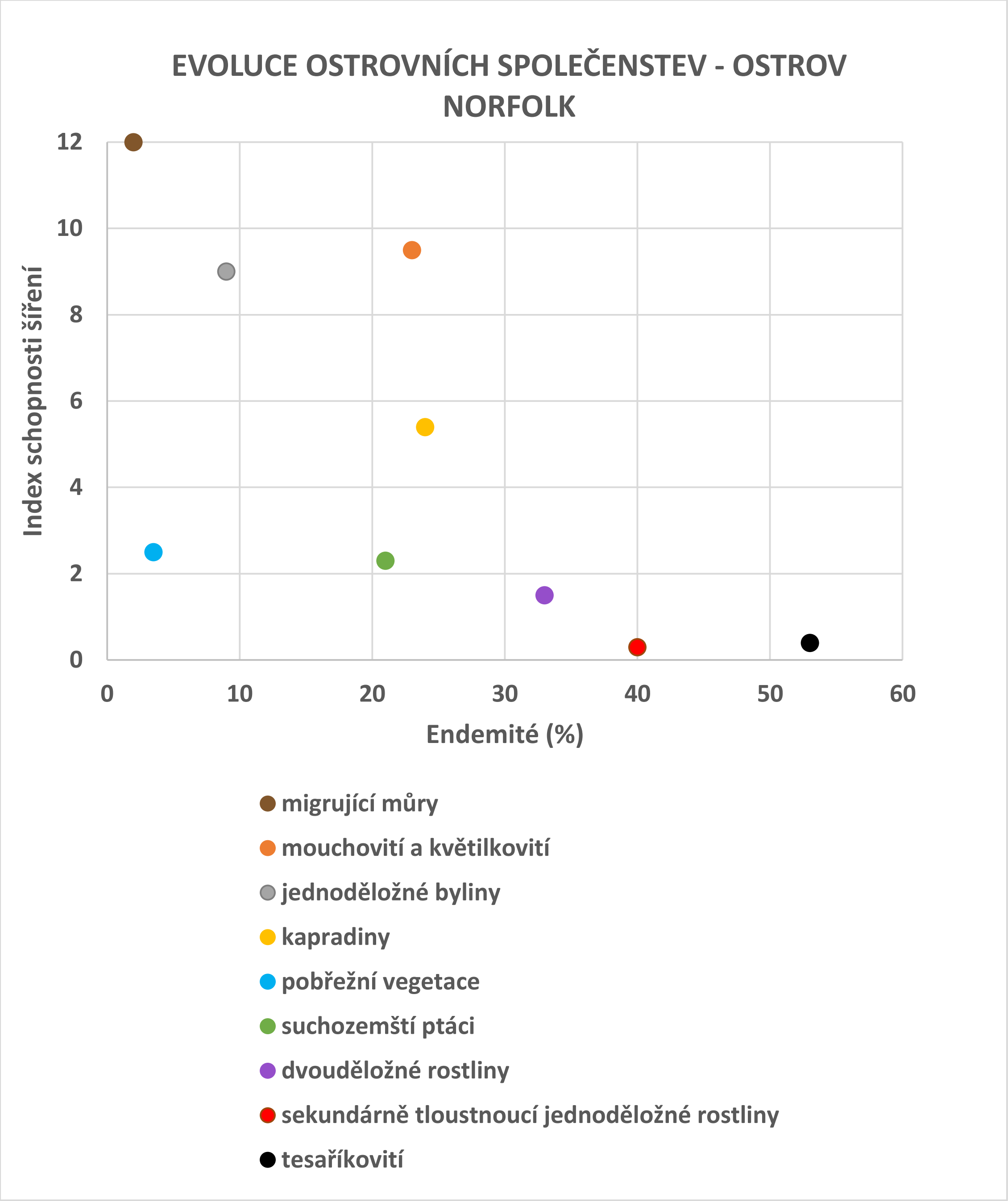
Princip biogeografické teorie ostrovů má podle Míchala (1994) základní význam pro teorii dynamické rovnováhy společenstev organismů a lze ji zobecnit takto:

1. Počet druhů na ostrově se časem ustaluje na úrovni, která je výsledkem nepřetržité dynamiky druhového bohatství, kdy některé druhy na ostrově vymírají a jiné imigrují.
2. Velké ostrovy mají obvykle větší druhové bohatství než malé. Při překročení minimální velikosti ostrova se na něm nemůže ustavit druhově vyrovnané společenstvo, a tuto minimální velikost lze odhadnout.
3. Druhové bohatství obvykle klesá s rostoucí vzdáleností nejbližšího ostrova.
4. Druhové bohatství území, jež bylo ekologicky součástí přírodního kontinua, se přeměnou v malý ostrov zákonitě sníží. Pro trvalou existenci a rozvoj potřebuje takový ostrov zdroje k dosycování svého druhového inventáře

z jiných ostrovů v přijatelné vzdálenosti, která musí odpovídat biologickým vlastnostem jednotlivých druhů. (Např. Lomolino a kol. 2006, MacArthur, 1972; MacArthur a Wilson, 1967; Míchal, 1994; Warren a kol. 2014)

4.1.2 Efekt odlehlosti

Na efekt odlehlosti je třeba pohlížet ze dvou hledisek. Fyzická izolace je odlišný pojem od relativní vzdálenosti pro různé typy organismů (odlehlost pro živočichy jako např. pro ptáky se liší od odlehlosti pro rostliny). Rychlost evoluce některých druhů na izolovaných a odlehlých ostrovech může v některých případech převyšovat rychlost imigrace (Holloway, 1977; Biogeografie, 2016; Mueller-Dombois a Fosberg, 1998). Toto tvrzení platí pro endemické druhy (Obr. 4). Holloway 1977 uvádí, že hůře se šířící skupiny taxonů na příkladu ostrova Norfolk mají větší podíl endemitů a s větší pravděpodobností se zde vyskytují druhy původem z Nové Kaledonie nebo Nového Zélandu. Výskyt druhů ze vzdálenější Austrálie je méně častý. Obecně platí, že taxony s nižší schopností šíření bývají vázané na jednu nebo více nepříliš od sebe vzdálených lokalit (typické např. pro tesaříkovité nebo jednoděložné sekundárně tloustnoucí rostliny). Opak lze podle Hollowaye (1977) tvrdit v případě taxonů s dobrou schopností šíření, kam se řadí můry, mouchy nebo jednoděložné rostliny bez schopnosti sekundárního tloustnutí.



Obr. 4 Evoluce ostrovních společenstev na příkladu ostrova Norfolk (Holloway, 1977). Pozn. Podle autora představuje Index schopnosti šíření ('Index of dispersal ability') normalizovanou míru rozptylu rozdělení pravděpodobnosti a pohybuje se ve škále 0-10, kdy 10 znamená vysokou schopnost šíření

4.2 DYNAMIKA DRUHOVÉHO BOHATSTVÍ ORGANISMŮ

Přírodní ekosystémy jsou neustále vystaveny změnám v druhové diverzitě. Příčiny extinkcí napříč historickými obdobími planety Země byly podle mnohých autorů, výsledkem náhlých změn prostředí (Gaston a Spicer, 2004; Santucci, 2005). Současné vymírání řady druhů, ať už na lokální nebo globální úrovni, je podle nich z velké míry ovlivněno antropogenními vlivy, jmenovitě způsobem využívání krajiny, biologickou invazí, atmosférickými a environmentálními změnami. Nebezpečí ztráty biodiverzity spočívá zvláště v její ireverzibilitě.

4.2.1 Ekologické faktory

Druhová diverzita určitého území souvisí s působením ekologických a historických faktorů, zejména se zeměpisnou polohou, mírou izolovanosti území a historickou biogeografií (Lobo a Halffter, 2000; Santucci, 2005; Wiens a Donoghue, 2004). Existence a vývoj organismů probíhá v rámci ekosystémů různého řádu. Míchal (1994) zastává názor, že extinkce jediného druhu rostliny znamená podle zoologů zánik nejméně pěti závislých druhů hmyzu jako konzumentů a mnoha druhů specializovaných parazitů. Ztráta genetické diverzity je podle něho mnohem významnější, než plyne z pouhé četnosti druhů. Jak výstižně uvádí Hendrych (1984), ekologické faktory obecně umožňují existenci určitých druhů a současně limitují jejich rozšíření. Jejich působením dochází ke vzniku evolučních přizpůsobení i nedědičných změn. Autoři Guo (2015) a Olyarnik a kol. (2009) se shodují v názoru, že diverzita každého společenstva je určena množstvím druhů, které mohou na stanoviště kolonizovat a biotickými a abiotickými faktory, které určují, zda druh na daném místě přežije.

Sala a kol. (2000) predikovali vývoj biologické rozmanitosti 10 terestrických a 2 sladkovodních biomů v celosvětovém měřítku v horizontu následujících 100 let.

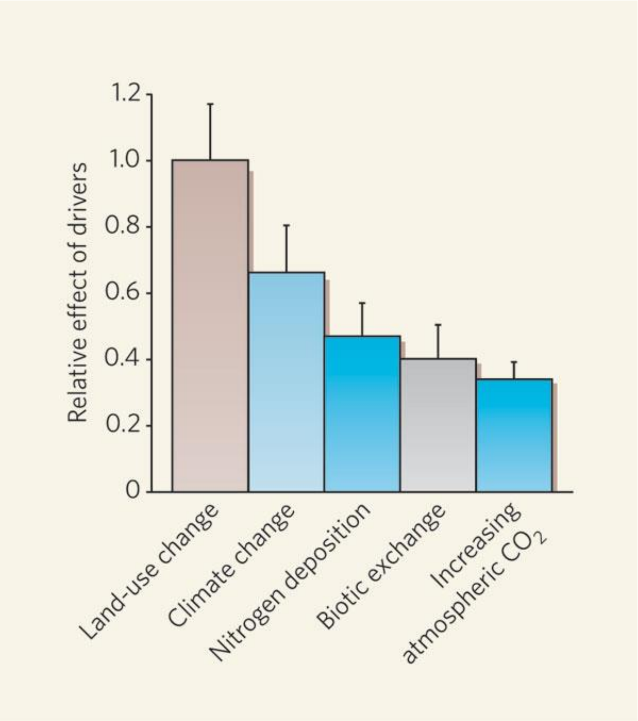
Autoři porovnávali změny pěti faktorů:

1. změna ve využití půdy (zejména ztráta stanovišť a deforestace)
2. změna klimatu
3. změna v depozicích dusíku

4. biotická výměna

5. změna v množství CO_2 v atmosféře

Pro odhad a porovnání změn použili škálu 5 hodnot, kdy 1 značila malou změnu a 5 změnu značnou (viz Obr. 5).



Obr. 5 Odhad relativních vlivů nejvýznamnějších rizik pro globální biodiverzitu v horizontu následujících 100 let (Sala a kol. 2000 In Thuiller 2007)

Výsledky ukazují, že změny ve využití půdy mají, a do budoucna budou mít, zásadní vliv na celkovou biodiverzitu. Jednotlivé hodnoty míry rizik se liší v závislosti na ekosystému. Na základě odhadů Sala a jeho kolegů (Sala a kol. 2000) je zřejmé, že arktické, alpinské a boreální ekosystémy budou v následujících 100 letech zásadně ovlivňovány klimatickými změnami, zatímco sub-tropické, tropické, pouštní oblasti a mediterán se budou potýkat s následky změn ve využívání krajiny. Další rizika v těchto oblastech mohou představovat klimatické změny a šíření invazních druhů. Biotická výměna je podle nich zásadní hrozbou sladkovodních ekosystémů.

4.2.2 Adaptace rostlin na podmínky prostředí

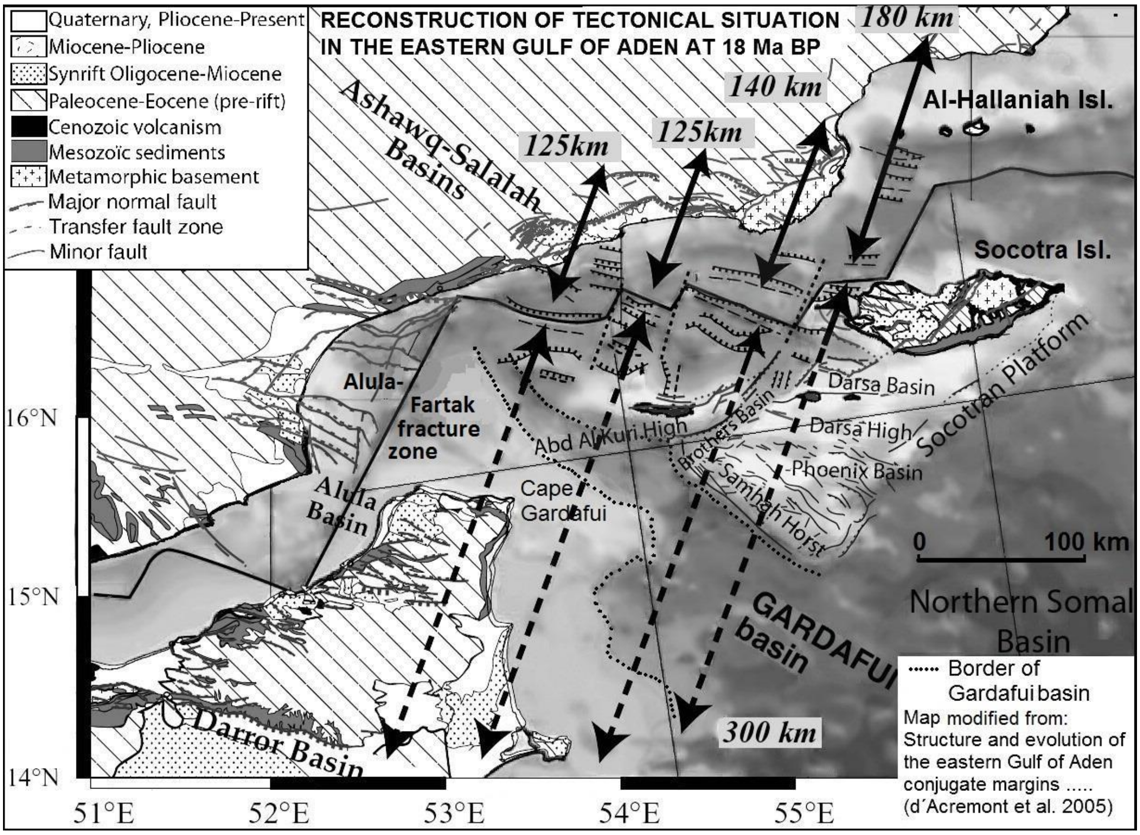
Organismy žijící v prostoru vstupují do vzájemných interakcí. Síť mezidruhových vztahů ve společenstvu je podle Hejcmana (2016) výsledkem dlouhého koevolučního vývoje a je jedním z mechanismů vzniku nových adaptací. Významnou interakcí související s ostrovním pravidlem je vzájemná kompetice, jejíž sílu mezi dvěma druhy určuje to, do jaké míry se překrývají jejich ekologické niky a dostupnost čerpaných zdrojů. Hejcman (2016) dále podotýká, že výsledkem asymetrické kompetice může být úplné vyloučení druhu z ekosystému, vyšší rostliny například mohou potlačit ty nižší. Jeho tvrzení doplňuje Rejžek (2016) faktem, že vztah mezi druhy může být i symbiotický a komenzální. Jako příklad Rejžek (2016) uvádí růst keře *Euryops arabicus* pod korunou *Dracaena cinnabari* na Sokotře.

4.3 FYTOGEOGRAFIE OSTROVA SOKOTRA

Šerý (2013) upozorňuje na skutečnost, že Sokotra je největším kontinentálním ostrovem Sokotránského souostroví, druhým největším pevninským ostrovem a celkově druhým největším africkým ostrovem, přestože rozloha Sokotry je v porovnání s Madagaskarem 163krát menší. Zároveň dodává, že z politicko-geografického hlediska je ostrov integrální součástí Jemenské republiky.

Fytogeografické vazby v oblasti dnešního Sokotránského souostroví podrobně popsal Culek (2013):
První biogeograficky relevantní vznik pevniny v oblasti dnešního Sokotránského souostroví započal během období staršího eocénu (před 38-34 Ma let). Některé ostrovy nezanikly následkem transgrese. Následovalo odtržení tektonických desek a vznik Adenského zálivu (před 20-17 Ma let), což bylo doprovázeno velkoplošným vyzdvihnutím litosférických desek. V tomto období mohlo naposledy dojít k šíření terestrické bioty na Sokotránské souostroví, a to s relativně vysokou pravděpodobností z africké pevniny nebo se středně vysokou pravděpodobností z dnešní oblasti Arábie. Celkové vypařování Rudého moře (před 11-5 Ma let) umožnilo migraci terestrických druhů do a z Arábie přes Somálsko. Možné migrační bariéry mohly představovat kanály

„Guardafui“ a „The Brothers“ (Obr. 6). Posledním a nejvýznamnějším procesem byl zdvih pohoří Haggeher v centrální části Sokotry, který nastal koncem miocénu (před 9-6 Ma let). Pravděpodobně se jednalo o poslední možnost migrace druhů napříč fragmenty pevniny mezi kanály „Guardafui“ a „The Brothers“. V období čtvrtohor výrazně kolísala hladina moře, což mělo vliv na tvar a velikost ostrova (Culek, 2013; Maděra a kol. 2011). Výše uvedené kanály zůstaly zachovány a mezi pevninou a Sokotránským souostrovím představovaly migrační bariéru pro nepůvodní druhy. Izolovanost jednotlivých ostrovů v rámci souostroví vedla k výrazným rozdílům v potenciální biotě daným geografickou polohou (Culek, 2013). Ve čtvrtohorním pleistocénu (před 2 Ma let) se okolo pobřeží Sokotry začaly formovat pobřežní a mořské sedimenty včetně korálových útesů (Herman-Izycki a Dul, 2011; Maděra a kol. 2011).



Map modified from: Structure and evolution of the eastern Gulf of Aden conjugate margins ..... (d´Acremont et al. 2005)

Obr. 6 Rekonstrukce tektonické situace ve východní části Adenského zálivu před 18 Ma let (Culek, 2013)

4.3.1 Vegetace Sokotry

Sokotra náleží do paleotropické oblasti, která se rozkládá na převážné části Afriky, Indie, jižní Asie a Indonésie (Botany, 2016; Hendrych, 1984). Podle uvedených zdrojů se jedná o floristicky bohatou oblast s výskytem okolo 40 endemických čeledí, rozdělenou kontinentálním driftem (Obr. 6). Oblast se dělí do 13 podoblastí, Sokotra je součástí Súdánsko-zambezijské oblasti a Sokotranské provincie (Botany, 2016).

Podle Miller a Morris (2004) je rozmanitost bioty Sokotry výsledkem dlouhodobého geologického vývoje, miliony let trvající izolace od pevniny a adaptace organismů na extrémní klimatické podmínky. Maděra a kol. (2011) uvádí, že Sokotra patří mezi 10 ostrovů světa s nejvyšším podílem endemických druhů. Poznatky druhové diverzity rostlin shrnují Brown a Mies (2012). Podle nich je v současnosti na souostroví determinováno 842 endemických druhů cévnatých rostlin, z nichž některé jsou již pravděpodobně vyhynulé. Míra endemismu u cévnatých rostlin tak dosahuje více než 37 %. Na souostroví se dále nachází okolo 30 druhů kapradin, 1 nahosemenná rostlina (*Ephedra foliata* Boiss. Ex C.A. Mey.), 180 jednoděložných rostlin a 631 dvouděložných rostlin (Brown a Mies, 2012). Zmínění autoři uvádí mezi nejpočetnější čeledi: *Poaceae* (100 druhů), *Fabaceae* (72 druhů), *Asteraceae* (57 druhů), *Acanthaceae* (34 druhů), *Euphorbiaceae* (34 druhů), *Apocynaceae* s *Asclepiadoideae* (30), *Boraginaceae* (29 druhů), *Cyperaceae* (27), *Malvaceae* (25), *Convolvulaceae* (24), *Scrophulariaceae* (23) a *Rubiaceae* (22). Přestože je pro ostrovy většinou typická menší druhová diverzita na jednotku plochy než na pevnině (Whittaker a Fernández-Palacios, 2007 In Brown a Mies, 2012), Sokotra tvoří v tomto smyslu výjimku (Cronk, 1997 In Brown a Mies, 2012). Cronk (1997) přisuzuje vysokou ostrovní biodiverzitu (1) blízkosti Sokotry k Arábii a Somálsku, (2) geodiverzitě ostrova, (3) specifickým klimatickým podmínkám, (4) ekologické diverzitě spojené s výrazným výškovým převýšením od 0 m n. m. (mořská hladina) po 1 526 m n. m. (hora Jabal Dryet v centrálním pohoří Haggeher), (5) dlouhodobému geologickému vývoji a afiliaci s přilehlým Arabským poloostrovem (351 km) a severo-východní Afrikou (232 km), (6) stabilitě krajiny v období holocénu a benignímu obhospodařování, které ještě nedávno zaručovalo uchování jedinečné ostrovní biodiverzity.

Vegetační typy, které se vyskytují na ostrově, vymezili Miller a Morris (2004) a jsou popsány v Tab. 2.

Tab. 2 Vegetační typy Sokotry (Miller a Morris, 2004)

TYPY	**SUB-TYPY**	**TOPOGRAFIE**	**NADM. VÝŠKA**	**CHARAKTERISTIKA**	**DOMINANTNÍ DRUHY**
pobřežní vegetace	mangrovy	pobřežní zátoky, brakické oblasti	hladina moře	mangrovové houštiny (výška 5m)	*Avicennia marina*
pobřežní vegetace	vegetace mělkých pobř. oblastí	pobřežní jemné i hrubší sedimenty	hladina moře	mozaika nízkých sukulentních keříků (h 1,5 m), společenstva dřevnatících bylin (h 0,5 m) a hloučky křovin (výška 3 m)	*Limonium* spp., *Tamarix nilotica*, *Suaeda* spp., *Atriplex* spp.
křoviny (*Croton*) v nížinách		pobřežní a vnitrozemní oblasti	0-100 m n. m.	křoviny opadavých druhů (h 2,5 m) místy s vyššími (h 5 m) a v podrostu s nižšími keři (h 1 m); v případě intenzivního spásání dominance bylinného patra zastoupeného zejména druhy *Cassia holosericea* a *Tephrosia apollinea*	*Croton socotranus*
sukulentní vegetace		skály a vápencové srázy, skalnaté svahy a žulové nebo vápenc. kopce, strmé stěny vádí	0-150 (-500) m n. m.	rozvolněná opadavá sukulent. společenstva (h <4m) s emergentními stromy (h <6m), nízkou polštářovou vegetací a polokeři (h <1m)	*Jatropha unicostata*, *Croton socotranus*, *Euphorbia arbuscula*, *Adenium obesum*, *Teophrosia apollinea*
poloopadavé řídké porosty na srázech v nižších polohách a v roklích		strmé vápenc. srázy, chráněná území vápenc. plošin, občas se vyskytující na žul. podloží (Homhil)	150-750 m n. m.	poloopadavé houštiny (h <5m) s emergentními stromy (h <8m)	*Rhus thyrsiflora*, *Buxanthus pedicellatus*, *Carphalea obovata*, *Sterculia africana*
společenstva sekundárně tloustnoucích bylin na vápenc. plošinách		vápencové plošiny	500-720 m n. m.	mozaika sekundárně tloustnoucích bylin (h <0,5m), travinných a keříčkovitých společenstev (h <2m); místy výskyt reliktních porostů, typicky s *Dracaena cinnabari* a *Boswellia elongata*	*Jatropha unicostata*, *Lycium sokotranum*, *Gnidia socotrana*, *Cocculus balfourii*
mozaika horských stálezelených porostů, travin, nízkých keřových společenstev a polštářové vegetace		exponované vrcholy, skalní svahy, rokle a ostrůvky travin na žul. podloží	950-1500 m n. m.	mozaika hustých stálezelených porostů a houštin (h <5 m), travin, nízkých keřů (h <1,5 m) a polštářové vegetace na exponovaných vrcholech	*Dracaena cinnabari*, *Rhus thyrsiflora*, *Hypericum species*, *Helichrysum species*, *Euryops arabicus*

4.3.2 *Dracaena cinnabari* Balf. f.

Dračinec rumělkový (*Dracaena cinnabari* Balf. f.) je třetihorním reliktním endemitem a vlajkovým druhem Sokotry. Jak ve své studii potvrzuje Forrest a kol. 2013, druh byl poprvé zdokumentován skotským botanikem Isaacem Bayleyem Balfourem v roce 1880. Rozšíření druhu je nesouvislé s několika izolovanými sub-populacemi ve střední a východní části ostrova (Miller a Morris, 2004). Stáří porostů se odhaduje na několik stovek let, nejzachovalejší porosty se vyskytují na vápencové plošině Firmihin (390 až 760 m n. m.) a na lokalitě Skand v granitovém pohoří Haggeher (950 až 1500 m n. m.) (viz Tab. 2). Z četných studií (např. Adolt a Pavliš 2004; Attore a kol. 2007; Habrová a kol. 2009; Miller a Morris 2004; Adolt a kol. 2012 a 2013) je prokazatelné zřejmé, že četnost druhu na ostrově klesá a podle odhadů je současný výskyt omezen na 5 % potenciálního biotopu. Přestárlé porosty se s výjimkou nedostupných terénů (převážně skalních stěn) neobnovují. Absence zmlazení se přisuzuje efektu spolupůsobení více faktorů, zejména nadměrnému spásání kozami a dlouhodobé aridifikaci krajiny na ostrově (Brown a Mies 2012). Dračinec rumělkový je významným stromovitým druhem a jeho zánik synergickým vlivem stresu a disturbance by představoval významné ochuzení biodiverzity Sokotry a zároveň ochuzení rostlinného genofondu na celosvětové úrovni.

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SEZNAM ZKRATEK

IGA	Interní grantová agentura
JIF	Journal with impact factor
Ma	Miliony let
S	Species
SVS	The Stand Visualization System
UNESCO	United Nations Educational, Scientific and Cultural Organization

SEZNAM OBRÁZKŮ

SEZNAM TABULEK

V disertační práci je použita jednotná podoba geografických názvů podle Millera a Morrisové (2004) a fylogenetická klasifikace APG IV (The Linnean Society of London, 2016).

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I

6. PREDICTION OF DRAGON'S BLOOD TREE (*Dracaena cinnabari* Balf.) STAND SAMPLE DENSITY ON SOCOTRA ISLAND (KEY STUDY)

Irena Hubálková

Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Forest Botany, Dendrology and Geobiocoenology, Zemědělská 3, 613 00 Brno, Czech Republic irena.hubalkova@mendelu.cz

Abstract

Dracaena cinnabari Balf. On the Socotra Island is a spectacural relict of the Tethys tropical forest. This unique endemic plant producing medicinally valuable sap covered larger area in the past. There is no natural regeneration of this species except inaccessible localities with steep slopes. The seedlings are threatened by goats grazing. Age structure of *Dracaena* populations indicates maturity and overmaturity depending on browsing.

The objective of this work is to predict growing dynamic of Dragon's Blood Trees in permanent sample plot at Firmihin, where is the largest closed stand of *Dracaena* species. The prediction and visualization of variation in the number of trees during 100 years is based on realized direct field measurements supported by mathematical calculations. The study presents options in forest regeneration together with caution about the threats in the way of its implementation.

Key words - *Dracaena cinnabari*, Socotra, stand visualization, trees density prediction

6.1 INTRODUCTION

The Socotra Archipelago (see Fig. 1) is located in the northwestern part of the Indian Ocean. It consists from two main islands Socotra (also written Sokotra, Soqotra, Suqutra) and Abdalkuri (Abd El Kuri), and the smaller ones, Samhah and Darsa, called The Brothers, and of the rocks of Cal Farun and Hertha (Mies and Beyhl, 1996). Politically, this archipelago belongs to the Republic of Yemen. With an area of 3625 km^2 is Socotra the largest island in the Arab world (Elie, 2002), lies about 235 km east of the Horn of Africa (12°18´-12°42´ N latitude and 53°18´-54°32´ E longitude) and the highest elevations is reached in Haggeher Mountains on Socotra (over 1500 m a. s. l.).

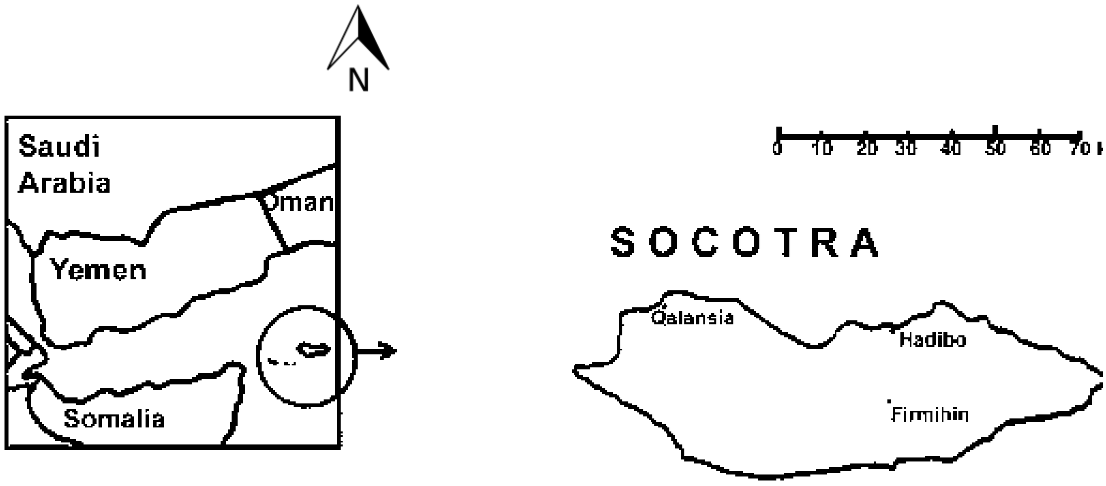


Fig. 1 – Geographical location of Socotra Island.

Many authors have provided information about climate on Socotra, but this information seems to be based on individual experience from short-term stays on island or considered from wider climatic characteristics from Indian Ocean or nearby mainlands (Habrová, 2007). According to Mies and Beyhl (1996), the islands are situated in the arid tropical zone where evapotranspiration generally surpasses precipitation by far. The climate of the ecoregion is influenced by the southwest (summer) and northeast (winter) monsoons. The south-west monsoon (from May to September) brings only humidity, the north-east monsoon (from November to March) is milder but brings expected winter rain (Fleitmann et al., 2007) and the rest of the year can be expected only dry weather conditions.

Tab. I - Annual statistics of 'daily mean values' of selected climatic variables calculated from completed values in 'ideal year' (2000-2004) at Firmihin locality (Král, 2005).

Variable	Min	Max	Mean
Air temperature [°C]	19.3	28.9	23.7
Air humidity [%]	36.6	99.5	72.6
Wind speed [m/s]	0.3	8.2	2.6
Precipitation [mm/day]	0.0	207.5	1.1

The Socotra Island is undoubtedly a most precious natural asset, not only for the Republic of Yemen, but for many people from around the world (Yucer, 1988). In 2003, the archipelago was declared the first UNESCO Man and Biosphere Reserve in Yemen, because of Socotra Island was recognised as one of the best preserved island ecosystems on Earth (Miller et al., 2006). Habrová et al. (2009) mentioned island ranking into the World Heritage Site in 2008. Separated from continent during the Tertiary period the island hosts no indigenous mammals whatsoever, but its floral endemism rate making it one of the most biodiverse island in the world (Grant, 2005). 825 species of flowering plants and ferns were recorded on the archipelago, from which 12 genera and 307 species (37 %) are thought to be endemic (Miller et al., 2006). According to Buček et al. (2004), also the majority of woody species forming natural forest, woodland and/or shrub communities ranks among endemic species. Important of them are arborescent frankincense trees (*Boswellia* sp.), myrrh trees (*Commiphora* sp.), arborescent spurges (*Euphorbia* sp.), a rare endemic shrub *Dirachma socotrana* and the only known wild pome granate species (*Punica protopunica*). Typical for Socotra are remarkable succulent woody species particularly the endemic cucumber tree (*Dendrosycios socotrana*), desert rose (*Adenium obesum,* ssp*. socotranum*) and endemic *Dorstenia gigas*. The unique vegetation formation is the evergreen woodland dominated by the famous Dragon’s Blood Tree (*Dracaena cinnabari*), Socotra’s most iconic plant (Miller at al., 2006). Socotra Island is rightly compared with Mauritius, the Galapagos or the Canary Islands. It is given by floristic richness and level of endemism. Also fauna of Socotra is rich in species and not fully investigated yet.

For thousands of years, the people of Socotra have lived with and used the biological resources in a sustainable manner (Mies and Beyhl, 1996) harvesting only what they needed and practising rotational grazing (Miller et al., 2006). However, the Socotra Archipelago with an estimated human population ranging from 40 to 80000 people is described as one of the poorest and most disadvantaged group of islands anywhere in the world (Elie, 2002). Most of people are concentrated in the capital Hadiboh and in its surroundings. They speak Socotri and Arabic. The people have survived through fishing, ranging of livestock (mostly goats) and home gardening, particularly date palms (Ceccolini, 2000). Since antiquity, the island was famous for its Dragon's Blood, obtained from the sap of *Dracaena cinnabari*, (Mies and Beyhl, 1996). Nowadays, the island is losing its isolation rapidly. This is due to industrial and tourism development.

The genus *Dracaena* comprises between 60 and 100 species and recent taxonomic ambiguity has caused its classification within three families i.e. *Agavaceae*, *Liliaceae* and *Dracaenaceae*, the latter as a family arching over the former confusion (Adolt and Pavliš, 2004). Representatives of the *Dracaena* genus have survived in woodlands on dry margins of the Tethys tropical forest since the Tertiary Period. Most of the *Dracaena* species grow as shrubs or geophytes often having ornamental potential (Adolt and Pavliš, 2004). There are some species having the growth habit of a tree: *Dracaena cinnabari* Balf. on Socotra, *Dracaena serrulata* Baker in Southwestern Arabia, *Dracaena ombet* Kotschy & Peyr in Eastern Africa, *Dracaena schizantha* Baker on Macaronesian Islands, *Dracaena draco* L. in Moricci, *Dracaena tamaranae* A. Marrero, R.S. Almeina and M. Gonzáles-Martín in Canary Islands and *Dracaena steudneri* Engl. in Ethiopia and Eastern Africa (Bekele, 2007).

Dracaena cinnabari is an evergreen tree with a typical umbrella-shaped crown due to a „dracoid" ramification of branches (Adolt and Pavliš, 2004). *Dracaena* species are exceptional among monocotyledonous plants because of their capacity for secondary thickening of stems and roots (Habrová et al., 2009). Its area of distribution ranges from an altitude of 150 m to 1600 m above sea level, it dominates above 600 m a. s. l. (Petroncini, 2001). Dragon's Blood Tree is not widely spread over the Socotra Island. It is fixed to the area of the large central plateau of Diksam, the central granite massive of Haggeher and the eastern area of Hamadero, Sirahon and Kilisan (Petroncini, 2001). Plant density is not homogenous. Analyses show that the area of *Dracaena* woodland land-cover class on Socotra reaches 3658 ha, i. e. 1.1 % of the total island area (Král and Pavliš, 2006). There is no natural seeding except of inaccessible places with steep slopes.

Multiyear activities of a Mendel University team from Brno has brought important data concerning particularly ecophysiology, phenology, morphology, growth characteristics, estimation of age, population dynamics of *Dracaena cinnabari*, site conditions or species composition. Precise geobiocoenological differentiation was created for recognizing the detailed state of natural conditions of the island (Buček, 2003). Mendel University team also installed a weather station including an automatic data logger at Firmihin in November 2000, at an approximate altitude of 440 m above sea level. According to Habrová (2007), it is clear, that only a long-term, continuous period of measurement at different locations on the island can lead to an understanding of its present climate. That is why other 5 mini-stations measuring only air temperature and air humidity were placed at different localities in 2004 (one of these 5 mini-stations has been stolen on Skand just after one month).

According to mentioned researches, the population of *Dracaena cinnabari* is getting old. Stands density decreases. There is absence of natural regeneration at most sites of natural range. The species are threatened mainly by omnipresent goat grazing, extraction of blood-red sap and fuelwood production.

6.2 MATERIAL AND METHODS

6.2.1 Data collection and field measurement

Data about Socotra Archipelago and *Dracaena cinnabari* were collected. It was focused on general information about Socotra Island (localization, climatic conditions, natural environment and nature conservation, local people and their natural resources utilization). Other part of introduction dealt with *Dracaena* genus and Socotra's most iconic plant *Dracaena cinnabari* (habit, distribution, utilization and its importance). Also the connections with causes of threats to this species were mentioned.

Field measurements were realized at Firmihin, where the largest closed stand of Dragon's Blood Trees was identified. One square sample plot with side lenght 100 m in locality of the youngest *Dracaena* trees was chosen. The inventory of each tree in sample plot was carried out. Measuring-tape for girth meassuring in 1.3 m and crown diameter, hypsometer Silva, camera and field notebook were used. Usage of laser rangefinder was expected, but the instrument was confiscated by soldiers at the airport in capital of Yemen. All trees were photographed. The central point of sample plot was located by GPS Trimble-Juno SB and stabilized by metal spile.

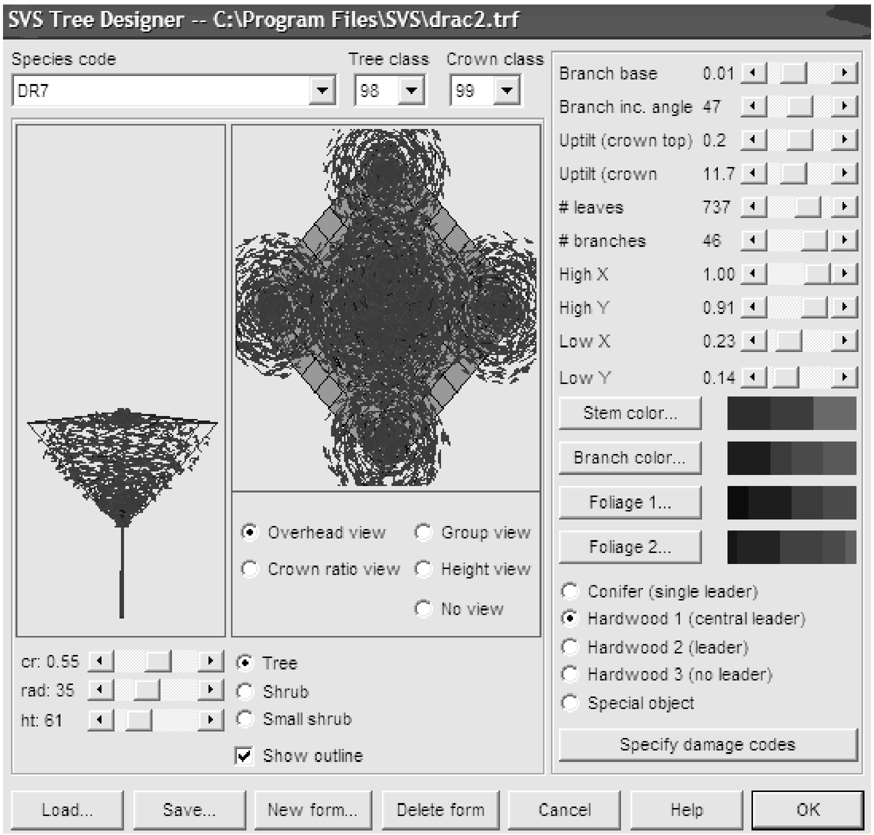
6.2.2 Data processing

Collected data were compiled in Microsoft Office Program Excel, copied to electronic scratch pad and applicated to Stand Visualization System (SVS). The scratch pad files were saved with the ending tbl (xls ending was useless). The data applicable to SVS consist of a simple stand table containing species, diameter at breast height (DBH) in cm, height in m, ratio (= crown height/tree height in m), crown radius in m, X and Y coordinates. Except these parameters 'sausage-shape' sections of branches (see Fig. 3) and circumferential inflorescence were counted during fieldwork. Also columns Tree class and Crown class were added in Microsoft Office Program Excel, which are necessary to processing in SVS.

In general, 100 tables for 100 year prediction of this sample plot were generated. Prediction of trees sample density was developed on basis of previous long-term measurement and statistical evaluation made by members of Mendel University team (Adolt and Pavliš, 2004) at Firmihin.

Next step consisted in assignment of all trees into 16 age categories by Habrová (2005) (Tab. III). The categories were called from DR16 (seed) to DR1 (the oldest trees). The number of trees in particular category provided the vector of a population (Habrová et al., 2009). The age of one branch section reaches about 19 years (Adolt and Pavliš, 2004). It was necessary to predefine tree habits with different species codes in Tree Designer of SVS (see Fig. 2). The auxiliary view in SVS Tree Designer was used to display trees as they appear in an SVS image. Every created tree form was marked with assigned species code, which allows user to make changes to the form definition parameters. The tree class list shows all the tree class values currently represented for the current species. The crown class list shows all crown class values currently represented for the current species and current tree class. It was necessary to create a new plant form for *Dracaena* sp. based on an existing form. The form usable as the model was selected and then the species, tree class and crown class for the new plant form were modified.

According to SVS Manual created by McGaughey (2002), SVS generates images depicting stand conditions represented by a list of individual stand components (e. g. trees, shrubs) using detailed geometric models. The images produced by SVS provide a readily understood representation of stand conditions.



SVS Tree Designer -- C:\Program Files\SVS\drac2.trf

Species code: DR7
Tree class: 98
Crown class: 99

Branch base: 0.01
Branch inc. angle: 47
Uptilt (crown top): 0.2
Uptilt (crown: 11.7
leaves: 737
branches: 46
High X: 1.00
High Y: 0.91
Low X: 0.23
Low Y: 0.14

● Overhead view ○ Group view
○ Crown ratio view ○ Height view
○ No view

cr: 0.55
rad: 35
ht: 61

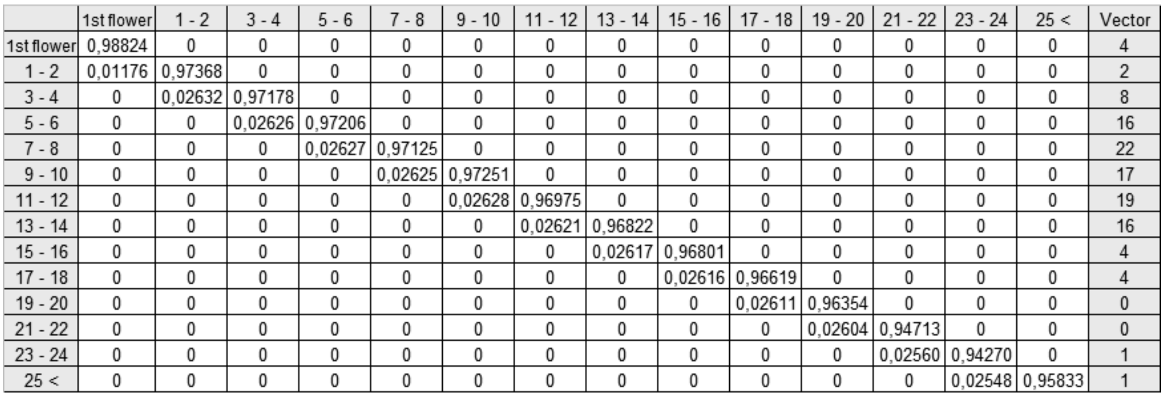
● Tree
○ Shrub
○ Small shrub
☑ Show outline

○ Conifer (single leader)
● Hardwood 1 (central leader)
○ Hardwood 2 (leader)
○ Hardwood 3 (no leader)
○ Special object

Fig. 2 – Modeling of tree age classes in SVS Tree Designer.

In order to construct a model of population development in the following years, it was necessary to compile a generally applicable matrix created by Habrová et al. (2009). The matrix (Tab. II) is 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. The matrix was multiplied by a particular vector in a numerical computing environment MATLAB (i.e., by the actual number of trees in particular categories). Graph expressing the decrease in the number of trees during 100 years was created in MATLAB by mentioned multiplying the matrix and vectors.

Tab. II - Matrix and the vector (= real number of trees fallen into each category for a given "number of narrowed branch sections").



	1st flower	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
1st flower	0,98824	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1 - 2	0,01176	0,97368	0	0	0	0	0	0	0	0	0	0	0	0	2
3 - 4	0	0,02632	0,97178	0	0	0	0	0	0	0	0	0	0	0	8
5 - 6	0	0	0,02626	0,97206	0	0	0	0	0	0	0	0	0	0	16
7 - 8	0	0	0	0,02627	0,97125	0	0	0	0	0	0	0	0	0	22
9 - 10	0	0	0	0	0,02625	0,97251	0	0	0	0	0	0	0	0	17
11 - 12	0	0	0	0	0	0,02628	0,96975	0	0	0	0	0	0	0	19
13 - 14	0	0	0	0	0	0	0,02621	0,96822	0	0	0	0	0	0	16
15 - 16	0	0	0	0	0	0	0	0,02617	0,96801	0	0	0	0	0	4
17 - 18	0	0	0	0	0	0	0	0	0,02616	0,96619	0	0	0	0	4
19 - 20	0	0	0	0	0	0	0	0	0	0,02611	0,96354	0	0	0	0
21 - 22	0	0	0	0	0	0	0	0	0	0	0,02604	0,94713	0	0	0
23 - 24	0	0	0	0	0	0	0	0	0	0	0	0,02560	0,94270	0	1
25 <	0	0	0	0	0	0	0	0	0	0	0	0	0,02548	0,95833	1

6.3 RESULTS

The research was realized on Firmihin, located in the central part of Socotra Island. The dense *Dracaena* woodland found at Firmihin is unique in the world. Exact location of the stabilized central point of the sample plot is X 175964,9968856; Y 1381889,1487503; Z 544,8 (WGS-84 reference system).

114 *Dracaena* trees were identified on selected sample plot. In average trees have had from 9 to 10 branch sections (see Fig. 3).

Tab. III - Number of trees belonging to each age category.

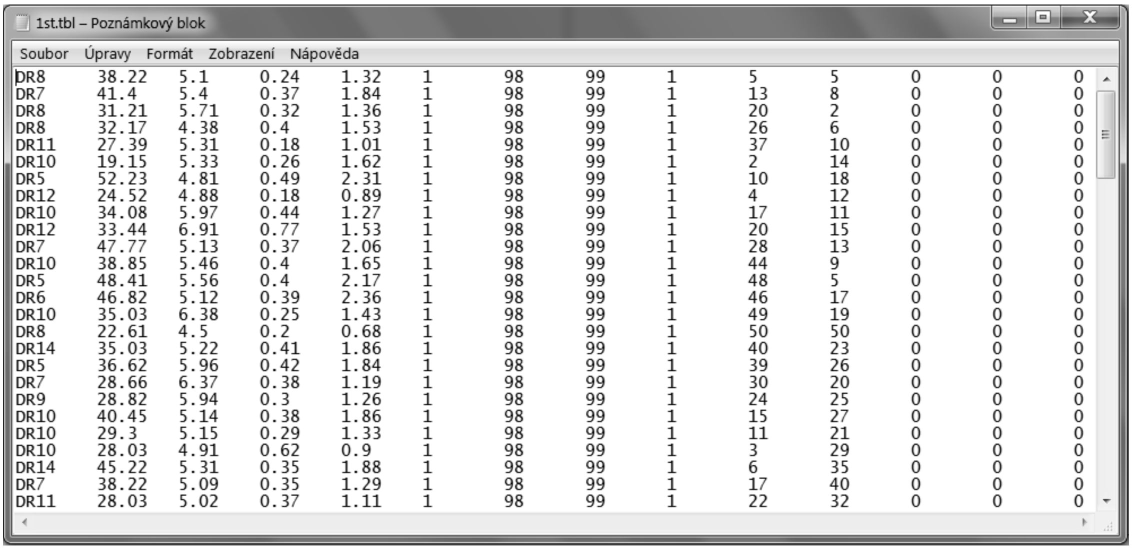
Marking of age category	Number of branch sections	Number of trees
DR16	seed	0
DR15	seedling	0
DR14	the first flowering plant	4
DR13	1 and 2	2
DR12	3 and 4	8
DR11	5 and 6	16
DR10	7 and 8	22
DR9	9 and 10	17
DR8	11 and 12	19
DR7	13 and 14	16
DR6	15 and 16	4
DR5	17 and 18	4
DR4	19 and 20	0
DR3	21 and 22	0
DR2	23 and 24	1
DR1	25 <	1

Fig. 3 – Branches segregated by narrowed 'sausage-shape' sections (photo by authoress).

As mentioned above, 100 tables for 100 year prediction of this sample plot were generated in Microsoft Office Program Excel. The data in first table (age class, DBH, height, ratio, crown radius, X a Y coordinates) showed present condition of the trees (in the year 2010). The data in hundredth table showed the same parameters 100 years later (in the year 2110). The diameter at breast height (DBH) has been averagely increasing 0.053 cm per year and crown radius 0.0089 m per year (Adolt and Pavliš, 2004).

First and last table were copied from Microsoft Office Program Excel to electronic scratch pad (Tab. IV), which is form applicable in Stand Visualization System (SVS).

Tab. IV Parameters of *Dracaena* trees in 2010 displayed in electronic scratch pad.



```
DR8     38.22   5.1     0.24    1.32    1       98      99      1       5       5       0       0       0
DR7     41.4    5.4     0.37    1.84    1       98      99      1       13      8       0       0       0
DR8     31.21   5.71    0.32    1.36    1       98      99      1       20      2       0       0       0
DR8     32.17   4.38    0.4     1.53    1       98      99      1       26      6       0       0       0
DR11    27.39   5.31    0.18    1.01    1       98      99      1       37      10      0       0       0
DR10    19.15   5.33    0.26    1.62    1       98      99      1       2       14      0       0       0
DR5     52.23   4.81    0.49    2.31    1       98      99      1       10      18      0       0       0
DR12    24.52   4.88    0.18    0.89    1       98      99      1       4       12      0       0       0
DR10    34.08   5.97    0.44    1.27    1       98      99      1       17      11      0       0       0
DR12    33.44   6.91    0.77    1.53    1       98      99      1       20      15      0       0       0
DR7     47.77   5.13    0.37    2.06    1       98      99      1       28      13      0       0       0
DR10    38.85   5.46    0.4     1.65    1       98      99      1       44      9       0       0       0
DR5     48.41   5.56    0.4     2.17    1       98      99      1       48      5       0       0       0
DR6     46.82   5.12    0.39    2.36    1       98      99      1       46      17      0       0       0
DR10    35.03   6.38    0.25    1.43    1       98      99      1       49      19      0       0       0
DR8     22.61   4.5     0.2     0.68    1       98      99      1       50      50      0       0       0
DR14    35.03   5.22    0.41    1.86    1       98      99      1       40      23      0       0       0
DR5     36.62   5.96    0.42    1.84    1       98      99      1       39      26      0       0       0
DR7     28.66   6.37    0.38    1.19    1       98      99      1       30      20      0       0       0
DR9     28.82   5.94    0.3     1.26    1       98      99      1       24      25      0       0       0
DR10    40.45   5.14    0.38    1.86    1       98      99      1       15      27      0       0       0
DR10    29.3    5.15    0.29    1.33    1       98      99      1       11      21      0       0       0
DR10    28.03   4.91    0.62    0.9     1       98      99      1       3       29      0       0       0
DR14    45.22   5.31    0.35    1.88    1       98      99      1       6       35      0       0       0
DR7     38.22   5.09    0.35    1.29    1       98      99      1       17      40      0       0       0
DR11    28.03   5.02    0.37    1.11    1       98      99      1       22      32      0       0       0
```

Graph (see Fig. 4) expresses prediction of tree density between 2010 and 2110. The graphical representation shows, that from 114 trees, approximately 73 trees will remain. Thus the number of trees will decrease by 36 %.

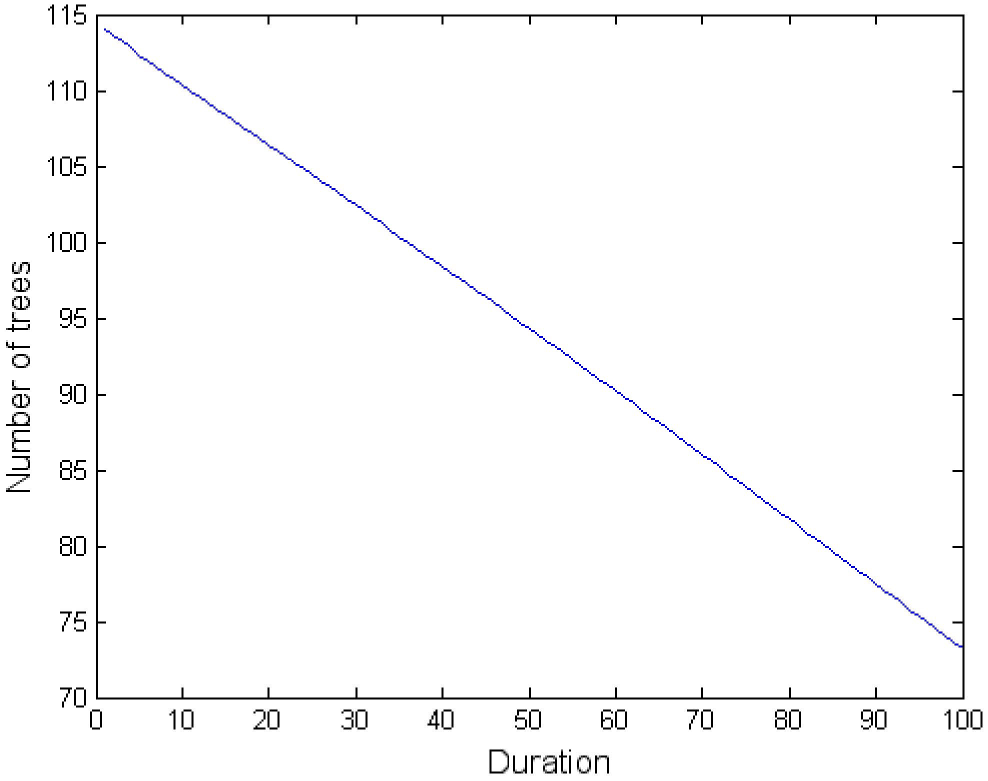


Fig. 4 – Graph expressing the decrease in the number of *Dracaena* trees during 100 years; ten years interval between 0 and 100 is represented.

Two models were created in SVS on the basis of proven results. The first model shows present condition of the trees (see Fig 5). The second model expresses the decrease in the number of trees during 100 years (see Fig. 6). The disappearance of the trees was choosen in consideration of age, vitality and degree of damage. The most frequent type of damage was stem scar caused by extraction of blood-red sap. An intensive pasture of goats is expected. That is the reason why no natural regeneration and/or artificial plantation are included.

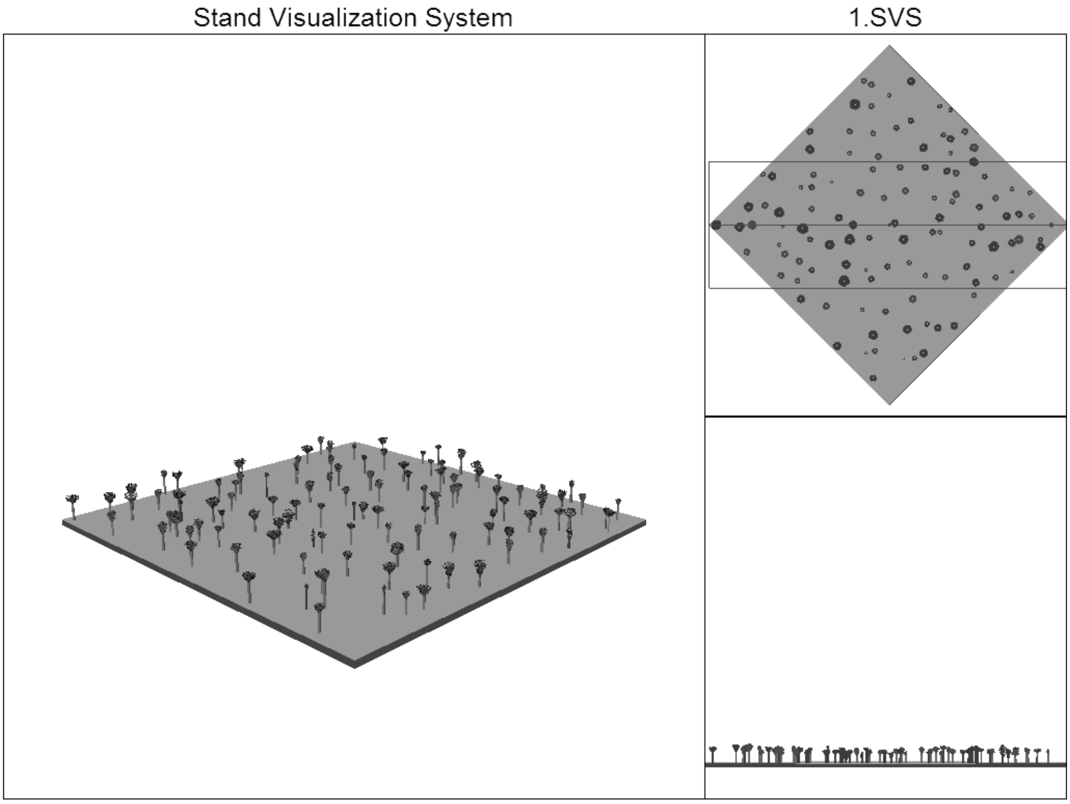


Fig. 5 – Model in SVS showing *Dracaena* trees sample density in 2010.

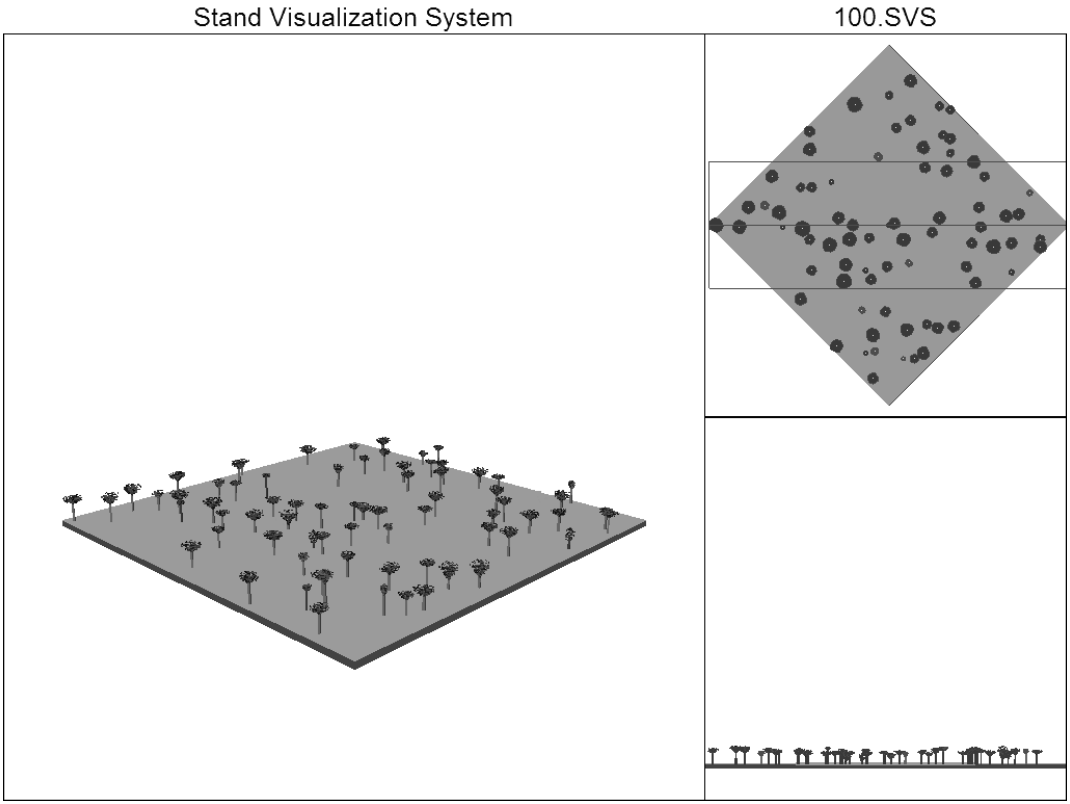


Fig. 6 – Model in SVS showing *Dracaena* trees sample density in 2110.

It is necessary to mention, that this prediction is very optimistic, because currently (in 2010) there are the youngest *Dracaena* trees in Firmihin on chosen sample plot. Natural disasters or other unexpected events are not assumed.

6.4 DISCUSSION

Age determination of monocotyledons in general, is very difficult task (Habrová et al., 2009). One study (Adolt and Pavliš, 2004) on the estimation of the age of *Dracaena* tree species has been published. According to mentioned study, background is an indirect method reflecting relationship between the number of flowering periods and the actual age of a specimen. The relation can be well defined through specific branching of arborescent *Dracaena* species characterized by markedly swollen branches segregated individually by narrowed sections or 'sausage-shaped' sections. Based on this method, one branch section reaches about 19 years and *Dracaena* achieves an age up to 650 years. But even so it is hard to determine the age of stem before crown branching, because there are no growth rings in cross section of the stem. Habrová (2005) mentioned that there are three main growth stages in *Dracaena*'s ontogeny. The seedling creates no trunk some time after germination, just a single rosette is growing and the number of leaves is increasing. After some time the trunk is creating, but there is still only one single rosette on the top (Attorre et al., 2007). The branching and crown forming is related to the maturing stage (certain stem height) and ability to flower. Height growth cessation happens with ability to flower and moves between 40 and 1200 cm (Habrová, 2005).

According to the method developed by Adolt and Pavliš (2004), the crown of the oldest tree on sample plot was 532 years old (28 branch sections). There were no seedlings without stem and only three young trees creating stem with no branching.

Based on statistical analyses as well as on direct field observations, *Dracaena* populations on Socotra do not regenerate to a great extent and their age structure generally indicates overmaturity (Král and Pavliš, 2006). This research results confirm the claim by Adolt and Pavliš (2004), that with 95% probability, it is possible to expect that larger part of the world's most extensive *Dracaena* woodland complex at Firmihin will be in the stage of intensive disintegration within 30 to 77 years. Graphical representation as well as two models created by SVS show absence of natural regeneration. There are mostly middle aged trees in a sample plot, despite the fact that it is locality with one of the youngest trees at Firmihin. The results demonstrate gradual degradation and disappearance of trees.

Some scientists (Attorre et al., 2007) attribute the Dragon's Blood Tree reduction to climatic changes. According to Attorre et al. (2007), the predicted climate change may lead to a 45 % loss of *Dracaena* potential distribution area by 2080. The study published by Attorre et al. (2007) suggests that the original distribution of *Dracaena cinnabari* has been significantly reduced in the past. They hypothesise that a combination of factors may have contributed to its reduction (human activities, soil erosion, increased aridity and biotic interactions). They also suppose that current pattern of distribution, though fragmented may be primarily explained in terms of response to climatic constraints. Attorre et al. (2007) opine that Dragon's Blood Tree is able to colonise suitable areas if the present climatic conditions will remain stable and if a reduction of grazing and human pressure will occur.

Mendel University team does not consider climate change as a significant factor in the process of *Dracaena* tree reduction. We are tending to opinion that grazing by livestock, predominantly by goats, is the reason for its decline. Cattle grazing and excessive consumption of fuelwood and building timber most markedly represent an increasing anthropogenic pressure on natural resources of Socotra (Buček, 2003). Seed production capability of Dragon's Blood Trees is optimal. However, thanks to intensive browsing, there is the absence of natural regeneration except inaccesible steep slopes. The only way to prevent the decrease in stand density is a strict reserve and protection from grazing at Firmihin. Mentioned solution appears unrealistic in condisions of Socotra Island, where most of people support livestock grazing. Even so, the only way to prevent the degradation and disappearance of trees is to prevent grazing damage.

The *Dracaena* woodland on Socotra Island is rightly considered as one of the oldest forest community on Earth. It is a unique phytocoenose, which covered larger area in the past. Mendel University team activities lead towards promotion of *Dracaena cinnabari* regeneration, which count tree nursery establishement, endorsement and plants protection. The team is attempting to plant cultivated plants on the original localities of the species. Obstacles to successful behaviour consist partially in distrust local people to foreigners, habitual way of traditional grazing management, long periods of dry weather conditions etc. It is necessary to support optimizing of Dragon's Blood Tree age structure.

6.5 SUMMARY

The aim of this study was to predict and visualize variation in the number of Dragon's Blood Trees during 100 years in permanent sample plot at Firmihin on the Island of Socotra. Field measurements were realized in Firmihin, where the largest closed stand of *Dracaena cinnabari* was identified. One square sample plot of side lenght 100 m in locality of the youngest Dragon's Blood Trees was chosen. The inventory of each tree in sample plot was carried out. Collected data were compiled in Microsoft Office Program Excel, copied to electronic scratch pad and applicated to Stand Visualization System (SVS). The prediction of growing dynamic was developed on basis of previous long-term measurement and statistical evaluation made by Mendel University team. The mortality of trees during next 100 years was evaluated, graphically figured out and the models of stand development were created on the basis of matrix indicating the probability of tree within branch section category persistance (Habrová et al., 2009).

114 *Dracaena* trees on selected sample plot were identified. According to the method based on architectural age and statistical analyses published by Adolt and Pavliš (2004), the crown of the oldest tree was 532 years old (28 branch sections). The average trees have about 9 sections. There were found no seedlings without stem and only three young trees with created stem without branching. The graphical representation created in MATLAB shows, that from 114 trees, aproximately 73 trees will remain 100 years later. Thus the number of trees will decrease by 36%.

Two models were created in SVS on the basis of proven results. The first model shows trees sample density in 2010. The second model expresses the decrease in the number of 41 trees during 100 years. The curve (see Fig. 4) as well as two models created by SVS show absence of natural regeneration. Most likely this is due to livestock grazing, primarily by goats. The only way to prevent the degradation and disappearance of trees is to prevent grazing damage.

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II

7. GROWTH DYNAMICS OF *DRACAENA CINNABARI* UNDER CONTROLLED CONDITIONS AS THE MOST EFFECTIVE WAY TO PROTECT ENDANGERED SPECIES

Irena Hubálková[1], Petr Maděra[2], Daniel Volařík[2]

Department of Forest Botany, Dendrology and Geobiocoenology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic; xhubalko@node.mendelu.cz

Abstract

Dracaena cinnabari Balf. fil. is an endangered endemic species growing on the Yemeni island of Socotra. *Dracaena* woodlands are considered as one of the oldest forest communities on Earth. Uncontrolled grazing unfortunately caused a lack of naturally occurring regeneration. Our two-year research was focused on the growth dynamics of *Dracaena* seedlings from two separate populations. One hundred of germinated seeds from two different altitudes from the island were sown and planted under the same conditions. Average increment and difference between the growth dynamics of plants from the two localities were investigated. The observed data on this plant species revealed very interesting, hitherto unknown results. (1) The seedlings germinated within a time period from four to ten weeks. Germination rate was 90 % on the Firmihin highland plateau and 78 % on the Skand Mountain. (2) Average plant length from both localities was almost the same (24.9 cm) at the end of measurement. Differences in values between the two populations proved as non-significant. (3) A significant difference was found in the number of leaves and in the sum of lengths of all leaves on one plant. While the seedlings from Firmihin featured a wide spreading above-ground part with a large number of leaves, the plants from Skand invested more energy into faster leaves elongation rate. (4) Growth dynamics reflected seasonal changes. Increments were slower or ceased during the period of vegetative rest from autumn to spring. (5) Average mortality rate was 13 %. Most of the plants died during the period of vegetative rest. Further study on germination and regeneration under artificial conditions seems like the only way to prevent species extinction.

Keywords: Dragon’s Blood Tree; Germination; Growth rate; Height increment; Mortality

7.1 INTRODUCTION

The genus *Dracaena* comprises between 60 and 100 species (Adolt and Pavliš, 2004). It belongs in the family of *Asparagaceae* or *Dracaenaceae* (Brown and Mies, 2012). *Dracaena* species are exceptional among monocotyledonous plants because of their ability of the secondary growth of stems, branches and roots (Habrová et al., 2009). Most of *Dracaena* species grow as shrubs or geophytes. There are only seven species featuring arborescent growth and the xeromorphic *Dracaena cinnabari* belongs to them (Bekele, 2007).

D. cinnabari is a large, single-trunked tree with height up to 10 m and smooth grey bark. Branches with sausage-shaped sections form an umbrella-shaped crown. The crown shape is adapted to arid climates and is affected by the availability of atmospheric moisture. Tough leaves are densely tufted, dark green and elongated, up to 60 cm long and up to 4 cm wide. The leaves are scleromorphic as a specialised feature to prevent excessive loss of water (Brown and Mies, 2012). Small creamy flowers grow in large terminal panicles. Globose fruits have about 1 cm in diameter and contain from 1 to 3 spherical and brownish-red seeds, which are very hard. Their stage of ripening goes from black to red (Miller and Morris, 2004). The seeds are spread by birds. Since ancient times, the plant has been used for harvesting blood-red medicinal resin and as fuel wood. Moreover, flowers, fruits and leaves have been used as a source of dry season feed for livestock.

D. cinnabari (Dragon's Blood Tree) is an endemic species and the most iconic plant of the Socotra Island. It is a highly conspicuous element in the landscape of Socotra, specifically at altitudes between ca. 300 and 1480 m (Brown and Mies, 2012). Socotra is an isolated island lying in the Indian Ocean between the Horn of Africa and the Arabian Peninsula. It belongs to the Republic of Yemen. Separated from the continent during the Tertiary period, the island's floral endemism rate makes it one of the most biodiverse islands in the world (Grant, 2005). Today, it hosts more than 950 plant species, including some 825 terrestrial plants (430 genera, 114 families) and about 130 algae and seagrasses (Miller and Morris, 2004, Cheung and DeVantier, 2006 and Brown and Mies, 2012). Of the total number of flowering plants and ferns, 37 % are endemic, when compared with other archipelagos. In 2003, upon the international recognition of these outstanding attributes, the island became a UNESCO Man and Biosphere Reserve. In 2005, the islands were nominated for World Heritage listing (Cheung and DeVantier, 2006 and Scholte et al., 2011). According to Cheung and DeVantier (2006), during the long period of isolation, evolution of the island's flora and fauna has proceeded in various adaptations to cope with the arid, wind-swept environment. The umbrella-shaped shrubs and trees have adopted eco-morphological strategy. The unique vegetation formation adapted to semi-arid environment is an evergreen woodland dominated by the Dragon's Blood Tree (*D. cinnabari*) (Miller et al., 2006). The *Dracaena* woodland covers 3658 ha, i. e. 1.1 % of the island (Král and Pavliš, 2006). The general distribution of *Dracaena* on Socotra reflects the size of areas that are affected by the monsoon mists (Brown and Mies, 2012).

The Socotra's flagship species *D. cinnabari* suffers from the lack of regeneration due to intensified goat grazing (Miller and Morris, 2004). Therefore, the seedlings and young trees grow mainly on rock ledges and other sites that are inaccessible to goats. There are only mature and overmature trees in the accessible terrain. Plant density is not homogenous. The *Dracaena* woodland on Firmihin is considered as one of the oldest forest communities on Earth (Miller and Morris, 2004). However, further development of this community is not optimistic. Prediction of tree density development was made for Firmihin, the locality with the highest density of *Dracaena* trees (Hubálková, 2011). It showed that the *Dracaena* tree density would decrease by 36 % until 2110, if the actual grazing intensity remains unchanged. A similar situation occurs with the Frankincense tree *Boswellia papyrifera* growing in Eritrea and in the Horn of Africa. Its populations are declining due to human pressure and environmental degradation, the trees are found mainly in hilly areas on steep slopes as an adaption to harsh growing conditions (Ogbazghi et al. 2006). To assess the perspectives of woodland restoration, Negussie et al. (2008) examined *Boswellia* seedling densities in grazed woodland and a grazing exclosure in the lower Geba river catchment in northern Ethiopia. According to the results of their experiment, the number of *Boswellia* seedlings varied throughout the year, showing higher values in the rainy season. There were more seedlings in the exclosure than in grazed woodland. The authors also mention dry season as a serious cause of seedling mortality which limits the potential of native woodland recovery. Ogbazghi et al. (2006) devoted to the role of environment and land use factors determining the distribution limits of *B. papyrifera* in Eritrea. Their field survey was conducted in 113 village areas. Species occurrence was related to rainfall, air temperature, length of growing period, physical and chemical soil factors, topography and land-use types. The results show decreasing distribution as a result of several interrelated human factors such as the conversion of woodlands into agricultural fields and increasing livestock pressure.

The vulnerable Dragon's Blood Tree has been therefore one of the main concerns for conservation efforts and research activities on Socotra in recent years (Attore et al., 2007 and Habrová et al., 2009). Several detailed studies have been conducted to assess the potential impacts of various environmental factors on the plant development (Brown and Mies, 2012, Van Damme and Banfield, 2011 and Scholte et al., 2011). However, there is little information about phenology and growth of *D. cinnabari*. There are few current studies related to the growth dynamics of *D. cinnabari* (Adolt et al., 2012, Attore et al., 2007 and Habrová et al., 2009). Germination of *Dracaena* seeds under greenhouse conditions appears to be unproblematic (Brown and Mies, 2012). Adolt and Pavliš (2004) in Brown and Mies (2012) reported that germination rates as high as 77 % could be achieved under greenhouse conditions, and that the mortality of seedlings amounted to only 10 %. Beyhl (1996) mentioned comparably low rates of 35% germinability, which would appear to be adequate to maintain populations. In his thesis, Adolt (2001) carried out a germination experiment using 50 seeds of *D. cinnabari* from the Diksam area and 100 seeds of *Dracaena draco* from Tenerife. The experiment was conducted in the greenhouse of Mendel University in Brno, Czech Republic, at an average temperature of 22 °C. The germination was boosted by variously diluted solutions of hydrogen peroxide. The germination rate of *D. draco* was significantly higher (34 %) than that of *D. cinnabari* (5 %). One percent hydrogen peroxide solution increased the germination of Dragon's Blood Tree to 22 %. Petroncini et al. (2003) studied anatomy and genetic variability of the species using 45 randomly collected seeds from a highland plateau on Socotra (14 seeds sown in summer 2001, 31 seeds sown in February 2002). The plants were cultivated in a greenhouse of the Botanical Garden of Florence. The authors observed the development of a thick layer of cuticular waxes on the leaves. Unfortunately, they didn't devote their interest to growth dynamics of the seedlings. Under natural conditions, germination and successful establishment are going to be substantially lower (Brown and Mies, 2012). According to Beyhl (1998), during their germination, the seeds of *D. cinnabari* form a little root and a cotyledon, that remains stuck to the seed like in other monocotyledons. Directly after the germination with the outlet of the little root and of the little leaf, the seeds develop a cylindrical swelling or a tubular epicotyl, which gives rise to a tuber. Beyhl (1998) also claims that at the first stage of germination the little leaves remain etiolated for some days after exposure to light. After a short time, they start to produce chlorophyll and assimilate. Other leaves are green since the beginning. The first three or five leaves are distich disposed, just the next leaves have a pent – spiral collocation. Koopowitz and Kay (1990) suppose that *Dracaena* trees grow easily from the seed but their seedlings are very vulnerable to grazing animals. They also point out the fact, that the information about the growth dynamics of *D. cinnabari* is scarce. Beyhl (1996) asserts that the growth of the branches of *Dracaena* trees happens after the development of the terminal bud, after flourishing, or after a traumatic event. Earlier botanists (e.g. Symon, 1974 and Wright, 1901) in their studies of palms and other arborescent monocotyledons devoted considerable attention to few forms with secondary vascular tissues. Tomlinson and Zimmermann (1969) created and described sketches of the habitus of monocotyledons with the secondary growth. According to these authors, the development of *Beaucarnea recurvata*, for example, begins with a rapidly growing main axis, which remains unbranched for several years. Tomlinson (1970) studied the peculiarities of branching and crown shape changes in dependence on the plant age. According to Banfield et al. (2011), widely spread branches and tightly packed leaves may increase the surface area available for the condensation of water from the surrounding fogs and mists. The canopy also creates a cooling shade, which reduces solar radiation and evaporation in the area around the trunk or stem, benefiting both the tree and other plants growing thereunder (Banfield et al., 2011). However, the age at which *Dracaena* reaches a particular height or begins to branch, remains unexplored.

The aim of this study is to describe the growth dynamics of *D. cinnabari* seedlings in the first two years after germination. We included also the germination phase as we considered the germination rates reported by Adolt (2001) very low. Moreover, we focused on two populations (one from the highland plateau of Firmihin and the other one from the Skand Mountain) from different elevations as we had a hypothesis about a certain genetic adaptation to the different conditions. Another intention was to compare seed germination and seedling mortality between the two groups and to find a rational explanation to the obtained results. We also wanted to know if the total plant biomass could be estimated from the plant height. Within the growth dynamics, we hypothesised as follows: (1) the average germination rate would be around 80 % and thus the results published by Adolt and Pavliš (2004) would be corroborated. (2) The length of the highest leaf would be in favour of seedlings from Skand. Let us assume that this was due to genetic adaptation and higher plant resistance in the Skand area (e.g. Banfield et al., 2011 and Brown and Mies, 2012). (3) The number of leaves would be higher in the plants from Firmihin as an adaptation to the drier and warmer climate and more effective interception of horizontal precipitation (e.g. Banfield et al., 2011 and Brown and Mies, 2012). (4) The leaf length increment would reflect seasonal changes. (5) The average mortality rate of seedlings would be about 10 % as well as in the study written by Adolt and Pavliš (2004).

7.2 MATERIALS AND METHODS

7.2.1 Study area

The Socotra Archipelago, situated in the northern part of the Indian Ocean between 12°06′–12°42′N and 52°03′–54°32′E, comprises the name-giving Socotra Island, the islets of Abd-al Kuri, Samha and Darsa and a few cliffs (Kürschner et al., 2006). The major island, Socotra, the furthest east of the group, is approximately 3600 km^2 in area, spanning 133 km west to east and 43 km north to south (Cheung and DeVantier, 2006). According to Mies and Beyhl (1996), the islands are situated in the arid tropical zone where evapotranspiration generally surpasses precipitation by far. The climate of ecoregions is influenced by the south-west (summer) and north-east (winter) monsoons. The south-west monsoon (from May to September) brings only humidity, the north-east monsoon (from November to March) is milder but brings expected winter rain (Scholte and De Geest, 2010 and Culek et al., 2006). The remaining part of the year is characterised by dry weather conditions. Socotra can be divided into three physiographic zones: the coastal plains, the limestone plateau and the igneous Haggeher Mountains (Miller and Morris, 2004). According to Attorre et al. (2007), *D. cinnabari*, absent in the west, has a fragmented distribution in the central and eastern part of the island. It is common and often abundant on the granites of the Haggeher Mountains (Skand) and the adjacent limestone plateaus (Firmihin) where it is frequently dominant in the evergreen and semi-deciduous woodland (Miller and Morris, 2004). The species occurrence dominates above 600 m a.s.l. The seeds used in our experiment originated from the two last closed populations of D*. cinnabari*: from the Firmihin plateau at an altitude of approx. 580 m a.s.l. and from Skand situated at approximately 1450 m above sea level.

Firmihin is a highland plateau in the central part of the island. Altitude of the plateau ranges from 390 to 760 m a.s.l. According to Miller et al. (2000), the area belongs to the third vegetation belt where the plant starts to be dominant. According to Habrová et al. (2007), annual mean temperature on Firmihin is 23.4 °C, daily means range between 20 °C in February and 29 °C in May. The minimum temperature recorded on the plateau was 14.35 °C in January, the maximum temperature recorded was 36.26 °C in May. Annual mean relative air humidity is 71.87 %. Horizontal precipitation is relatively low and infrequent compared to Skand; therefore, the crowns are wide. Firmihin is a limestone plateau. Karstification of the landscape is a conspicuous feature and locally, the limestone is interrupted by small areas of sandstone (Brown and Mies, 2012). The soil is characterised by high calcium content and lower content of organic carbon with quick mineralisation. In general, the surface topography is characterised by the eroded limestone bedrock and by soils deficient in organic material (Brown and Mies, 2012). Two deep ravines surround and protect this amazing protected area. Due to this phenomenon, the unique vegetation has been preserved there, headed by the largest closed stand of Dragon’s Blood Tree on the island. In spite of geographic barriers, all natural regeneration is decimated by browsing.

Skand is situated northeast of Firmihin, in the Haggeher Mountains, which are strongly dissected by deep wadis, sheltered gullies and cliffs (Brown and Mies, 2012). With 1526 m a.s.l., Skand is the highest peak of the island. According to Miller et al. (2000), the area belongs to the fifth vegetation belt where the plant is dominant. According to Habrová et al. (2007), annual mean temperature on Skand is 17.85 °C. Minimum temperature recorded on Socotra was 8.16 °C on Skand in January, the maximum recorded was 31.96 °C in May. Annual mean relative air humidity is 80.03 %. Horizontal precipitation is typical of the Skand area (higher air humidity, frequent fogs). Relative humidity is at or close to 100 % for most of the period of darkness (Brown and Mies, 2012). Therefore, the crowns are narrower up to conical shape. The Haggeher Mountains represent a massif of granite. Thin and little developed soil is characterised by higher sodium content due to the presence of Riebeckite mineral. Natural regeneration is more successful in contrast with Firmihin due to the broken topography and inaccessible localities with steep slopes, which are protected against grazing and human impact (particularly in sheltered gullies, in cracks and on the peaks).

7.2.2 Seed collection, planting and measurement of seedlings

In total one hundred and forty seeds were collected at the turn of January and February 2011 on Firmihin (N12°28,867′; E54°0,602′) and on Skand (N12°34,592′; E54°01,642′), 70 seeds per locality. On both localities, sites of less exposed eastern slopes were chosen. Slope was 15° on Firmihin and 45° on Skand. Altitude was 580 m a.s.l. on Firmihin and 1450 m a.s.l. on Skand. The seeds have probably been lying on the ground for no more than seven days. They were collected at the slope bottom under crowns of ca. 10 trees on each locality, stored in laboratory tubes and with the permission of Yemeni nature conservation authorities they were transported to the Czech Republic. The research could not be done on the island because the observation of plants and their periodic measurement were impossible.

The two-year experiment was conducted in Brno (Czech Republic) in the period from March 2011 to June 2013. The Czech Republic has a moderate continental climate with warm, dry summers and fairly cold and snowy winters. Brno belongs among the warmest places in the country with an average annual temperature of 8.8 °C, an average annual precipitation of 493 mm and an average annual hours of sunshine of 1678 h (Climatedata.eu, 2015). One hundred high quality – large, brownish and undamaged – seeds were sown on 9 March 2011 separately into pots of 350 ml and planted under uniform conditions – constant room temperature (20–23 °C) and relative humidity (55–60 %), twice-weekly watering, the same soil substrate (universal full-featured cultivation soil substrate with adjusted organic matter content and proper acidity), the same light intensity (S-facing windows, no curtains). We did not use any germinator or solution accelerating the germination.

After germination, measurements of the above-ground part were carried out at one week interval. Every new leaf was numbered and the length of each leaf was measured continuously until the end of the experiment. The seedlings were transplanted into larger pots on 22 December 2011.

7.2.3 Data analysis

To assess differences in germination rates and seedling mortality between the two localities (Firmihin/Skand), we used a logistic regression approach. Locality (Firmihin/Skand) was used as an explanatory variable. The growth dynamics during the whole experiment was visually explored using graphs for the length of the first leaf, length of the highest leaf, total length of all leaves and for the number of leaves with a smoothed curve added separately for Firmihin and Skand seedlings using the loess method (local polynomial regression, Cleveland et al., 1992). The significance of differences between the localities was tested at the end of the first half of the experiment and at the end of the whole experiment (week 50 and week 122) using the double sided t-test (variant with unequal variance). All statistical analyses were performed in the R statistical environment (R Core Team, 2013), graphs within ggplot2 package (Wickham, 2009).

7.3 RESULTS

7.3.1 Germination

The seedlings germinated within a time period from four to ten weeks after sowing the seeds. The highest germination rate was observed in the fifth and sixth week (between 1 and 7 April 2011) in the case of seeds from Firmihin, and in the seventh and eighth week (between 14 and 21 April 2011) in the case of seeds from Skand. The result indicates that 84 out of 100 seeds (Firmihin/Skand) germinated under proper conditions. The germination rate was somewhat higher on Firmihin (94 %) than on Skand (80 %); however, this difference was not significant (*p*-value = 0.098). One week after germination, the first leaf started to develop and elongate.

7.3.2 Growth dynamics

An average increment for the whole period of measurement was 0.211 cm per week. The length of the first leaf (Fig. A.1) could not be compared with the length of the highest leaf (Fig. A.2). While the average length of the highest leaf was almost the same (24.9 cm) in the two groups (Firmihin/Skand), the average length of the first leaf was 23.5 cm for Firmihin/Skand at the end of measurement. Although the length of the first leaf (Fig. A.1) was slightly greater in the seedlings from Skand than from Firmihin in the first half of observation (until week 75 at the beginning of August 2012), the difference was not significant for week 50 (Table 1). Similarly, it was not significant at the end of the experiment when the first leaf on Firmihin was somewhat longer than on Skand. We observed a similar pattern for the height of the above-ground part of the plant expressed by the length of the highest leaf (Fig. A.2). The height of seedlings from Skand was somewhat greater throughout the period of observation, but the difference was not significant (Table 1). Significant differences between the seedlings from Firmihin/Skand were found in the number of leaves and in the sum of lengths of all leaves on one plant. The number of leaves ranged from 8 to 16 in the seedlings from Firmihin and between 8 and 12 in the seedlings from Skand at the end of measurement (Fig. A.3). On average, it was higher on Firmihin than on Skand, 12 versus 10 leaves respectively. The difference in the total number of leaves was 132 in favour of plants from Firmihin at the end of June 2013. In the case of seedlings from Skand, the number of leaves was increasing more or less constantly up to week 75 of measurement (early August 2012), slowed down in the autumn of 2012, and then increased in the spring. Compared with Skand, the process of leaf development in the plants from Firmihin was more dynamic. The seedlings from Firmihin had less leaves in the first half of the experiment, but more leaves from the second half up to the end of the experiment. This trend was very similar for the sum of the lengths of all leaves indicating that the number of leaves mostly influenced this summed leaf length (Fig. A.4). The total length of leaves was greater in the Skand plants until the end of November 2012. Two months later (in week 100), the total length between the two groups was equalled, followed by a greater total leaf length of Firmihin seedlings at the end of the two-year measurement.

Table 1. t-Test results showing the significance of the effect of locality (Firmihin/Skand) on the measured parameters in week 50 and at the end of the experiment (week 122). The effect of locality was significant only for the length of all leaves and for the number of leaves per plant.

	Week 50			Week 122		
Parameter	t	d.f.	p-value	t	d.f.	p-value
Length of the first leaf	-1.220	60.0	0.227	1.599	58.9	0.115
Length of the highest leaf	-1.326	60.7	0.190	-0.258	70.7	0.797
Length of all leaves	-2.942	51.7	0.005	4.116	59.0	<0.001
Number of leaves	-2.683	54.9	0.010	3.963	65.0	<0.001

7.3.3 Mortality

Out of 45 germinated seedlings from Firmihin, five died during the experiment. Out of 39 germinated seedlings from Skand, six died. This shows that the mortality was almost the same (difference was not significant with p-value = 0.568). The first seedling died about 3 months after seeding (source from Firmihin). Most of the seedlings withered during the autumn and winter of 2011, in the period from 13 October 2011 to 5 January 2012. We responded to the increasing mortality rate by transplanting the seedlings into larger pots on 22 December 2011. The last two plants withered in the summer of 2012 (plants from Skand).

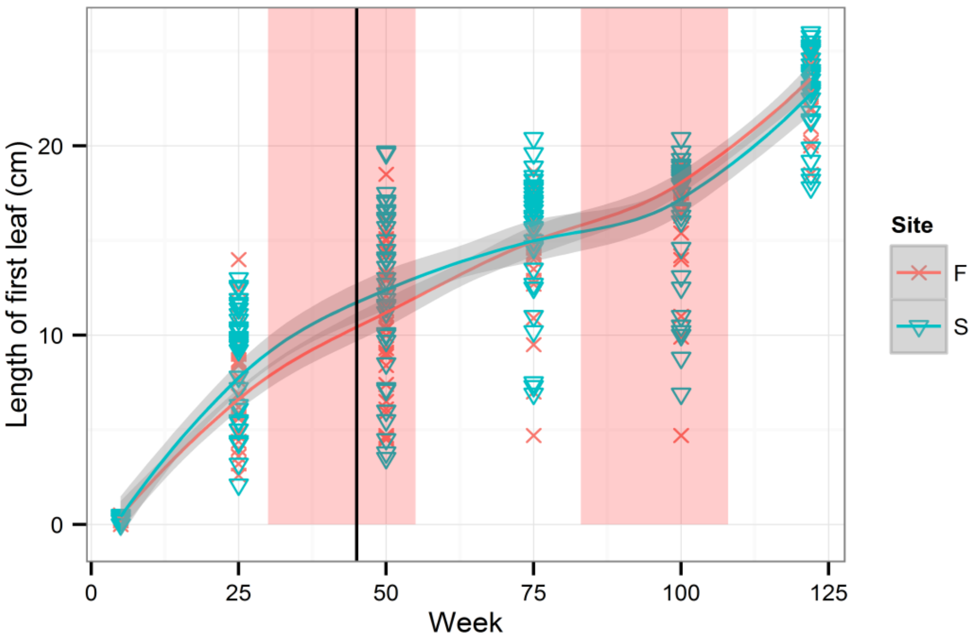

Figure A.1. Development of the first leaf length during the whole experiment. Smoothed curves are fitted separately for Firmihin and Skand using the loess method. Grey areas show a period from the autumnal to vernal equinox. The bold black vertical line represents week 43 when the seedlings were transplanted.

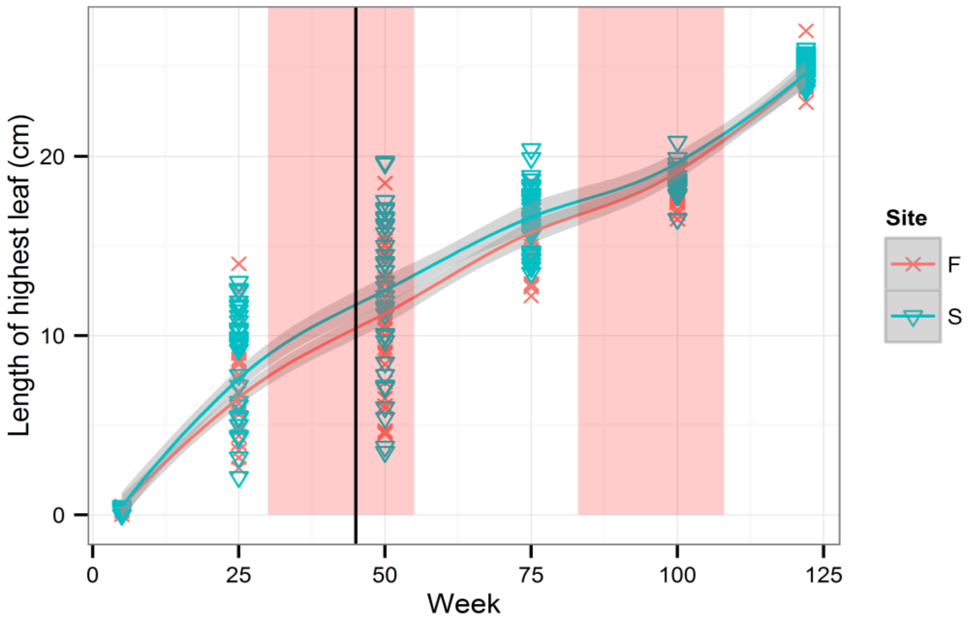

Figure A.2. Length of the highest leaf

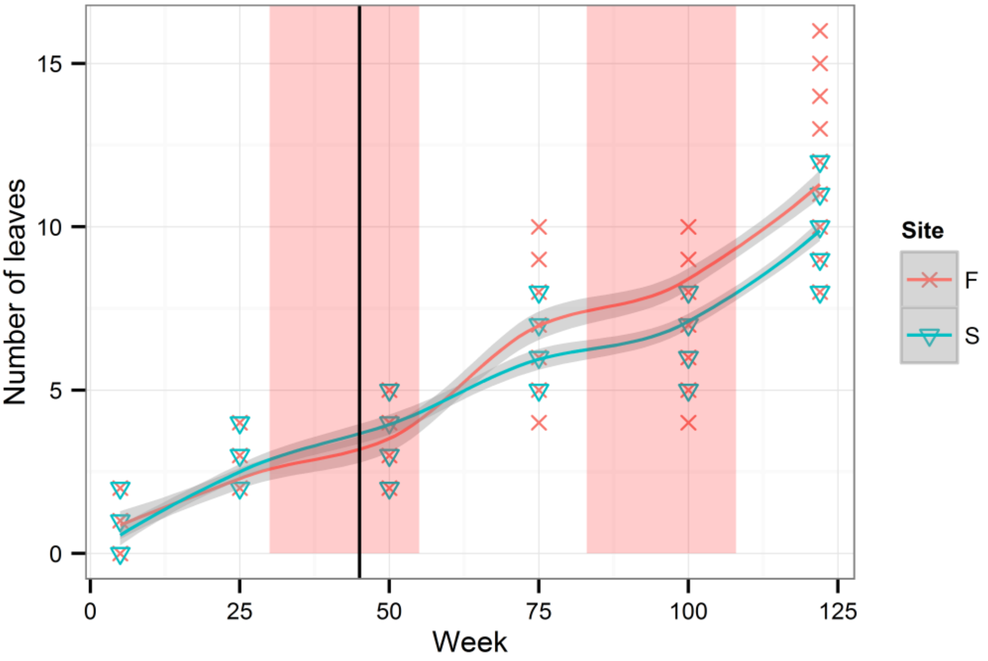

Figure A.3. Number of leaves

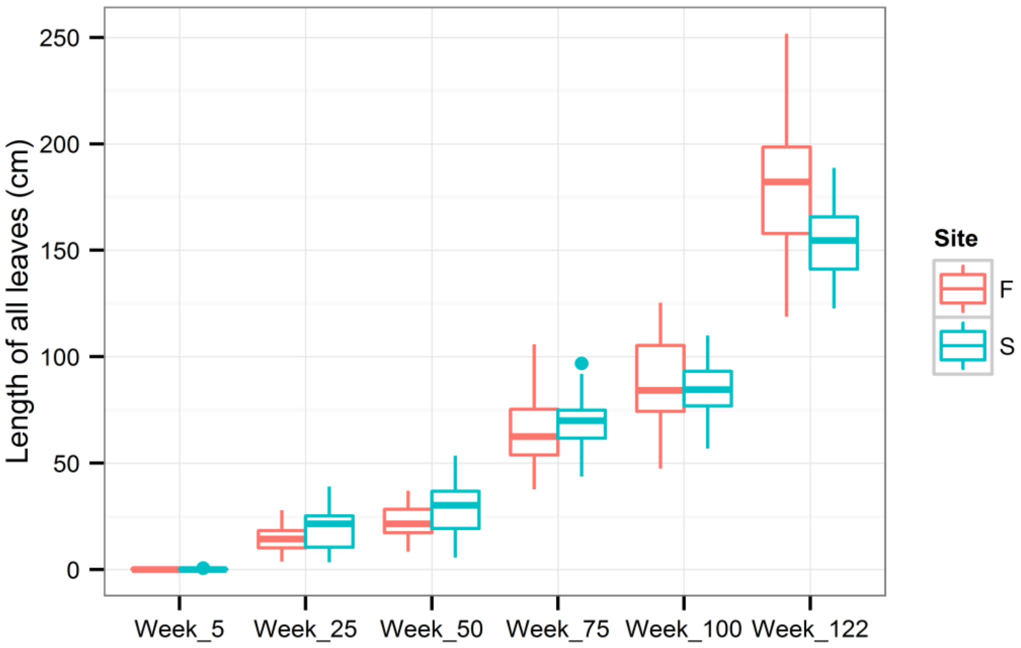

Figure A.4. Length of all leaves

7.4 DISCUSSION

7.4.1 Germination

The highest germination was observed in the sixth and seventh week after sowing, during April 2011. The seeds from Firmihin germinated about ten days before the seeds from Skand. It could have been given by the lower vitality of seeds from Skand, which were visibly smaller than the seeds from Firmihin. Moreover, the seeds were collected from the ground, because infructescences in the crowns were already dry. The phenology of *D. cinnabari* is not yet known, but local Socotrans claim that phenological phases of the species do not repeat in regular time periods. The difference in the germination rate on Firmihin (94 %) and on Skand (80 %) was non-significant. The slightly higher germination rate on Firmihin could have been also caused by the better seed quality. The results confirm our hypothesis 1 and the statement of Adolt and Pavliš (2004) that germination rates as high as 77 % could be achieved under greenhouse conditions. Our results showed even a slightly higher germinability under controlled room conditions than in the greenhouse, particularly for Firmihin. Adolt and Pavliš (2004) used the seeds from the Diksam plateau situated at the same altitude as Firmihin. The air temperature in their greenhouse (22 °C) was similar to our in-room temperature (21 °C). The results also confirm the opinion that the germination of *Dracaena* seeds under artificial conditions seems to be unproblematic (Brown and Mies, 2012). We agree with Brown and Mies (2012) that germination under natural conditions is going to be significantly lower. The seeds are eaten by birds (on the other hand, scarified seeds in bird droppings may shorten dormancy). Some seeds exposed to sunlight dry out from the lack of moisture, namely those on the bare ground without a litter layer. Higher humidity in the mountain area ensures successful germination of seeds fallen into the cracks of bare rocks.

7.4.2 Growth dynamics

Weekly measurements of seedlings increments have not been taken before. Beyhl (1998) described the plant morphology of young plants. According to him, at the first stage of germination, little leaves remain etiolated for some days after exposure to light. According to our observations, the first leaf remains etiolated no later than 2 days after exposure to light and then turns green due to chlorophyll production and assimilation. As Beyhl (1998) states, further leaves are green since the beginning. Based on our observations, we can confidently confirm the opinion of Tomlinson and Zimmermann (1969) that the plant growth begins with a rapidly growing main axis, which is typical for monocots with the secondary growth. After germination, the new plant probably puts most of its energy into creating a storage organ in the form of underground tuber, and into terminal leaf development. Other parts of the plant body develop only after the above-described main growth has been completed. Another formation of leaves was observed in May 2011, approximately from the third week at an average length of the above-ground part being 1.7 cm. New leaves started to elongate rapidly, overgrowing the first leaf at the beginning of the growing season in 2012. This trend was more pronounced in the seedlings from Skand where the further leaves overgrew the first leaf in almost a half of the seedlings (data from week 75). In contrast, the further leaves of plants from Firmihin overgrew the first leaf in less than a quarter of plants.

Nevertheless, the differences in values between the two populations proved as non-significant. The results were almost equal at the end of measurement in June 2013, when the other leaves in more than a half of the seedlings from both populations overgrew the first leaves, as seen in Fig. A.1. In view of the results, the first developed leaf wasn't generally the highest leaf on the plant in the end of our experiment. Fig. A.2 shows the height of the above-ground part of the plant expressed by the length of the highest leaf. The seedlings from Skand were somewhat higher throughout the period of observation, but the difference was not significant. An average plant length for both populations started to be similar almost at the end of measurement between March and May 2013. The recorded outcome disproved our hypothesis 2 that the length of the highest leaf would be in favour of seedlings from Skand due to the genetic adaptation and higher plant resistance in the Skand area. The gradual equalisation in the length of the highest leaf might have been caused by the lateral development of roots in the seedlings from Skand. The development of other leaves may increase the surface area available for the condensation of water from the surrounding fogs and mists (Banfield et al., 2011) to compensate for the lacking soil moisture. Thus, the plant ensures a sufficient water supply necessary for the dissolution of substances, moving nutrients throughout the plant body, vital metabolic processes and thermoregulation (Taiz and Zeiger, 2010). Banfield et al. (2011) or Brown and Mies (2012) mentioned that the leaves are narrow, elongated and sometimes curved due to reduced solar radiation and evaporation. As shown in Fig. A.3, the increase in the number of leaves on one plant from Skand was more or less gradual, without significant fluctuations. Compared to plants from Firmihin, the number of leaves in the seedlings from Skand was slightly higher until early May 2012 in response to shorter sunshine during the period of vegetative rest. The difference in the number of leaves in favour of plants from Firmihin started to increase noticeably from the beginning of the vegetation season in the second year of measurement. Our hypothesis 3 about a higher number of leaves in the plants from Firmihin as an adaptation to drier and warmer climate and a more effective interception of horizontal precipitation was confirmed. A significant difference was found also in the sum of the lengths of all leaves on one plant (Fig. A.4). The results show the same trend as in the number of leaves. The results indicate different growth dynamics at the first stage of development. While the seedlings from Firmihin invest more energy into the construction of root system and into the wide spreading above-ground part with a large number of leaves, the plants from Skand invest more energy into faster leaf elongation rate, at the expense of root development and increased number of leaves. It should be emphasised that the plants from Skand were exposed to less favourable growth conditions compared to natural conditions, where much higher air humidity with frequent drizzles and mists is typical. According to Brown and Mies (2012), investing more energy into the construction of tougher, longer-lived leaves with a thick layer of cuticular waxes protects the plants considerably from the mechanical damage and makes them less attractive to small herbivores. Moreover, the shape of the above-ground parts of seedlings confirms the well-known theory published by Valladares and Pearcy (1998) in Brown and Mies (2012), that leaves consistently exposed to the sun are inclined at a much steeper angle to the horizontal plane than shade leaves of the same species. Hypothesis 4 about the dependence of the length increment on seasonal changes was verified. Compared to the growing season, the plants grew slower during the period of vegetative rest due to worsened ambient conditions.

7.4.3 Mortality

Out of 84 germinated plants, about 13 % died during the period of measurement. The recorded number confirms the data published by Adolt and Pavliš (2004) and our hypothesis 5 that an average mortality rate of seedlings ex-situ is about 10 %. As Brown and Mies (2012) mentioned, the survival of plants is substantially lower under natural conditions. The significant difference between Firmihin and Skand was not proven. Most of the plants died during the period of vegetative rest in the second year of observation. The higher mortality rate could have been due to a combination of several negative factors (esp. shorter sunshine duration and lower light intensity).

Despite an undeniable importance of the endemic species of Socotra, the research on its growth dynamics is still in its infancy. Only a few studies have been devoted to the germination and growing patterns of *D. cinnabari* at the stages of early growth. The reason is a ban on exporting the products of nature out of the island and difficulties with ensuring a long-term stay. This research was carried out thanks to a special permission issued by The Environment Protection Authority, which is an administrative body of the Ministry of Water and Environment in Yemen. Previously published data regarding the observation and measurement of young plants are thin, the seeds originating from a single population and the seedlings being planted artificially, under regulated in-room or greenhouse conditions. Natural conditions differ from the controlled cultivation by specific features of the subtropical monsoon climate together with insular biogeography (absence of vertical precipitation for most of the year, horizontal precipitation, two monsoon seasons accompanied by rains, temperature fluctuations between day and night, much higher sunlight intensity, different soil types and bedrock, very little or no soil layer, overgrazing, etc.). The Czech research team from the Mendel University in Brno established a fenced sample plot with the *Dracaena* seedlings on the Dixam plateau six years ago. The ongoing measurement of seedlings at two-year intervals is a next step to elucidate the growth dynamics of young *Dracaena* plants in situ.

The paper demonstrates very little known facts about *D. cinnabari* and its distinct phases during early stages of development as well as about growth of seedlings. The species is dramatically threatened with extinction, because the natural regeneration is extremely limited by excessive goat grazing and changing environmental conditions. It is very important to study germination and growth dynamics of this highly endangered species under controlled conditions, because the pasture management is deep-rooted in the culture of local people. Artificial regeneration seems to be the only way to protect one of the oldest plant species on Earth.

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III

8. GROWTH DYNAMICS OF ENDEMIC *DRACAENA CINNABARI* OF SOCOTRA ISLAND SUGGEST ESSENTIAL ELEMENTS FOR A CONSERVATION STRATEGY

Maděra P.[1], Habrová H. [1], Šenfeldr M. [1], Hubálková I. [1], Lvončík S. [1], Ehrenbergerová L. [1], Roth M. [1], Nadědžina N. [1], Němec P. [1], Rosenthal J. [2], Pavliš J. [1]

1) Department of Forest Botany, Dendrology and Geobiocoenology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1, Brno, 613 00, Czech Republic
2) Ecological Research Institute, Kingston, New York, USA

Abstract

Dragon blood tree (*Dracaena cinnabari*), a Tertiary relict species that is the flagship endemic of Socotra Island, is threatened by extinction due to lack of natural regeneration, likely because of goat herbivory and/or climatic factors (especially drought). Loss of dragon blood tree, a crucial forest canopy component, would likely result in loss of other native flora, heightening the importance of formulating an effective conservation strategy for it. Although artificial afforestation might be used to offset the lack of natural regeneration, it would have to overcome the same threats faced by naturally occurring seedlings. Moreover, there is no published information on the growth dynamics of seedlings in plantations *in situ* on Socotra. To fill this information gap, we compared seedling growth over an 8-year period after planting at two sites that differed both in the degree to which goats were excluded and in whether they were watered regularly over the 8-year period. In addition to developing a new classification of the growth stages, which will enable better tracking of population dynamics, we found that continuous goat exclusion was necessary to prevent seedling mortality. Also, although seedling growth overall was slow, growth parameters of regularly irrigated seedlings ranged from 156 % to 446 % of those not regularly watered, suggesting that this treatment can speed seedlings' escape from goat browsing. This finding that may be applicable to imperilled *Draceaena* tree species elsewhere in the world. However, we also found that the plants and humans can compete for irrigation water, suggesting that local residents need to realize some benefit from allowing water to be directed to the trees.

Key words: Dragon’s Blood Tree, Socotra, regeneration, afforestation, browsing, arid tropical zone

8.1 INTRODUCTION

Dracaena cinnabari Balf. F., *D. draco* (L.) L, also known as the dragon‘s blood tree, is a Tertiary relict species that is the flagship endemic of Yemen’s Socotra (Soqotra) Island, in the Indian Ocean (Attore 2007; Culek 2013). It is also an endangered species (Scholte et al. 2011). Indeed, the biota of Socotra, a World Heritage site (Brown & Mies 2012) has attracted worldwide conservation concern due not only to its uniqueness, with most of it endemic, but also because of the threats that it faces. Dragon blood tree is especially well-suited as a representative of this biota because it is a charismatic species with a striking appearance that has captured the public imagination. Moreover, this species is especially important ecologically because of the dependence of other endemic plants upon its canopy, and diminishment of its population is forecasted to lead to an overall decline in plant biodiversity (Rejžek et al. 2016). Unfortunately, such diminution has already occurred at a large scale, and effective conservation measures need to urgently be identified.

Of the 60-100 species of genus *Dracaena*, family *Asparagaceae* (Brown & Mies 2012), only relatively few, commonly known as dragon trees, have a tree growth habit, including *D. cinnabari* (Marrero 1998). Dragon tree species are found mainly in the Arabian Peninsula, Africa, and nearby islands, but also include representatives from as far afield as Southeast Asia and one from the Neotropics (Zona et al. 2014). The most extensive population of arborescent *Dracaena* is the dragon blood tree forest (Fig. 1) found at Firmihin, Socotra (Adolt et al. 2013). This forest is a relict of the Mio-Pliocene thermo-sclerophyllous southern Tethys flora, and thus one of the oldest forest ecosystems in the world (Miller & Morris 2004; Habrová et al. 2009, Brown & Mies 2012). Král and Pavliš (2006) estimated the total occurrence of dragon blood tree on Socotra Island at 7,230 ha, comprising 6,200 ha of woodlands, 230 ha of forests and 800 ha of mixed forests. Present populations are discontinuous, with heterogeneous plant density and unbalanced age structure, occuring over a much smaller area than in the past (Adolt & Pavliš 2004; Habrová et al. 2009; Adolt et al. 2012). In fact, Attore et al. (2007) estimated that dragon blood tree now occupies only 5% of its potential habitat on the island, as defined by moisture index, mean annual temperature and slope.

Figure 1: Dragon blood tree forest at Firmihin, Socotra Island

Two hypotheses, not mutually exclusive, have been advanced to explain the present limited distribution of dragon blood tree. One attributes it to changes in physical environmental factors. Thus, Pietsch and Kühn (2009) suggested that patterns of soil polygenesis attributable to changing climate conditions have played an important role in reducing regeneration. Similarly, dragon blood tree regeneration could be affected by long-term climate oscillations of wet and dry periods as described by Van Rampellbergh et al. (2013). The other hypothesis blames the decline in dragon blood tree populations on overgrazing (Habrová 2004; Hubálková 2011; Brown & Mies 2012). Support for the latter explanation is provided by the fact that although only mature and overmature trees occur at most of the species' localities, regeneration is found on the steepest cliffs and other places inaccessible to goats.

Indeed, overgrazing by livestock has played a particularly important role in the decline of native biota more generally on Socotra, as the environment there has been affected for centuries by goats, sheep and camels on the limestone plateaus and by dwarf cattle in the mountains (Scholte et al. 2011). Moreover, the biodiversity has been projected to continue to decline unless grazing is restricted (Habrová 2004; Habrová & Pavliš 2016).

In the case of dragon blood tree, although the underlying causes of the widespread lack of regeneration have not been determined with certainty, this failure to regenerate and the consequent decline in population densities have been well documented (Habrová et al. 2004; Miler et al. 2004; Adolt & Pavliš 2006; Attore et al. 2007; Hubálková 2011; Adolt et al. 2012, 2013; Brown & Mies 2012; Habrová & Pavliš 2016, Hubálková et al. 2016). This decline has been predicted to continue, so that, for example, dragon blood tree tree density on a permanent plot at Firmihin has been projected to decrease by 36% over the years 2010 to 2100 (Hubálková 2011). Effective conservation measures for dragon blood tree are thus urgently needed, but designing them requires a better understanding of the species' population dynamics. This, in turn, requires knowledge of the populations' age structures (Adolt & Pavliš 2004; Adolt et al. 2012), which must overcome the inherent difficulty in precisely determining ages of monocots.

Some progress has been made in identifying particular stages within the vegetative phase of development of dragon blood tree, a remarkably long-lived and slowly maturing species. Habrová (2005) divided this phase into three main stages. In the first, the plant creates no trunk, just a single rosette with increasing numbers of elongating leaves. After a number of years depending on site conditions, the plant develops a stem with a single rosette at the top. In the last stage, the crown branches and gradually forms the distinctive, umbrella-shaped crown of the adult tree. This final form is adapted to catch horizontal precipitation in the form of fog, which is a significant water source, especially above 700 m.a.s.l. (Culek 2013).

Attore et al. (2007) used more details to divide dragon blood tree ontogeny into four stages. In this classification, in the first stage the plant consists of a single rosette without a trunk, whereas in the second stage the plant has added a trunk. The third stage in this classification is represented by a plant with more than one rosette, as well as a crown of diameter less than 2.5 m, whereas in the fourth stage the plant has a crown larger than 2.5m. More recently, Hubálková et al. (2016) described the first two years of dragon blood tree plants' growth in greenhouse conditions, with average seedling height of 24.9 cm and leaf number 8-16 at the end of this period. Crucially, although it is not known how many years each of the growth stages takes, the lifespan of dragon blood tree has been estimated (Adolt et al. 2012) to be more than 500 years. Moreover, because the juvenile trees are slow-growing, it can take years for plants to escape from the „browse zone“, making them particularly susceptible to consumption by herbivorous mammals.

In the present study, we examined the growth dynamics of dragon blood tree in plantation conditions *in situ* in Socotra. We chose two plantations as our study sites due to the paucity of natural regeneration. Importantly, although the study was not designed as a formal experiment, the plantations differed in their livestock exclosure and irrigation treatments, enabling us to gain some insight into how these management approaches might alter the growth dynamics and assist in regeneration of this species.

8.2 MATERIALS AND METHODS

8.2.1 Study sites

Two sites were employed in this study. The first was the Ras-Ayre reforestation area (see Appendix 3), situated on the Shibehon Plateau, 715 masl, and gently sloping towards to the northwest. In May 2006, a total of 715 three/four/five-year-old dragon blood tree seedlings (grown in a forest nursery) were planted there in a fenced, 1-ha area. An irrigation system was installed at the nursery before the seedlings was planted. However, due to competing needs of local villagers for the water, the irrigation this system provided was irregular and to only some of the trees during the first three years of seedling growth. By the third year, the system fell into disrepair.

In the course of conducting plant measurements in May 2009, we found that although the fence was still in good condition, the irrigation system had been destroyed. In March 2012, we found that the fence was in bad condition, allowing goats to browse inside of it. New fencing was installed in June 2012, and 170 additional seedlings were planted in it; these were of the same age cohort (i.e., 9 to 11 years old) as the seedlings originally planted. The fence was noted to be in excellent condition when plants were measured in November 2013, but new browsing was again visible during measurements done in November 2014, when the new fencing began to show damage.

The other study site, 30 km away and at 30 masl, consisted of the Oam al-Cora elementary school garden (see Appendix 3), where 17 individuals of dragon blood tree were planted as seedlings in 2006, the same year as those planted at Shibehon. These plants were irrigated regularly at weekly intervals. Additionally, they were protected from goats and other livestock by a stone fence for the whole period during which we observed their development. Thus, the Oam Al-Cora school plantings can provide an example of growth dynamics in the best site conditions and provide a comparative baseline for the Shibehon plantation.

An automated climatological station was installed in the Ras-Ayre fenced area in March 2000, remaining operational until October of that year, and was again collecting data from June, 2009 to November, 2014. Over the periods March 15, 2000 to October 21, 2000 and June 25, 2009 to November 17, 2014, the mean annual temperature recorded there was 21.98°C and the mean annual precipitation was 350 mm. A sensor for air temperature and moisture was installed at Hadibo (close to the Oam al-Cora locality) in June 2004, showing the mean annual temperature there to be 28.7°C. The monthly mean values for these variables at both locations are shown in Supporting Information. Appendix 1. Mean monthly air temperature and humidity, Shibehon (Sh) Plateau climatic station, March 15, 2000 to October 21, 2000 and June 25, 2009 to November 17, 2014 and Hadibo (Ha) climatic station from June 15, 2004 to November 26, 2014.

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
temp. Sh.	19.9	20.4	22.9	24.4	24.6	22.4	21.3	21.1	21.2	22.2	22.3	20.6
humidity Sh.	79.1	77.6	60.6	75.5	87.7	90.1	89.2	91.9	97.2	87.7	69.0	75.2
temp. Ha	24,4	24,9	26,5	28,8	30,9	33,8	33,1	32,9	30,3	27,2	26,4	25,3
humidity Ha	71,7	70,6	69,7	71,3	67,9	46,1	41,0	42,9	59,6	75,7	76,3	70,3

8.2.2 Data collection

At the plantation at Shibehon, growth metrics consisting of total height, number of leaves, browsing presence and vitality were recorded in 2009, 2012 and 2013. In addition to these variables, stem height and stem diameter (at ground level) were measured in 2014. Browsing occurrence was assessed only as yes/no; vitality was evaluated using a semi-quantitative scale with four possible values: 1 = seedlings fully vital, leaves dark green and firm; 2 = seedlings vital, leaves light green to yellowish, drying on the top; 3 = seedlings not vital, leaves yellowish to yellow, partially drying; 4 = seedling dead.

Data were collected from the 17 dragon blood tree trees planted in the Oam al-Cora school garden in November 2014 for comparison with the trees at the Shibehon plantation.

8.2.3 Data analysis

After testing the assumptions for using analysis of variance (ANOVA), we used a one-way ANOVA to assess the effect of time on dragon blood tree seedling characteristics (height, leaf number, vitality). We also used a one-way ANOVA to test differences in dragon blood tree seedling characteristics between the Oam al-Cora and Shibehon sites. All statistical analyses were caried out using Statistica software (Statsoft 2001).

8.3 RESULTS

8.3.1 Seedling mortality, vitality and growth: Shibehon site

Of the 715 seedlings planted at the 2006 Shibehon site, 680 remained when we next counted them, in 2009. Thus, the mortality was only 4.9 % over this 3-year period. However, by the subsequent counting, in 2012, it had reached 30.5 % of the initial number of seedlings because the fence had broken and the seedlings were under goat browsing pressure.

The mean vitality (on the four-level scale, with higher values indicating lower vitality) went from 1.9 (SD 0.69) in 2009 to 2.35 (SD 0.72) in 2012, 1.26 (SD 0.39) in 2013 and 1.18 (SD 0.30) in 2014 (Fig. 2). Thus, the vitality increased with increasing age of the plants, except in 2012, when the fence was broken.

The recorded height growth was very slow. Mean height was 23.0 cm (SD 8.17) in 2009; 25.72 cm (SD 9.46) in 2012; 33.31 cm (SD 9.76) in 2013 and 36.27 cm (SD 10.02) in 2014 (Fig. 2). The mean annual height increment was only 0.9 cm between 2009 and 2012 years, increased to 7.6 cm in 2013 and decreased to 3.0 cm in 2014. Over the whole five years of the study, the mean annual height increment was only 2.65 cm.

The initial value of mean number of leaves per seedling was 21.3 (SD 11.18) at the first measurement, in 2009, three years after plantation establishment. The value increased to 26.9 (SD 11.88) in 2012, to 46.0 (SD 21.60) in 2013 and to 53.2 (SD 24.84) in 2014 (Fig. 2). The mean annual leaf number increment was only 1.9 leaves per seedling over the period 2009 to 2012. The mean annual leaf increment increased to 19.1 per seedling in 2013 and decreased to 7.2 leaves in 2014. Over the whole five years of the study, the mean annual leaf increment was 6.39.

All studied seedlings characteristics changed significantly over time ($p < 0.05$, see Fig. 2).

Figure 2. Boxplots showing changes in studied *Dracaena cinnabari* seedling characteristics (A - height; B - leaf number; C - vitality) over time. The ANOVA results for the effect of time on *Dracaena cinnabari* seedling characteristics (height, leaf number and vitality) showed the significant time effect on all characteristic (height $p<0.05$, $f=286.63$; leaf number $p<0.05$, $f=427.05$ and vitality $p<0.05$, $f=600.82$).

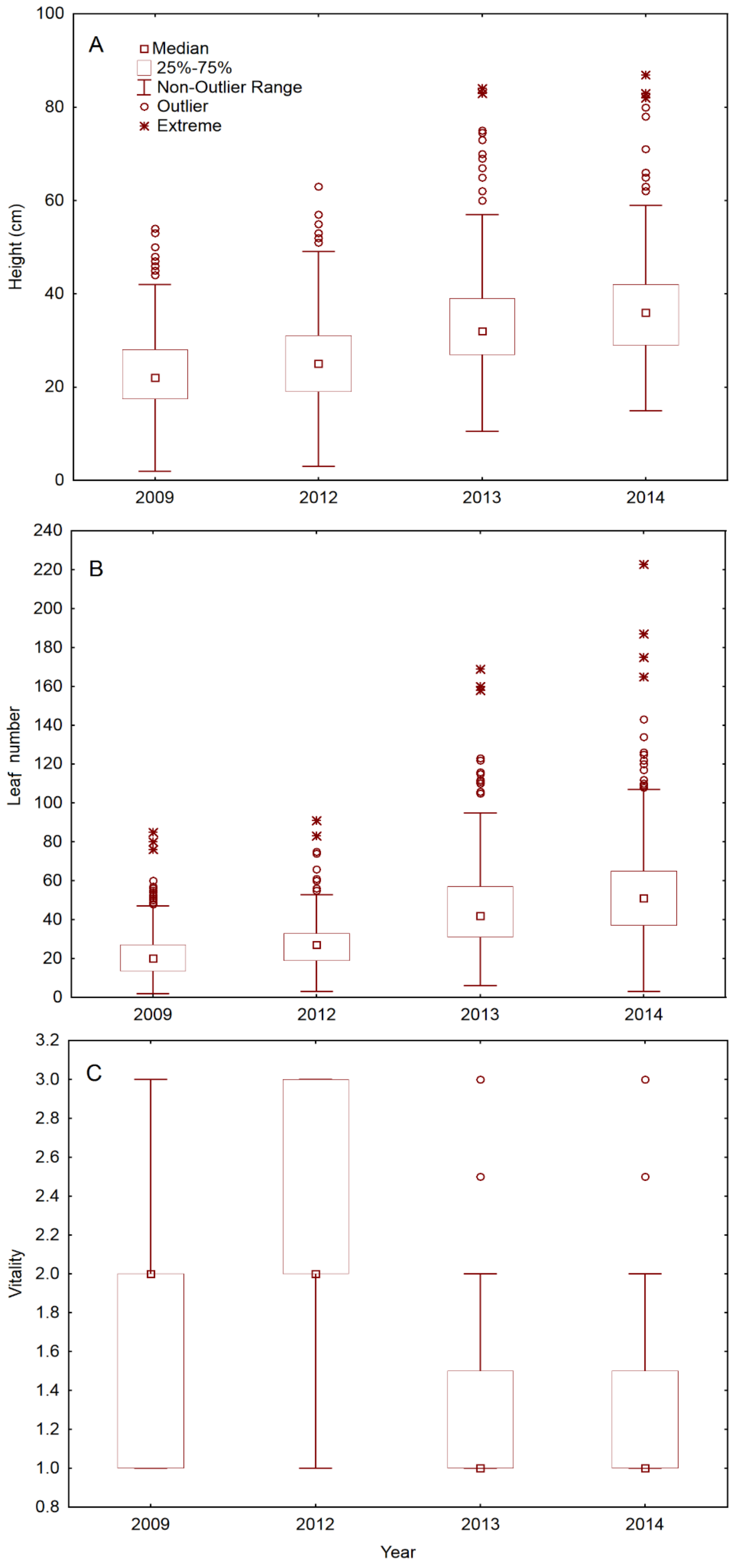

A
Median
25%-75%
Non-Outlier Range
Outlier
Extreme
Height (cm)
0
20
40
60
80
100
2009
2012
2013
2014
B
Leaf number
0
20
40
60
80
100
120
140
160
180
200
220
240
2009
2012
2013
2014
C
Vitality
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
2009
2012
2013
2014
Year

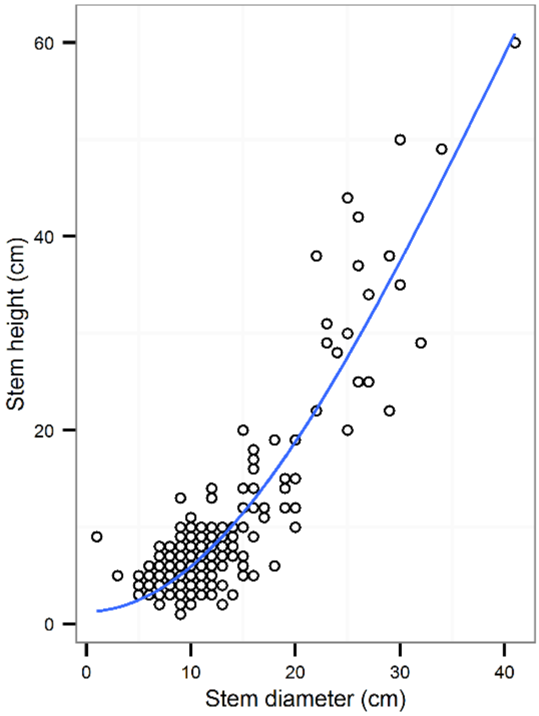
Table 1: ANOVA results for the effect of time on *Dracaena cinnabari* seedling characteristics (height, leaf number and vitality).

Characteristic	**Degrees of freeedom**	**F**	**p-value**
Height	3	286.63	0.000
Leaf number	3	427.054	0.000
Vitality	3	600.82	0.000

8.3.2 Stem development

The stem was developed by 55.9 % of seedlings in 2014, when we began measuring the stems. The mean height was 6.7 cm (SD 3.31), and mean diameter at ground level was 10.3 cm (SD 3.12). The ages of seedlings ranged from 11 to 13 years. Thus, seedling stem development starts at approximately ten years or later. We found a clear trend of increasing stem height with increasing stem diameter (Supporting Information).

Appendix 2: Naeslund's (1936) height curve (y = 6.5243 + 0.5706*x) showing relationship between stem diameter (x axis) and stem height (y axis). (R2 = 0.74, p = 0.000).

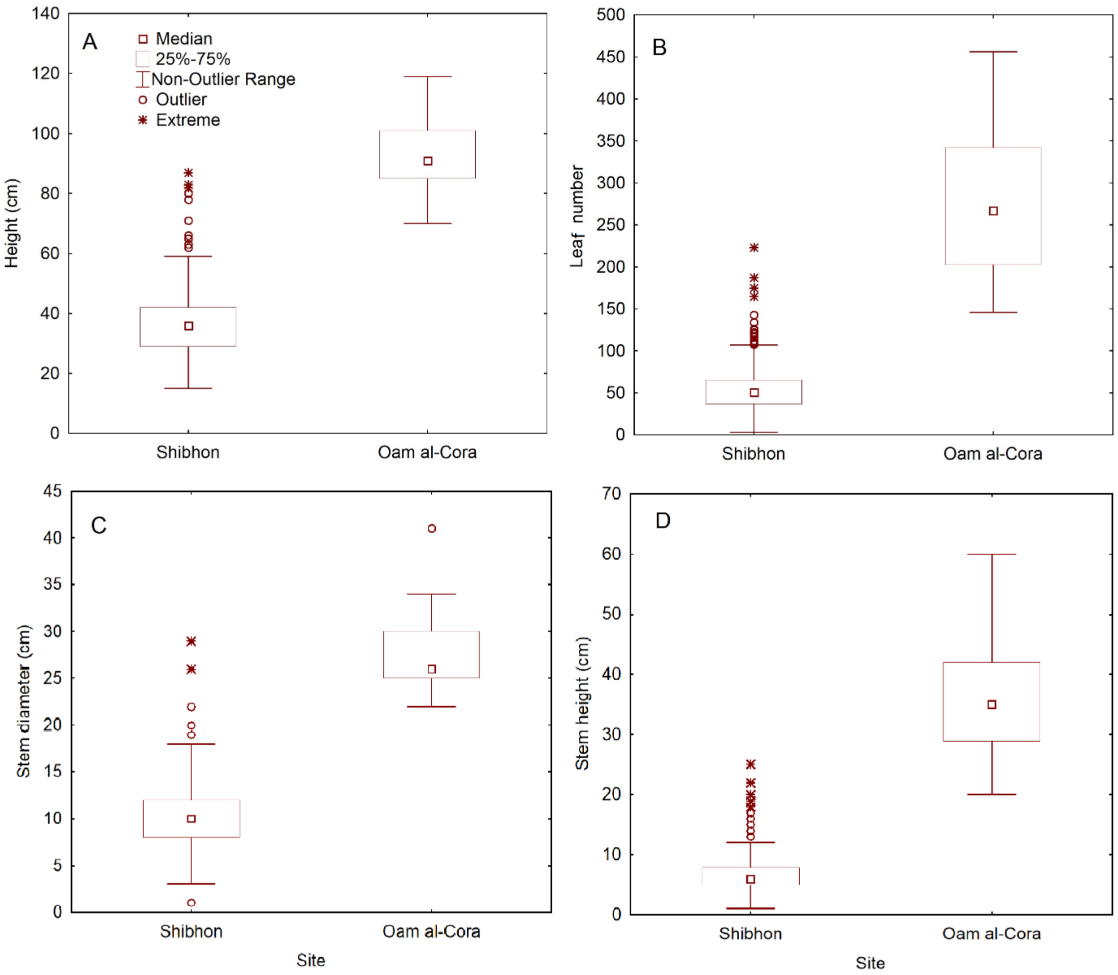


8.3.3 Comparison with Oam Al-Cora site

We compared the 2014 measurements from the Shibehon site (watering comprising only irrelgular irrigation early in the study, and fencing broken at times) with those recorded in 2014 from the plants at the Oam Al-Cora elementary school garden (irrigated weekly and continuously fenced). Fig. 3 shows the statistically significant differences between the two sites. In all measured parameters, the plants at Oam Al- Cora performed better than those at Shibehon. Thus, the mean tree height at the school was 92.9 cm (SD 12.41), i.e.,156% greater than at Shibehon, the mean number of leaves was 281.3 per tree (SD 82.64), i.e., 428% greater, the stem was developed by all trees, with its height averaging 36.4 cm (SD 9.86), i.e., 446% greater, the mean diameter at ground-level was 27.6 cm (SD 4.64), i.e., 167% bigger, and the vitality value averaged 1.0 (SD 0.00), i.e., all the trees at the school were in the best vitality category.

Appendix 3: Dragon blood trees in Ras-Ayre (left) and Oam al-Cora (right) plantations

Figure 3: Boxplot showing differnces of studied *Dracena cinnabari* seedling characteristics (Height - A, leaf number - B, stem diameter - C, stem height - D) between Shibehon and Oam al-Cora sites in 2014.



All studied seedling growth characteristics (height, leaf number, stem diameter, stem height) were significantly greater at Oam al-Cora than at the Shibehon site. Moreover, seedling vitality was significantly better at the Oam al-Cora site ($p < 0.05$, see Fig. 3).

Table 2: ANOVA results for the effects of Site on *Dracaena cinnabari* seedling characteristics (height, leaf number, stem diameter, stem height, vitality)

Characteristic	**Degrees of freeedom**	**F**	**p-value**
Height	1	520.84	0.000
Leaf number	1	1115.493	0.000
Stem diameter	1	163.530	0.000
Stem height	1	556.54	0.000
Vitality	1	909.232	0.000

8.4 DISCUSSION

Our study enabled us to document juvenile growth stages of dragon blood tree, to record the juvenile growth dynamics in different conditions, and also to make some tentative inferences about the roles of herbivory and water availability on the species' growth dynamics. As mentioned above, the vegetative growth phase of dragon blood tree has previously been divided by Habrová (2005) and Attore et al. (2007) into three and four stages, respectively. However, the juvenile growth stages of dragon blood tree were not studied in detail until now (these stages are followed by the adult stage, described well by Adolt et al. (2012), which begins after first flowering, when the dichotomously branching crown is created). Here, using the observations of this species for the first two years of their lives in greenhouse conditions documented by Hubálková et al. (2016), along with the present study's observations of seedlings from 6 to 13 years and the findings from other studies, we have constructed the following classification of the juvenile stages of dragon blood tree:

Seedling – this stage is characterized by height increase being realized through leaf elongation. In both irrigated, fertilized nursery conditions and in controlled, greenhouse conditions the stage lasts two to three years (described well by Hubálková et al. 2016). *In situ*, in natural conditions, this stage lasts minimally five years, probably more. The completion of leaf elongation defines the end of this stage.

Early juvenile stage – the number of leaves increases, and height growth is realized by addition of new leaves to the rosette. This stage typically lasts 5 to 10 years, but can be as short as 3 years and as long as 15 years. The appearance of stem formation defines the end of this stage.

Medium juvenile stage – the onset of this stage is defined by the first appearance of the stem, and height increase is realized by stem growth, with mean annual increment estimated by Adolt and Pavliš (2004) at 1 cm per year. The end of this stage is defined by the stem height reach in 100 cm, which typically occurs when the tree is about 100 years.

Late juvenile stage – the stem height is more than 1.0 m and the tree is beyond the influence of goat browsing. This stage lasts between 100 and 150 or more years, and its end is defined by the onset of first flowering.

The recognition of these ontogenetic stages can help in more precisely projecting population dynamics for natural populations of this species as well as in assessing the efficacy of conservation and propagation efforts over time. Nevertheless, as mentioned above, widespread regeneration failure of dragon blood tree has already been well documented. Although our study was not designed to rigorously test any of the hypotheses for the lack of natural regeneration of this species, our results are suggestive regarding the roles of grazing and water availability and their interplay. In particular, the dramatic increase in seedling mortality that we observed at the Shibehon plantation after the fencing was damaged is indicative of the huge role played by goat herbivory in limiting dragon blood tree regeneration. These results are consistent with those of a study explicitly examining the effect of fenced exclosures (Habrová & Pavliš 2015). Indeed, although we did not compare the relative roles of herbivory and other possible drivers, they are compatible with the view, held by various researchers, that the lack of dragon blood tree regeneration is due principally to overgrazing (Adolt & Pavliš 2004; Habrová 2004; Hubálková 2011; Brown & Mies 2012).

Our evidence regarding the potential role of drought is more nuanced, in that even though there was no irrigation at the Shibehon planation at the time, during the one-year period 2012-2013 after the fence was rebuilt, the growth capability of the seedlings after browsing damage was high, with the mean annual height increment increasing to 7.59 cm and mean leaf number increment increasing to 19.14. However, the growth parameter data we recorded at that site over the of 8-year study period showed dragon blood tree to be among the slowest growing tree species in the world, with a mean annual height increment of only 2.65 cm/yr. Other studies have found slow D. cinnabari growth to be caused especially by the extreme climatic conditions of the arid tropical zone of Socotra Island (Culek et al. 2006; Scholte & de Geest 2010), although in order to survive such arid conditions, this species has evolved morphological, anatomical and physiological adaptations, as discussed by Nadezdina et al. (2015). Moreover, slow growth, by itself, would not prevent regeneration, and if the growth rate observed is typical of the species in response to climate typical of its range, then this would not explain its current failure to regenerate.

On the other hand, extremely slow growth, in combination with elevated herbivory pressure, could severely limit regeneration, because the seedlings would take such a long time to escape from the browse zone. Indeed, it can take dragon blood tree seedlings more than 50 years to be large enough to escape from goat browsing. In this regard, our findings from Oam al-Cora can be quite important, because at that site, which was consistently irrigated weekly, stem growth started sooner and growth parameters were 156% to 446% higher than the corresponding values at the Shibehon plantation. Although the two sites likely differed in various environmental variables (and definitely showed substantial differences in average monthly temperatures), the great disparity in growth parameters suggests that increased water availability can accelerate growth and thus speed escape from the browse zone. Similarly, Pietsch et al. (2013) found that other land improvement measures, including steps to increase soil fertility and reduce its erosion, are also advantageous to the growth of *D. cinnabari*.

It should be kept in mind that our findings, although they – similarly to other studies – suggest that browsing is the major source of mortality for dragon blood tree seedlings, do not exclude the possibility that increased aridity, whether due to long-term natural climate oscillations (Rampellbergh et al. 2013) or anthropogenic climate change (Attore et al. 2007) has contributed to the poor natural regeneration of this species. In fact, the hypothesis of Hildebrandt and Eltahir (2006) relating aridification, desertification, and deforestation of tropical arid landscapes to the loss of horizontal precipitation would seem to be particularly applicable to *D. cinnabari* on Socotra, although it would likely directly affect older trees (i.e., the final stage juveniles and adults exhibiting the umbrella-shaped growth form that captures fog) more than seedlings. Moreover, aridity could affect natural regeneration through various mechanisms other than making the juvenile plants more susceptible to herbivory, as for example, it could potentially hinder seedling establishment, which was not at all considered within our study, as the seedlings were started in greenhouse conditions and then planted individually.

Nevertheless, our findings suggest a potentially efficient conservation strategy for dragon blood tree conservation, in which seedlings are grown inside irrigated herbivore exclosures until they escape from the browse zone, with the irrigation speeding growth and therefore shortening the period for which the would need to be maintained. As we found at Shibehon, however, competition between humans and plants for the irrigation system can inhibit reliable provision of water to the juvenile trees. Therefore, it would be essential for some benefit to be rendered to the local populace in exchange for allowing the water to reach the trees.

One solution would for the trees to be the focus of ecotourism, bringing revenue to the area and building public support for conservation (Damme & Banfield 2011) and regeneration of dragon blood tree populations. Indeed, the unique umbrella-shaped growth form of adult dragon blood tree gives the landscape of Socotra's highlands an otherworldly appearance (see Adolt et al. 2012) and as the flagship endemic of the island this species already attracts visitors and supports increasing ecotourism (Scholte et al. 2011). However, the original concept of ecotourism does not currently seem to work on Socotra because of the low degree of tourist infrastucture (Damme & Banfield 2011), and tourism pressure has actually been cited as a driver of the loss of biodiversity there (Damme & Banfield 2011; Scholte et al. 2011). In particular, the current tourist development does not follow any planning concept, and employees in this sector are untrained or unaware of the fragility of the island's ecosystems, while the majority of tourists do not grasp the importance of respecting local culture and nature (Mayer 2009). This implies the need for improved planning, infrastructure, and outreach initiatives to enable ecotourism to promote rather than hinder conservation of dragon blood tree and the native biota more generally.

Finally, it should be noted that other species in the dragon tree group of genus *Dracaena* also show alarmingly low population densities often linked to weak regeneration, and the conservation strategy described above would be applicable to them to the extent that the drivers of their decline overlap with those for dragon blood tree. 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 (IUCN) Red List (IUCN 2016). Thus, for the *Dracaena ombet* occurring on the highest slopes of Gebel Elba National Park in Egypt (Kamel et al. 2015), only 46% were alive, only 27% were healthy, and only 1% were young, indicating not only a low regeneration rate, but also poor overall health. Moreover, Kamel et al. (2015) have suggested that 80% of these populations may soon be extinct. Severe decline has also been documented for the rest of the *D. ombet* distribution in NE Africa (Aynekulu et al. 2012).

Similarly, both *Dracaena draco* and *D. tamaranae* appear on the Red List of endangered species in Spain (Moreno 2008) and have low population densities and weak regeneration (Marrero et al. 1998). Indeed, the first of these two species has already been extirpated from some islands. A lack of natural regeneration was also recorded for *D. cambodiana*, endemic to Hainan Island (China) by Zheng et al. (2012). Additionally, Wilkin et al. (2012) described the endemic *Dracaena jayniana* of Thailand as endangered, and Zheng et al. (2012) assess the *D. cambodiana*, endemic to Hainan Island (China), as endangered and recently occurring in only ten isolated populations. The latter species has specifically been noted to display a lack of natural regeneration. Finally, although we found no published information on regeneration of *D. serrulata* in the Arabian Peninsula, we have observed the populations there to be rare, scattered and overmatured, with regeneration lacking there too (pers. obs.).

Although in the case of the Gebel Elba *D. ombet* populations, it has been stated that they are threatened by drought (Kamel et al. (2015), it is possible that general attributes of dragon trees and their populations might at least partly explain why many of these taxa are endangered an show low regeneration. Thus, Zheng et al. (2012) have categorized *Dracaena cambodiana* as a very slowly growing tree, and we suggest that this characteristic could contribute in multiple ways to low regeneration, including not only increased vulneribility to herbivory, as discussed above, but also relative inability to take advantage of temporary favorable periods, as well as slow evolutionary responses to changing conditions due to long generation times. Moreover, endemism, especially in the form of small, isolated populations, can impose further evolutionary constraints due to low genetic diversity (see Zheng et al 2012).

Here we suggest exploring a particular strategy for restoration of dragon blood tree, involving the use of exclosures and irrigation (and development of the appropriate outreach and incentives to support such initiatives). Additionally, we propose that the causes of regeneration failure and associated population declines be investigated across the dragon tree group so that common drivers can be addressed through broadly applicable strategies where appropriate. In the case of dragon blood tree and likely other taxa within this group, extremely slow growth and long generation times suggest that the conservation and restoration efforts will require a commitment to active management that will last decades, rather than a short-term approach.

Supporting Information

Mean monthly air temperature and humidity from Shibehon and Hadibo localities (Appendix 1), Naeslund's (1936) height curve showing relationship between stem diameter and stem height are available online. Queries should be directed to the corresponding author.

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IV

9. PRELIMINARY ANATOMICAL STUDY ON SECONDARY THICKENING PARTS OF ENDEMIC *DRACAENA CINNABARI* BALF. F. FROM THE SOCOTRA ISLAND

Irena Hubálková*, Jakub Houška, Jan Kubíček, Pavel Mazal, Jindřich Pavliš, Josef Pohořalý, Gabriela Vichrová

Mendel University in Brno, Faculty of Forestry and Wood Technology
Brno, Czech Republic

Martin Duchoslav

Palacký University in Olomouc, Faculty of Science, Department of Botany
Olomouc, Czech Republic

Abstract

The present study investigates anatomical structure of secondary thickening parts (root-stem-branch) of endemic monocot *Dracaena cinnabari*. The measurement of microscopic structure parameters was carried out using analytical imaging. The differences between vascular bundles were determined. The results show presence of concentric vascular bundles in all investigated plant organs. In general, the parenchyma cells cover majority of the total area (an average of 77 %), much less covers xylem (an average of 19 %) and phloem (an average of 4 %). The results indicate that the plant body is well adapted to sub-tropical climate regimes and specific environmental conditions prevailing on the island such as limited access to soil moisture and sufficient nocturnal dew which is essential for plant growth and survival.

Keywords: Dragon's Blood Tree, monocot, anatomy, secondary thickening, image analysis

9.1 INTRODUCTION

Dracaena genus is a living monocot representative of the Tertiary flora (Habrová et al. 2009). In the APG IV classification system, it is placed in the family *Asparagaceae*, subfamily *Nolinoideae* (The Linnean Society of London 2016). Endemic *D. cinnabari* growing on Socotra Island is unique for its tree habit as well as other 6 arborescent species out of a total of at least 60 species of *Dracaena* genus. According to Brown and Mies (2012), its closest relatives are found in southern Arabia (*D. serrulata*), eastern part of Africa (*D. ombet, D. schizantha*), Macaronesia and Morocco (*D. draco*).

Dracaena cinnabari grows in mist-affected areas of the island, usually above 300 m up to the highest mountain areas (Brown and Mies 2012). According to some studies (e.g. Hubálková 2011, Miller and Morris 2004), the occurrence and distribution of Dragon’s Blood Tree on the island is dangerously limited and seriously affected by excessive livestock grazing. *Dracaena cinnabari* as Socotra’s most iconic plant suffers from lack of regeneration due to a decline in the quality of habitat caused principally by overgrazing.

Dracaena cinnabari has been a focus of conservation efforts and research activities in recent years (e.g. Adolt et al. 2012, Attore et al. 2007, Habrová et al. 2009), but there are very few current studies on the anatomy and physiology (Adolt 2001, Jura-Morawiec and Wiland-Szymańska 2014).

D. *cinnabari* is a single-trunked tree with umbrella-shaped crown, branches forming a crown consist of sausage-shaped sections (Miller and Morris 2004). Elongated leaves are densely tufted, tipped and scleromorphic as a specialized feature to prevent excessive loss of water (Brown and Mies 2012). Earlier botanists (Scott and Brebner 1893, Tomlinson and Zimmermann 1967 and 1969) in their studies of palms and other arborescent monocotyledons devoted considerable attention to a few forms with secondary vascular tissues. Arborescent *Dracaena* species achieve stem thickening by means other than due to a fascicular cambium. In *Dracaena* sp. there is a 'typical' secondary thickening meristem (STM) with derivatives of radially aligned chaos of vascular bundles in a parenchymatous ground tissue, resulting in a 'woody' underground stem (Carlquist 2012, Rudall 1995). The exact definition of STM is problematical. Rudall (1995) mentions a clear relationship between STM and primary thickening meristem (PTM), the latter being almost ubiquitous in monocots.

Very little is known about root system of the *Dracaena*, which is not easily obtained for a study. Based on previous observations, successive growth of *Dracaena* trees is accompanied by vigorous development of horizontal roots which run far beyond the vertical projection of the crown (Hubálková et al. 2014). Their thickness generally exceeds that of the tap-root. Most of the horizontal roots are found within the upper 30 cm (Jeník 2014).

Adolt (2001) mentions presence of tracheids in xylem of the stem and presence of tracheas in metaxylem of young roots in *Dracaena* plants. According to Adolt (2001), there are collateral vascular bundles surrounded by sclerenchymatic sheaths and uniformly arranged parenchyma cells in young stems and on the other hand concentric vascular bundles without sclerenchymatic sheaths, surrounded by in-lines arranged parenchyma cells in secondary thickening stem. Jura-Morawiec and Wiland-Szymańska (2014) have studied the issue of the structure of amphivasal secondary bundles of *Dracaena draco* stem. They have described a secondary growth of stem as formation of amphivasal vascular bundles in which a centrally located phloem is surrounded by a ring of xylem cells. Röseler (1889) cit. in Jura-Morawiec and Wiland-Szymańska (2014) pointed out that the type of vascular bundles, their shape, distribution and the type of tracheary elements present become a useful criteria to identify secondary body in a cross section. According to Myburg et al. (2013), the parenchymatous pith is creating in central part of older stem. Mauseth (2009) adheres to the theory of diffuse secondary growth consisted of ground parenchyma cells and additional vascular bundles proliferation near the periphery.

The main goal of this paper is to complement previously published data on *Dracaena*'s anatomical structure by study of the anatomy of secondary thickening organs. Anatomic examination and description of roots, stems and branches of Dragon's Blood Tree is key to clarification yet unexplained questions about thickened organ's features associated with specific tree habit and ecological conditions. So far, little information is known about secondary thickening in arborescent *Dracaena*'s and no publication pursues all secondary thickening organs in *Dracaena cinnabari* despite its threat and limited distribution. This preliminary study serves as the basis for further ecophysiological research of the species.

9.2 MATERIAL AND METHODS

Dracaena cinnabari is a unique endemic plant occurring on Yemeni Island of Socotra whose floral endemism rate making it one of the most biodiverse islands in the world (Miller and Morris 2004).

9.2.1 Study area

The samples of secondary thickening parts (roots, stems and branches) of *Dracaena cinnabari* were collected from fresh wind-throw on Firmihin plateau on the Socotra Island (N 12°28´8.59´´, E 54°00´6.02´´). On Firmihin, there is the only closed forest stand of Dragon's Blood Trees because the plateau is isolated and protected by two deep valleys. As regards the type of relief, this is an elevated plateau with Tertiary limestone bedrock (Pietsch and Morris 2010). The wind-throw is at the altitude of 650 m ASL. The climate is strongly influenced by the seasonal Monsoon winds, blowing from the North-East during the period October-May and from South-West during the period June-September. Nocturnal dew is far more important to the water supply than monsoonal rain. The average annual air temperature is 23.7 °C and the average annual precipitation is 103.8 mm (Král 2005).

9.2.2 Field work

The wind-throws occurs sporadically in localities where *Dracaena* trees grow, especially due to lack of soil and strong fixing of anchor roots in parent material. Moreover, taking of live plant samples is strictly prohibited because of nature protection of the island. Therefore, the increment cores were taken from branch, stem, tap-root of the only found wind-throw on Firmihin. The age of the tree was estimated on 380 years according to the procedure described in Adolt et al. (2012). The basic dendrometric characteristics of the wind-throw, characterized by average values, are presented in Table 1.

Table 1: Basic dendrometric characteristics of the wind-throw

Dendrometric characteristics	Breast-height diameter (cm)	Tree height (m)	Crown base height (m)	No. of branch sections
Parameters	62	7.5	4.2	20

9.2.3 Laboratory work

Samples in the form of microcores were taken from all cardinal points of the stem. The increment cores were taken by means of a Haglöf Increment Borer. Sampling was conducted at the height of 1.3 m ± 20 cm. From branches and roots were taken 15 blocks of wood with peel (5 blocks from branches, 5 blocks from buttress roots and 5 blocks from tap-root). The increment cores were located separately in histological cassettes and immersed in fixative solution FAA (formaldehyde-acetic acid-ethanol) for a week. For longer storage, the samples were immersed in the solution of 96% ethanol and distilled water with the proportion of 30:70. Before further processing, the redundant wood and peel were cut off, and then the samples went through an alcohol series consisting of ethanol of various concentrations (70%, 70%, 90%, 90%, 95%, 100%, 100%) and xylene (triple maceration). The time of soaking the microcores was one and half hours in each solvent. The reason for this step is the preparation for the stage when the samples are impregnated in paraffin so that they could be cut using the rotation microtome. Paraffin is not soluble in water that is why the samples are dehydrated by ethanol. Then the ethanol has to be displaced by xylene which is mixable with paraffin. The samples are left in the paraffin for at least four hours.

The samples were placed in Petri dishes, embedded in paraffin by dispenser Leica EG 1120 and heated in oven at 60°C for 4 hours. After that, the samples were put in metal moulds and the moulds were filled by means of paraffin dispenser. When this cooled down, the paraffin block was taken out of the mould and cut using the rotation microtome (Leica RM 2235) so that a part of the microcore was uncovered. The microcores were then immersed in water overnight for repeated hydration so that they could be more easily cut on the microtome. Subsequently, microsections of 14 µm thickness were produced using the rotation microtome; these were laid on water surface (40°C) in Leica HI 1210. This straightened the microsections, which were then taken out and mounted on glass slides with special glue Albumin. The slides with specimens were dried for 5 minutes in the temperature of 60°C and then dried completely in the air. Further, the specimens went through another alcohol series, this time connected with dying. To highlight the non-lignified parts, Astra Blue stain was used and to highlight lignified parts safranin was used. The times of sample soaking are presented in Table 2.

Table 2: Times of microsection soaking before closing the specimens

Bioclear	30 min
Bioclear	30 min (displacement of paraffin)
Ethanol (96 %)	15 min
Ethanol (96 %)	15 min (displacement of Bioclear)
Safranin	5 min (dyeing of lignified parts)
Ethanol (96 %)	soaking, rinsing
Astra Blue	3 min (dyeing of non-lignified parts)
Ethanol (96 %)	soaking, rinsing
Ethanol (96 %)	soaking, rinsing
Xylene	soaking, rinsing

The specimens were closed with Canadian balsam and a cover slip. Cover slips of the resulting microscopic specimens were loaded with small magnets to dry (Vichrová et al. 2011).

9.2.4 Image analysis

The measurement of microscopic structure parameters was carried out using NIS – Elements AR image processing tools consisting of digital 5 Mpix camera Nikon DS – Fi 1 connected with a microscope Nikon Optiphot 2.

Prepared microscope slides were imaged using Nikon 4x objective.

Analytical Imaging can be summarized as follows:

- Taking a microphoto (displaced area ca. 2480 x 1860 µm).
- Creating a mask (range of interest), so-called sections in the image area where the measurements will be done. Three square masks (each with an area of 608481 μm^2) have been created for each analysed image.
- Creating the binary image of the area of xylem, phloem and parenchyma cells. Sequential measuring the areas of binary images (Fig. 1).
- Measuring internal diameter (semi-major and semi-minor axis) of all vessels (tracheae) within the masks and cross-sectional area calculation.
-

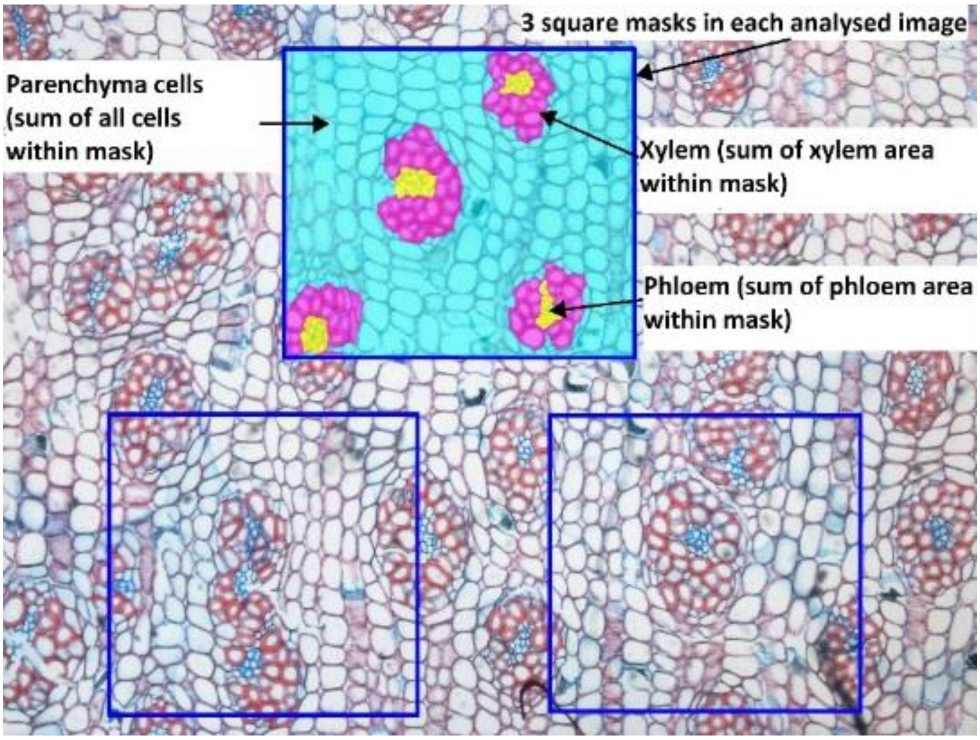

Fig. 1: Image area with 3 identic masks with binary image of xylem, phloem and parenchyma

9.2.5 Data analysis

To assess differences in the proportional area of xylem, phloem and parenchyma between three studied cross-sections (root, stem and branch), we used Multivariate ANOVA (MANOVA) with three dependent variables (proportional area of xylem, phloem and parenchyma), one fixed factor (organ including central part of stem, branch and root) and one random factor (masks) nested within a fixed factor. Wilks lambda was used as a test statistics. Planned vector comparisons between pairs of organs were done after significant effect of global test. Once a multivariate test had found a term significant, a nested ANOVA was used to determine which of the variables and factors were responsible for the significant effects. Data on proportions were log-ratio transformed before analyses (Aitchison 1986). A nested ANOVA was used to assess differences in area of vessels between central part of stem, root and branch as well as in case of various parts at cross section of stem (stem I – a pith; stem II – central part between stem I and stem III; stem III – peripheral part). Area of vessels was dependent variable, fixed factor comprised different organs or different zone of stem, and two random factors comprised the mask nested within the snap nested within the zone. Data were log transformed before analysis to improve normality and homoscedality. Tukey multiple comparison test was used to identify the differences in proportional area of respective organs between secondary growing parts of the plant. Box-and-whisker plots were used for visualization of untransformed data.

9.3 RESULTS

The results show differences between the anatomical structures of secondary growing parts. Similar concentric vascular bundles have been detected in all studied plant organs.

9.3.1 Xylem-Phloem-Parenchyma in Root-Stem-Branch

Relative area proportions of xylem, phloem and parenchyma significantly differed between each other studied cross-sections (Table 3, planned comparisons all $P < 0.05$). Parenchyma cells in central part of root, stem and branch always occupied on average more than 74 % of area but their proportional representation was significantly higher in root and branch in comparison with stem (Table 3, Fig. 2).

Xylem occupied on average from 17 to 23 % of area and occupied significantly higher area proportion in stem in comparison with both root and branch (Table 3, Fig. 2). Phloem occupies from 3 to 4 % of area on average with significantly higher area in branch in comparison with root (Table 3, Fig. 2). Xylem and phloem positively correlated each other for each organ (all r > 0.88 and P < 0.05).

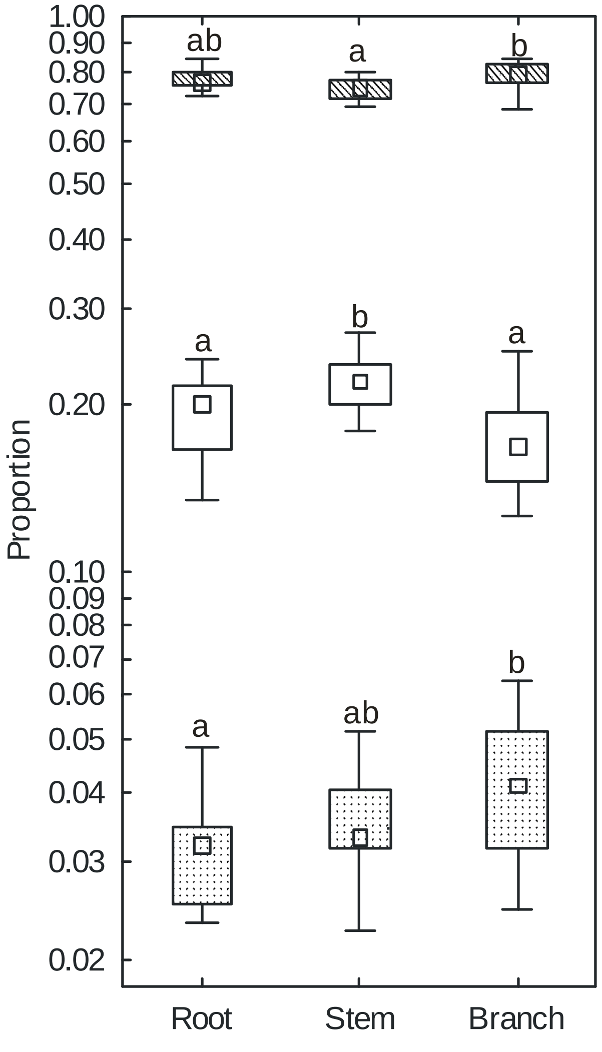

Fig. 2. Box-plots of the proportional area of parenchyma, xylem and phloem (top-down) in three studied cross-sections (root, stem and branch). Different letters suggest significantly different mean proportions of the respective tissue between organs (Tukey multiple comparison test at P ≤ 0.05).

9.3.2 Xylem-Phloem-Parenchyma in Stem III-Stem II-Stem I

Relative area proportions of xylem, phloem and parenchyma were similar between stem I and II (planned comparison, P = 0.459) and both significantly differed from stem-III (Table 3, planned comparisons, both P < 0.02). Parenchyma cells occupied on average from 74 to 78 % of area in various parts at cross section of stem with significantly lower parenchyma area in stem-II in comparison with stem-III (Fig. 3, Tab. 3). Xylem occupied from 19.1 % area in stem I (i.e. a pith area) to 22.1 % area in stem II (i.e. between pith and cork) and stem-II had significantly larger relative area in comparison with that in stem-III (Fig. 3). Phloem occupied 3.0 % area in stem I, 3.5 % area in stem II and 2.7 % area in stem III. There were no significant differences between the area of phloem across the stem (Fig. 3, Table 3).

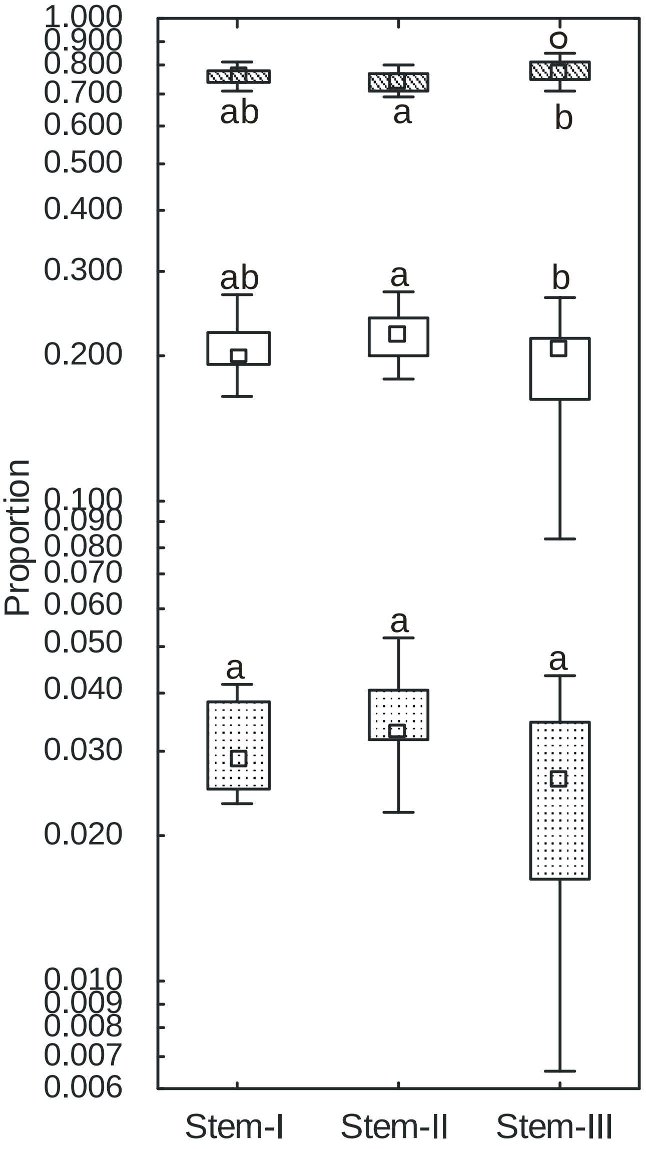

Fig. 3. Box-plots of the proportional area of parenchyma, xylem and phloem (top-down) in the cross section of a stem (stem-I, stem-II, stem-III). Different letters suggest significantly different mean proportions of the respective tissue between organs (Tukey multiple comparison test at P ≤ 0.05).

Table 3: Effects of zone and mask nested within zone on proportions of xylem, phloem and parenchyma in a cross-section (root-stem-branch, and stemI-stemII-stemIII). (a) Results of MANOVA, (b) results of separate nested ANOVA on each trait. Significant effect (P≤0.05) have P-values in bold.

Group/trait	(a) MANOVA						(b)	Xylem		Phloem		Parenchyma	
	Source of variation	Wilks lambda	F	DF effect	DF error	P	DF effect	F	P	F	P	F	P
Root-stem-branch	zone	0.242	9.3	6	54.0	< 0.001	2	12.0	< 0.001	2.5	0.010	6.0	0.007
	mask (zone)	0.253	1.2	39	80.7	0.221	12	1.5	0.177	0.5	0.916	1.0	0.429
Stem I-II-III (zone)	zone	0.592	2.80	6	56.0	0.019	2	4.3	0.038	3.1	0.080	4.9	0.028
	mask (zone)	0.295	1.19	36	83.5	0.259	12	0.6	0.828	1.5	0.198	0.7	0.761

9.3.3 Area of vessels in Root-Stem-Branch

Except for higher area of vessels in branch in comparison with root, no significant differences were found in area of vessels between cross sections (Table 4, Fig. 4A). Area of vessels comprised 39.3 % of total area of vessels in the branch section while only 30.5 % and 30.1 % of total area of vessels in the root and stem cross sections, respectively.

9.3.4 Area of Vessels in Stem Cross Section

The area of vessels significantly increased from the inner to the outer parts of a cross section of the stem (Table 4, Fig. 4B). Area of vessels in the stem-III section thus comprised 54.5 % of total area of vessels in the stem while that in the stem-I section comprised only 18 %.

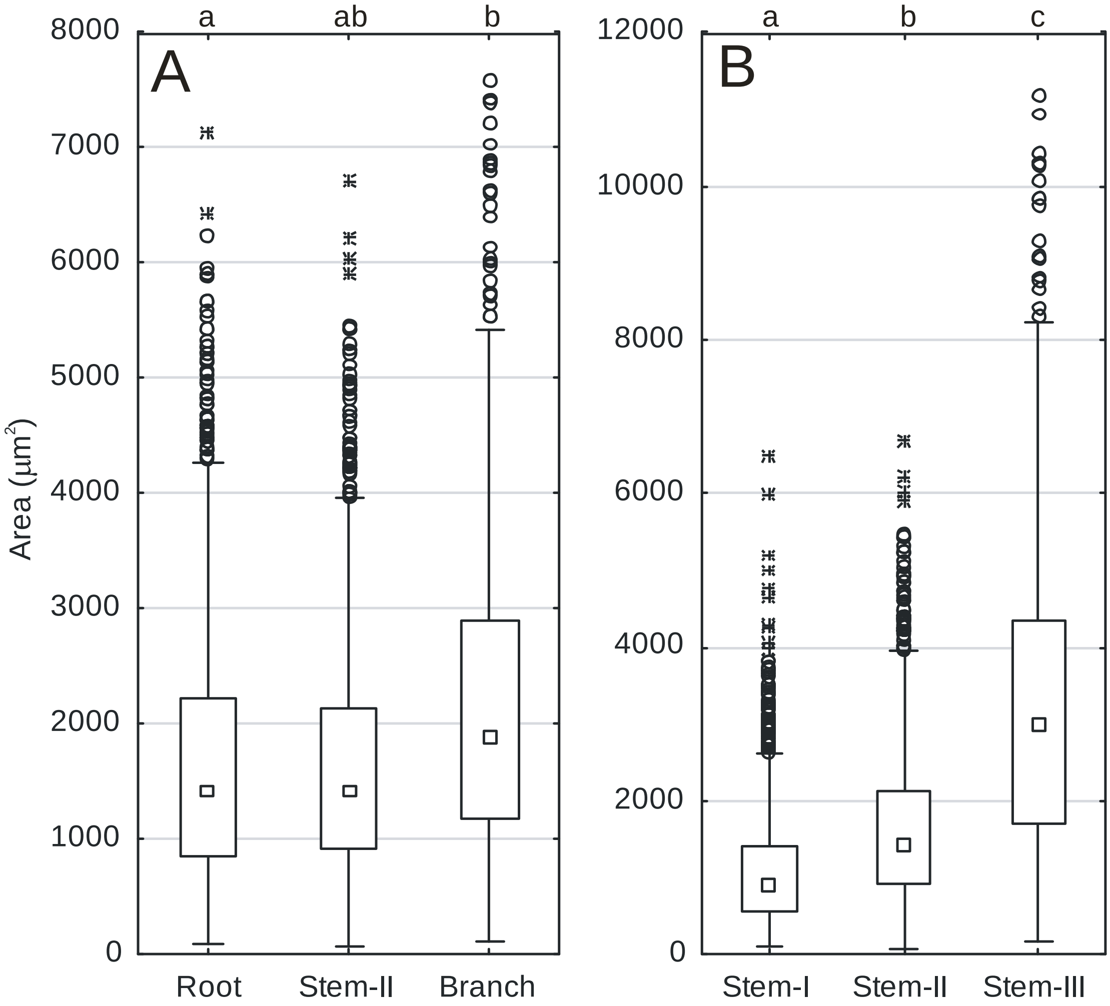

Fig. 4. (A) Box-plots of the area of vessels in three studied cross-sections (root, stem-II and branch). (B) Area of vessels in the cross section of a stem (stem-I, stem-II, stem-III). Different letters suggest significantly different group means (Tukey multiple comparison test at P ≤ 0.05).

Table 4: Effects of zone and snap nested within zone and mask nested within snap on area of vessels in a cross-section (root-stem-branch, and stemI-stemII-stemIII) tested by nested ANOVA. Significant effect (P≤0.05) have P-values in bold.

Group		Root-stem-branch		Stem I, II, III zone	
Source of variation	DF	F	P	F	P
zone	2	4.7	**0.034**	96.9	**< 0.001**
snap (zone)	12	2.7	**0.014**	2.1	**0.047**
mask (snap(zone))	30	5.7	**< 0.001**	4.4	**< 0.001**

9.4 DISCUSSION

We present a unique data on structure of secondary thickening parts (roots, stems and branches) of *Dracaena cinnabari*, an endemic single-trunked monocot tree growing on Socotra Island. The study material was sampled from one fresh wind-throw which guarantees similar growth conditions and thus allows direct comparison between anatomical structures. Significant differences in anatomical structure between secondary thickening parts and organs of *Dracaena* mature tree have been found. On the other hand, similar concentric vascular bundles were found in stem, branch as well as in the roots as an adaptation to specific climatic and environmental conditions. Thus the anatomical structure differs considerably from the vast majority of monocots and dicots (Rudall 1995; Tomlinson and Zimmermann 1969).

In general, the parenchyma cells cover majority of the total area (an average of 77 %), much less covers xylem (an average of 19 %) and phloem (an average of 4 %). Our outcomes confirm previous study (Adolt 2001) showing that most of the space inside stem and roots is filled by parenchyma cells. Concerning individual parts of plant body, we observed significantly larger proportional parenchyma area in branch and slightly also in root compared to stem. Parenchyma is the most common plant tissue and plays a major role as a water reservoir (Mauseth 2009). Function of drought resistance through parenchymatous tissues for storing water and starch (as found in our images) is essential for plants growing in dry subtropics. High moisture in the form of dews and fogs absorbed through plant cuticle is very important for *Dracaena* trees (Scholte and De Geest 2010). The plants are well adapted to interception of atmospheric humidity by extremely long horizontal skeletal roots, wide crowns and branches with sausage-shaped sections (Miller and Morris 2004). According to our study, these sections are filled with parenchyma cells as an important storage element.

Xylem occupied larger proportional area in cross-section of stem compared to root and branch. This interesting outcome indicates less importance of root system of Dragon´s Blood Tree as „a water pump“ compared with most plant species (Myburg et al. 2013). Apart from water distribution, xylem ensures transport of mineral nutrients and phytohormones in the plant and provides mechanical support which is extremely important for *Dracaena cinnabari* as a monocot plant with a possibility of secondary thickening. As the stem is from three quarters filled with parenchyma, strength is necessary attribute for stem elongation.

Opposite results were detected in determining the phloem area. Phloem occupied larger relative area in cross-section of branch compared to that of root and slightly also stem. The assimilate-conducting sieve elements are the most highly specialized cell types in plants. As is known, phloem is a living vascular tissue responsible for transport of sugars (starch or sucrose) and other molecules such as proteins and mRNAs via the pressure difference between source (leaves) and sink (roots, vegetative tips or fruits) (Schulz and Thompson 2001). Phloem occurs largely in crown as in the place of source.

In case of various parts at cross section of stem, we observed different proportional representation of parenchyma, xylem and phloem between outer (i.e. a layer beneath the epidermis, Stem-III) and inner parts of the stem: there is significantly largest relative parenchyma area in cross-section of the stem III. In young plants, the tissues link all the parts of the plant, allowing water, nutrients, and other compounds to be carried throughout the plant. Our results support the hypothesis (Myburg et al. 2013, Mauseth 2009) that changing the position of vascular bundles depends on age. Specialized processes occur during secondary thickening when the secondary thickening meristem (STM) is developed outside the primary vascular bundles (Carlquist 2012, Rudall 1995). The activity of STM leads to production of secondary vascular bundles and “filling” parenchyma on its inner side only and densified parenchymatous cells on the outer side. As stated by Adolt (2001), most of the stem mass consists of parenchyma and scattered concentric vascular bundles. Our field observation and results of the measurements proved changes of „initial“parenchymatous tissue in the central part of stem (stem I) depending on plant age. The density is decreasing and the parenchymatous tissue decays gradually, until the central cavity is formed (Hubálková et al. 2014, Myburg et al. 2013). This hypothesis is also supported by the changes of xylem and phloem relative area at cross section of stem showing their largest proportional area in stem II, i.e. the part between initial and densified parenchymatous layers. It is important to note that cork cambium activity is normal and produces cork and secondary cortex at the outer region.

In the case of individual parts of plant body, there is significantly larger area of vessels in branch compared to root (Fig. 4A). It is probably one of the physiological adaptations to help *Dracaena* with low levels of soil water (Myburg et al. 2013). If a large amount of parenchymatous tissue in stem serves as a water reservoir, water transport rate from the stem into the branches and then into the leaves is one of the crucial plant strategies to cope with drought in the arid region. It is much more important for the plant to have the vessels in the branches than in the roots due to lack of soil water for most of the year (Myburg et al. 2013).

In the case of various parts of cross section of stem, there is significantly largest area of vessels in stem III compared to stem II and stem I (Fig. 4B). We can assume that this phenomenon is associated with age-related formation of vascular bundles and its concentration in the peripheral part of the stem, tightly on the inner side of secondary thickening meristem.

9.5 CONCLUSION

Because of the strict protection, island isolation and problematic export of plant samples, the anatomical features of *Dracaena cinnabari* have received little attention. This study reports preliminary results presenting anatomical structure and function of secondary thickening organs of such a unique arborescent monocot. The results obtained in this study indicate interesting differences of proportional area of xylem, phloem and parenchyma between root, stem and branch. The achieved results lead us to conclusion that plant body of *Dracaena cinnabari* is well adapted to specific environmental conditions of Socotra Island. Based on this study, we can determine whole-plant hydraulic conductivity and other properties which will help us to better understand the principles of ecophysiological adaptation of the species. Nevertheless, further studies on the species are advisable with respect to its importance and level of endangerment.

ACKNOWLEDGEMENT

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9.6 REFERENCES

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10. CELKOVÝ ZÁVĚR

Disertační práce si kladla za cíl nalézt odpovědi na otázky, které se týkají růstové a populační dynamiky endemického druhu dračince rumělkového (*Dracaena cinnabari*), jehož přirozená obnova je významně limitována intenzivní pastvou koz. Predikci populačního vývoje dračince na ostrově nelze posoudit bez znalosti délky životního cyklu, bionomie a ekologických nároků rostliny. Práce se zabývá možnostmi pěstování dračinců v kontrolovaných podmíkách ex situ i in situ jako způsoby ochrany, které mají potenciál k tomu, aby sehrály dlouhodobě klíčovou roli v záchraně druhu. Součástí disertační práce je rovněž studie sekundární stavby rostlinných orgánů dračince jako málo probádaného tématu, které přispěje k pochopení významu proměnlivosti struktur a fyziologických procesů.

První článek predikuje vývoj sub-populace dračince rumělkového na lokalitě Firmihin. Na základě určení pravděpodobnosti, s jakou jedinci v určitém věku odumřou, při znalosti současné věkové a prostorové struktury stromů na trvalé zkusné ploše byly vytvořeny modely vývoje dračinců v horizontu sta let. Z výsledků je zřejmé, že v případě zachování současných podmínek prostředí a tradičního pastevního způsobu hospodaření místních obyvatel lze očekávat 36% mortalitu, tj. z celkových 114 stromů na hektarové zkusné ploše odumře 41 jedinců během následujících 100 let. Je nutné zdůraznit, že na ploše se v současnosti nevyskytuje žádné přirozené zmlazení.

Druhý článek popisuje růstovou dynamiku dvou skupin sazenic dračince rumělkového ze dvou lokalit Firmihin a Skand. Jedná se o lokality s nejčetnějším výskytem druhu na ostrově. Sledování přírůstů nadzemních částí ex situ v kontrolovaných podmínkách přineslo zajímavé výsledky. Minimální výskyt zmlazení dračince pravděpodobně není způsoben nízkou klíčivostí semen, protože ze 100 zasetých semen vyklíčilo 84, přičemž nebyla použita metoda na zvýšení klíčivosti. Mortalita sazenic v průběhu dvou let činila pouhých 13 %. Z výsledků vyplývá, že v prvním roce pozorování byla rychlost výškového růstu i tvorba biomasy nadzemní části vyšší u sazenic ze Skandu. V druhém roce se situace změnila a skupina sazenic z Firmihinu jevila větší vitalitu než skupina sazenic ze Skandu. Růstový potenciál sazenic ze Skandu byl pravděpodobně regulován různými mechanismy prostředí, které postupně vedly ke zpomalení růstu. Regulačními činiteli, které indikují nižší míru rezistence u skupiny rostlin ze Skandu, mohou být vyšší nároky na světlo a vzdušnou vlhkost v kombinaci se stresem z přesazení.

Třetí článek se zabývá možnostmi obnovy dračince rumělkového in situ na ostrově Sokotra. Ve dvou oplocenkách byla v roce 2006 provedena výsadba tří až pěti letých sazenic z místní školky. Oplocení brání přístupu koz a růstové podmínky sazenic jsou zlepšovány pravidelným zavlažováním. Osmileté pozorování a pravidelné zjišťování dendrometrických parametrů rostlin vedlo k poměrně podrobnému dokumentování růstu a vývoje sazenic. Na základě dlouhodobých pozorování byla vytvořena nová a přesnější klasifikace růstových fází, která významně přispěje k pochopení populační dynamiky dračinců. Ukázalo se, že ochrana proti okusu je nejlepší prevencí mortality rostlin. Dále bylo zjištěno, že pravidelná irigace výrazně urychluje odrůstání sazenic z dosahu okusu kozami.

Čtvrtý článek je studií sekundární stavby rostlinných orgánů dračince. Vzorky kořenu, stonku a větve byly odebrány z čerstvého vývratu na Firmihinu. Následně vytvořené mikropreparáty řezů byly podrobeny analýze obrazu. Výsledky ukázaly přítomnost roztroušených amfivazálních cévních svazků ve větvích, stoncích a překvapivě i v kořenech, kdy floém je obklopen xylémem. Parenchymatické buňky vyplňují většinu plochy řezu (77 %), méně tvoří xylém (19 %) a floém (4 %). Zároveň byla zjištěna signifikantně větší plocha lumen cév na příčném řezu větví v porovnání s kořenem, což lze vysvětlit jako fyziologickou adaptaci rostliny na velmi nízkou půdní vlhkost a naopak vyšší podíl horizontálních srážek ve formě mlh, zachycených listy, větvemi a kmeny.

Dračinec rumělkový je významným endemickým druhem a třetihorním reliktem Sokotry. Prohloubení znalostí o tomto druhu a pochopení interakcí s biotickým a abiotickým prostředím je klíčové pro jeho ochranu, které je třeba věnovat nejvyšší pozornost.

11. SUMMARY

The PhD thesis was aimed at finding answers to unsolved questions regarding population dynamics of endemic *Dracaena cinnabari*. Its natural regeneration is seriously limited by intensive grazing. It’s not possible to assess the prediction of population development of Dragon’s Blood Tree on the island in case the life cycle length, bionomy and ecological requirements of the plant aren´t known. The PhD thesis deals with growing the *Dracaena* seedlings under controlled conditions ex situ as well as in situ as a protection method. Both methods have potential to play a crutial role in species preservation. The study of secondary growth in Dragon’s Blood Tree is also included as a little explored research issue which will contribute to understanding the importance of structures variability and physiological processes.

First paper predicts the sub-population development of *Dracaena cinnabari* on Firmihin. The models of plant development in a 100 years time horizon have been created based on determing the probability of plants dieback with knowledge of present age and spatial arrangement of the trees on permanent sample plot. The results show us 36% mortality, i.e. 41 trees from the total of 114 trees within a hectar plot will die in coming 100 years in case of maintaining the current conditions and traditional pasture-based farming. Currently, there is no natural regeneration on the sample plot.

Second paper describes the growth dynamics of two groups of *Dracaena* seedlings from Firmihin and Skand as the localities with the most frequent occurence of the species on the island. Growth monitoring ex situ under controlled conditions has provided interesting results. Low incidence of natural regeneration probably isn’t caused by the low germination capacity. 84 seeds germinated out of 100 planted seeds even though no method to improve seed germination was used. Seedling mortality rate within two years was only 13 %. Results show larger growth and volume increment during the first year in case of seedlings from Skand. The situation has changed in the second year when the seedlings from Firmihin were more vigorous compared with seedlings from Skand. Growth potential of seedlings from Skand was probably regulated by various environmental factors leading to slower growth. Regulating factors indicating low resistance in case of plants from Skand may be higher demand for light and air humidity in combination with stress from transplanting.

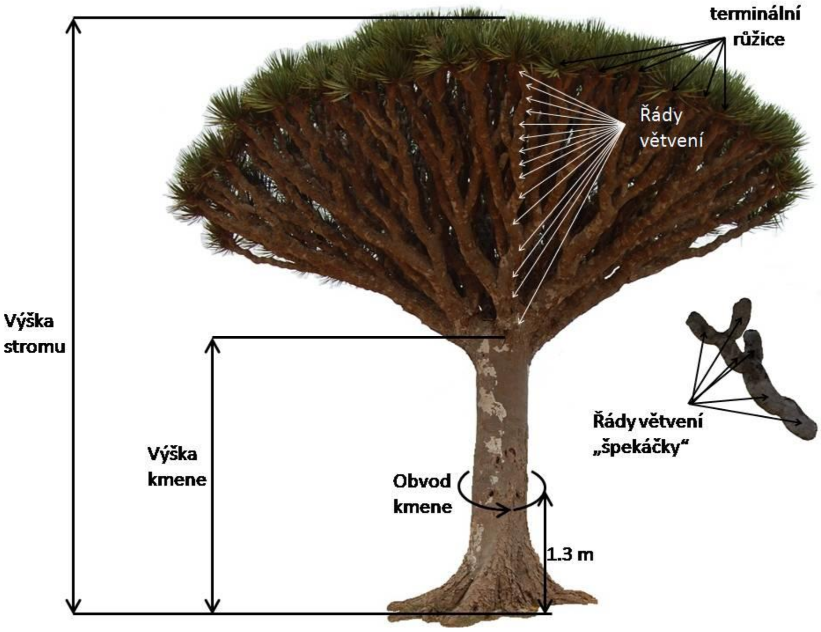
Third paper follows up regeneration possibilities of Dragon’s Blood Tree in situ on the Socotra Island. Three to five-year seedlings from local nursery has been planted in two separate fences in 2006. The fencing provides a barrier for goats and growth conditions of the seedlings are improved using regular irrigation. Eight years monitoring and dendrometric measurements resulted in comprehensive documentation of plant growth and development. New and accurate classification of growth stages has been developed based on long-term observations. The classification contributes significantly to population dynamics comprehension. The results indicate that the grazing control is the best prevention of plant mortality. It was also found that regular irrigation significantly accelerates growing up out of browsing range of goats.

Fourth paper is a study of secondary growth in Dragon’s Blood Tree. Root-stem-branch samples were taken from the fresh windthrow on Firmihin. Created microscope slides were processed by image analysis. Results indicate the presence of scattered concentric vascular bundles in branch, stem and even in root. Phloem is surrounded by xylem. Parenchyma cells fill most of the space (77 %), less area fills xylem (19 %) and phloem (4 %). Moreover, significantly larger lumen area of vessels in the cross section of branch compared to root was detected. This fact can be explained as a physiological adaptation to very low soil moisture content and higher proportion of horizontal precipitation in the form of fog or mist intercepted by the leaves and woody structures.

Dracaena cinnabari is a unique endemic species and Tertiary relic from the Socotra Island. Deeping our knowledge and understanding of the species and its interactions is essential to its protection.

12. FOTOGRAFICKÉ PŘÍLOHY

HUBÁLKOVÁ, I., 2011: Prediction of Dragon's Blood Tree (*Dracaena cinnabari* Balf. f.) stand sample density on Socotra Island. *Journal of Landscape Ecology*, 4(2): 5-17.



Obr. 1 Dendrometrické veličiny dračince rumělkového (Maděra a kol. 2011)

Obr. 2 a 3 Inventarizace dračinců na zkusné ploše na Firmihinu (foto autorka)

Obr. 4 Sub-populace dračince rumělkového na lokalitě Firmihin (foto autorka)

Obr. 5 Destrukce dračincových porostů na plató Diksam (foto autorka)

HUBÁLKOVÁ, I., 2011: Prediction of Dragon's Blood Tree (*Dracaena cinnabari* Balf. f.) stand sample density on Socotra Island. *Journal of Landscape Ecology*, 4(2): 5-17.

Obr. 6, 7, 8 Zachycení populační dynamiky dračinců na Firmihinu (fota autorka)

HUBÁLKOVÁ, I., MADĚRA, P., VOLAŘÍK, D., 2015: Growth dynamics of *Dracaena cinnabari* under controlled conditions as the most effective way to protect endangered species. *Saudi Journal of Biological Sciences*, doi:10.1016/j.sjbs.2015.09.011.

Obr. 9 Plody a semena dračince rumělkového (foto autorka)

Obr. 10 a 11 Semeno a semenáček dračince rumělkového (foto autorka)

HUBÁLKOVÁ, I., MADĚRA, P., VOLAŘÍK, D., 2015: Growth dynamics of *Dracaena cinnabari* under controlled conditions as the most effective way to protect endangered species. *Saudi Journal of Biological Sciences*, doi:10.1016/j.sjbs.2015.09.011.

Obr. 12 Klíčení vzorku semen dračince (foto autorka)

Obr. 13 a 14 Růst semenáčků (foto autorka)

Obr. 15 a 16 Dračinec se přirozeně zmlazuje pouze na nepřístupných lokalitách – Skand (foto autorka)

> HUBÁLKOVÁ, I., MADĚRA, P., VOLAŘÍK, D., 2015: Growth dynamics of *Dracaena cinnabari* under controlled conditions as the most effective way to protect endangered species. *Saudi Journal of Biological Sciences*, doi:10.1016/j.sjbs.2015.09.011.

Obr. 17 Sub-populace dračince rumělkového na lokalitě Skand (foto autorka)

> MADĚRA, P., HABROVÁ, H., ŠENFELDR, M., HUBÁLKOVÁ, I., LVONČÍK, S., EHRENBERGEROVÁ, L., ROTH, M., NADĚŽDINA, N., NĚMEC, P., ROSENTHAL, J., PAVLIŠ, J., 2016: Growth dynamics of endemic *Dracaena cinnabari* of Socotra Island suggest essential elements for a conservation strategy. V recenzním řízení v Conservation Biology.

Obr. 18 Úspěšná výsadba dračince v domácí zahradě v Hadiboh, stáří 12 let (foto autorka)

MADĚRA, P., HABROVÁ, H., ŠENFELDR, M., HUBÁLKOVÁ, I., LVONČÍK, S., EHRENBERGEROVÁ, L., ROTH, M., NADĚŽDINA, N., NĚMEC, P., ROSENTHAL, J., PAVLIŠ, J., 2016: Growth dynamics of endemic *Dracaena cinnabari* of Socotra Island suggest essential elements for a conservation strategy. V recenzním řízení v Conservation Biology.

Obr. 19 Výsadby v oplocence, Shibehon (foto autorka)

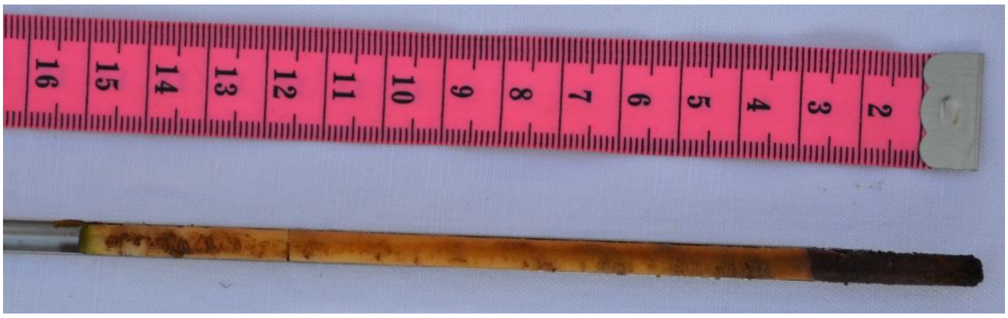
Obr. 20 Inventarizace výsadeb dračince v oplocence, Shibehon (foto P. Maděra)

> MADĚRA, P., HABROVÁ, H., ŠENFELDR, M., HUBÁLKOVÁ, I., LVONČÍK, S., EHRENBERGEROVÁ, L., ROTH, M., NADĚŽDINA, N., NĚMEC, P., ROSENTHAL, J., PAVLIŠ, J., 2016: Growth dynamics of endemic *Dracaena cinnabari* of Socotra Island suggest essential elements for a conservation strategy. V recenzním řízení v Conservation Biology.

Obr. 21 Výsadby ve školním dvoře, ZŠ Oam al-Cora, Hadiboh (foto autorka)

> HUBÁLKOVÁ, I., DUCHOSLAV, M., HOUŠKA, J., KUBÍČEK, J., MAZAL, P., PAVLIŠ, J., POHOŘALÝ, J., VICHROVÁ, G., 2016: Preliminary anatomical study on secondary thickening parts of endemic *Dracaena cinnabari* Balf.fil. from the Socotra Island. *V recenzním řízení ve Wood Research*.

Obr. 22 Odběr vzorků z vývratu, Firmihin (foto autorka)

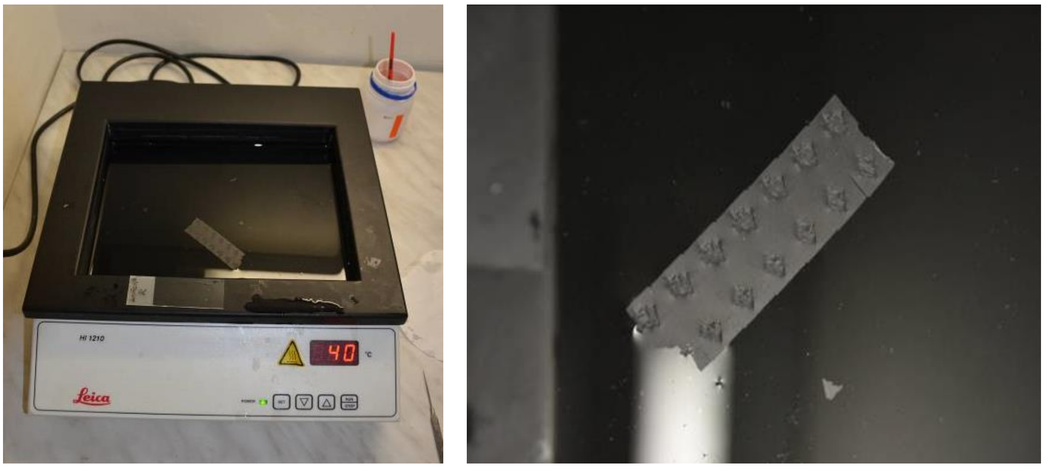


Obr. 23 Vývrt z kmene dračince (foto autorka)

Obr. 24 Průřez kořenem dračince a Obr. 25 Průřez větví dračince (fota autorka)

Obr. 26 Parafinové bloky se vzorky (foto autorka)

Obr. 27 a 28 Zhotovení sériových řezů (foto G. Vichrová, autorka)

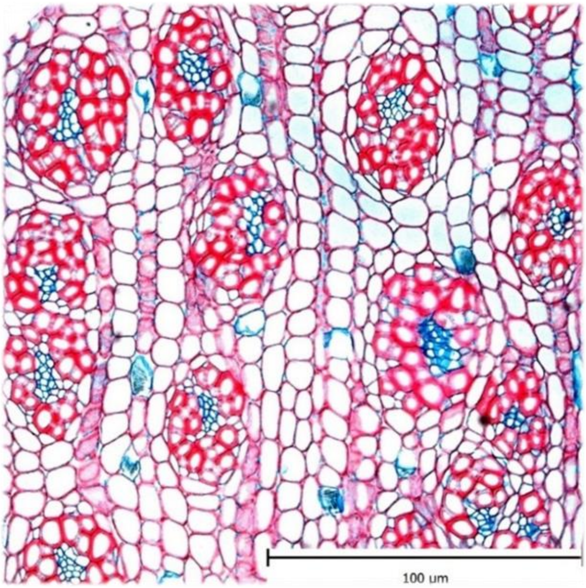


Obr. 29 a 30 Ponoření řezů do vodní lázně o teplotě 40°C (fota autorka)

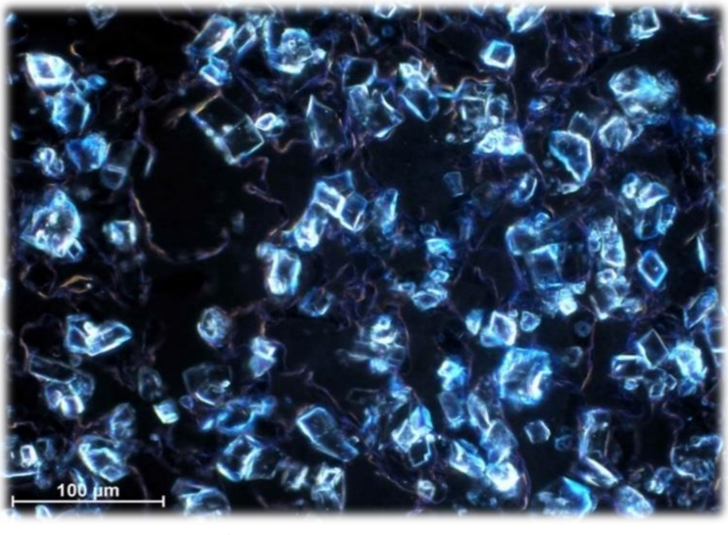
Obr. 31 Finální macerace a barvení v řadě roztoků (foto autorka)

HUBÁLKOVÁ, I., DUCHOSLAV, M., HOUŠKA, J., KUBÍČEK, J., MAZAL, P., PAVLIŠ, J., POHOŘALÝ, J., VICHROVÁ, G., 2016: Preliminary anatomical study on secondary thickening parts of endemic *Dracaena cinnabari* Balf.fil. from the Socotra Island. *V recenzním řízení ve Wood Research*.

Obr. 32 Zhotovené trvalé mikropreparáty (foto autorka)



Obr. 33 Příčný řez stonkem (foto autorka)



Obr. 34 Krystaly šťavelanu vápenatého ve vrstvě korku – četný výskyt v kořenu, stonku i ve větvi (foto P. Mazal)