Naturwissenschaften (2006) 93: 344–347
DOI 10.1007/s00114-006-0111-4

SHORT COMMUNICATION

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Primary colonization and breakdown of igneous rocks by endemic, succulent elephant trees (*Pachycormus discolor*) of the deserts in Baja California, Mexico

Received: 22 December 2005 / Accepted: 2 March 2006 / Published online: 1 April 2006

Abstract Trees growing in rocks without soil are uncommon. In two arid regions in Baja California, Mexico, field surveys found large numbers of rock-colonizing elephant trees (*Pachycormus discolor* (Benth.) Coville ex Standl. (Mexican name: copalquin) growing in igneous rocks (granite and basalt) as primary colonizers without the benefit of soil or with a very small amount of soil generated by their own growth. Many adult trees broke large granite boulders and were capable of wedging, growing in, and colonizing rocks and cliffs made of ancient lava flows. This is the first record of a tree species, apart from the previously recorded cacti, capable of primary colonization of rocks and rock rubble in hot deserts.

Introduction

In hot desert climates, rock weathering solely by abiotic processes (extreme temperatures, wind, and limited rain) may take several hundred thousand to millions of years, depending on variation in environmental forces, erosion and depositional process, and rock type. Plants can accelerate rock weathering and soil formation from rocks and improve soil structure by root penetration, production of weathering agents, such as organic acids, biogenic minerals, and biorecycling of cations (Kelly et al. 1998). Biological weathering of rocks is also known for microorganisms (Chang and Li 1998; Puente et al. 2006) where they play an essential role in maintaining a continuous supply of inorganic nutrients for plants (Puente et al. 2004b).

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In temperate regions, several pine species grow in substrate without soil. Lodgepole pine (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*) commonly occur on lava beds in central Oregon (USA) (Franklin and Dyness 1973) and Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) occur on granite bedrock in Scandinavia (Lundstrom et al. 2000). In the arid parts of the Baja California Peninsula, Mexico, four cacti (*Pachycereus pringlei*, *Stenocereus thurberi*, *Mamillaria fraileada*, and *Opuntia cholla*) were found as primary colonizers of ancient lava flows (Bashan et al. 2002).

The field surveys in this study extend our knowledge to plant species other than cacti, namely, a tree capable of growing and weathering igneous rocks in hot deserts.

Materials and methods

Study sites

We studied two sites in the Baja California extension of the Sonora Desert, located in the middle of the peninsula during two visits, December 2002 and March 2005. The areas (referred to as Cataviña and Tres Virgenes) are characterized by high temperatures in the summer, rarely dropping below 35–40°C during clear days and frequently exceeding 45°C in sun-exposed areas. In mild winters, temperatures occasionally fall to 3°C at nighttime [average of 24–51 years of continuous measurements of the two local meteorological stations—Servicio Meteorologico Nacional, Mexico, Station # 3052 at San Ignacio, B.C.S. (~27.15°N, 112.87°W), and Station #005 at Laguna Chapala, B.C. (29°23′N, 114°21′W, elev. 640 m), about 40–50 km south of Cataviña]. The frequency, duration, and extent of such occurrences vary by site. Rain is mainly associated with Eastern Pacific hurricanes (August–October), but there are years without rain or some winter rain associated with northern air mass incursions.

The Cataviña site (29°47′N, 114°47′W) is 10 km northwest of the hamlet of Cataviña, near the northern limit of the second largest protected area in Mexico

(~2.5×10^{6} ha), the Valle de los Cirios, that stretches from 28 to 30°N. The monthly average (51-year record) ranges from 15°C (January) to 23°C (July–August), while the average daily high temperature ranged from 27°C (January) to 42°C (August), with the six hottest months averaging 42°C and occasional temperatures reaching 47°C. The average night temperatures ranged from −1.9°C (January) to 10°C (August), with 7 months <2.4°C and averaging 3°C (December–January). Several days (not every year) freezing temperatures occur. The multiyear rainfall average is 121 mm year^{-1} (51-year record) with 8 months of rain higher than 5 mm (apart from the dry months of April–July), 10 mm (November) to 21 mm (December). The site encompasses a large expanse of elephant trees in a flat area (1–2% slope to the south) at an elevation of about 650 m. The sparse vegetation cover in this area is composed primarily of endemic cirio or boojum trees (*Idria columnaris*), cardon cacti (*Pachycereus pringlei*), and other desert vegetation described elsewhere in detail (Bashan et al. 2003; Minch et al. 1998). The area is grazed by cattle and goats. The surrounding area is covered with large (50–100 m diameter, up to 10 m tall) and small (3 m in diameter, 1 m tall) exposed granite boulders lacking vegetation (Minch et al. 1998). The soil is composed largely of weathered particles and fragments from the granite boulders and characterized as coarse-textured xeric lithosols (based on INEGI geological map of Santa Rosalia G12-1). The study concentrated solely on plants growing in boulders and not in nearby soil.

The Tres Virgenes site is located south of the volcano "Las Tres Virgenes" at 27°28′N, 112°35′W at 150 m elevation. Although the 28-year average ranges from 23°C (January) to 37°C (July–August), the average monthly high ranges from 29°C (January) to 42°C (August) with the average six hottest months at 41.6°C. The average cooler temperatures ranged from 7°C (January) to 20°C (August) with 7 months <7°C and a minimum of 2.8°C (December–January). The 28-year average rainfall is 92 mm year^{-1}, with 7 months of rain, July–January, 6 mm (November) to 18 mm (September), with less than 2 days month^{-1}. The entire area is composed of large volcanic flows (some over 1 km long and 30–40 m tall) composed of small and large piles of fractured rocks derived from the nearby Las Tres Virgenes volcano over a long geological time frame (Flores 1998). The older tertiary lava flows (about 65 My) are sparsely covered with vegetation common to the Vizcaíno Desert (Leon de la Luz et al. 1995). The younger, early quaternary lava flows (about 1.8 My) are almost barren, apart from small numbers of annuals growing in a few, small deposits of wind-blown dust. The study was conducted on three young lava flows. There is no visible grazing activity, rock formations are almost inaccessible to most large animals, and are almost devoid of annuals. The surrounding flat bottomlands are heavily grazed by cattle and goats.

Field methods

The field surveys of elephant trees were done using different counting methods because the terrain (boulders and open fields near Cataviña and loose igneous rocks in ancient lava flows without soil near Tres Virgenes) in the two areas are different. At Cataviña, three sites (Site #1, 1000×500 m, and Sites #2 and #3, 900×500 m) were chosen, parallel to each other. All boulders in these areas were inspected. Only elephant trees growing within the boulders were counted and photographed (boulder-associated trees) but not elephant trees growing in soil at a distance more than 0.5 m from the nearest boulder (no boulder-associated trees). This parameter was chosen because some trunks of older trees are thicker than 50 cm diameter. At Tres Virgenes, three relatively accessible large lava flow formations were chosen, measured, and all the

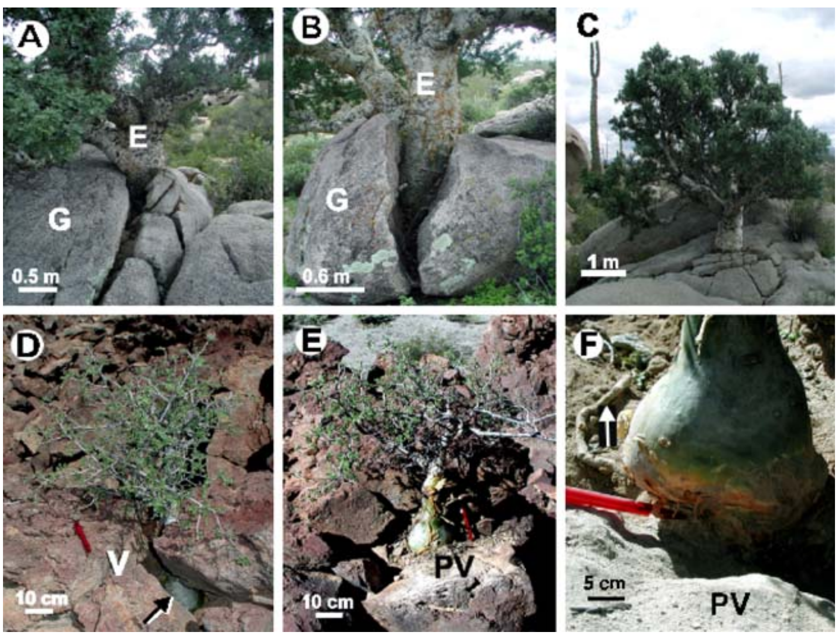

Fig. 1 Elephant trees growing in granite boulders at Cataviña. **a** A tree wedging a medium size boulder, **b** a tree wedge opens a small boulder, and **c** a tree growing in a large boulder as the sole plant species. Note major cracks in the boulders. Boulders without vegetation are intact. **d** A young elephant tree growing within the confinement of a single volcanic rock (*arrow*) in Tres Virgenes. **e** The same tree after the side part of the rock was chiseled away. **f** Enlargement of the exposed rock after chiseling, shows that the plant is intimately attached to the rock and the roots penetrate the rock (*arrow*). *E* elephant tree; *G* granite boulder; *V* volcanic rock; *PV* mechanical pulverizing of volcanic rock (photographs taken in March 2005)

elephant trees growing (regardless of size) were counted because they were the only vegetation located there. These counts should be considered minimal because small individuals may have been overlooked despite intensive efforts to locate all individuals in the sampled area because this area is difficult to reach on foot and large rocks may hide small individual during the survey.

Results

Two field surveys conducted in two rocky areas of Baja California revealed that the elephant tree *Pachycormus discolor* is growing as a singular tree species on granite boulders and bare basaltic lava flows. Vegetation is absent on these two rock types in the interior of the central Baja California Peninsula (Figs. 1 and 2).

The barren rocks support only a few individuals (Table 1). Tres Virgenes supports, on average, 8.83 trees 1,000 m^{-2} of barren rock and Cataviña supports 3.86 trees 1,000 m^{-2} on boulders (Figs. 1 and 2) (not including trees growing in the soil in the surrounding area). Notwithstanding these small numbers, they were on a par with the number of other tree-like species in the Cataviña area growing in soil, the succulent, endemic cirio tree and the tree-shaped cardon cactus, and elephant trees were the only tree species growing in Tres Virgenes area (Fig. 2b). As the areas and the type of stones differ, colonization by the elephant tree differs. At Cataviña, the elephant trees colonize barren granite boulder; larger trees were wedging the boulders (Fig. 1a–c). At Tres Virgenes, with smaller rock fragments, trees grew inside the rocks without any external crack (Fig. 2c–e) and small trees could not be extracted by heavy duty chiseling action (Fig. 1d–f). Mature trees (>3 m tall) grow everywhere in this soilless basaltic rock habitat that has a height of about 20–30 m (Fig. 2). The potential for soil formation by these elephant trees which support other desert vegetation, was observed in the nearby eroded older lava flows that were colonized by elephant trees and other vegetation (Fig. 2a) typical of this area (Leon de la Luz et al. 1995).

Discussion

The elephant tree is an endemic and common succulent tree of Baja California with several varieties. The variety grown in these rocks is *P. discolor* var. *pubescens* (J.L. Leon de la Luz, personal communication). This is an uncommon-looking tree; the trunk (60–80 cm in diameter) is covered with smooth, grayish-white to yellowish bark that repeatedly

Table 1 Number of elephant trees growing in granite boulders and volcanic rocks without soil at two locations in Baja California, Mexico

Site	Area (m^2)	Number of trees
Cataviña[a]	5,000	14
	4,500	17
	4,500	23
Tres Virgenes	5,600	52
	7,800	58
	4,600	49

[a]Only trees associated with granite boulders were counted

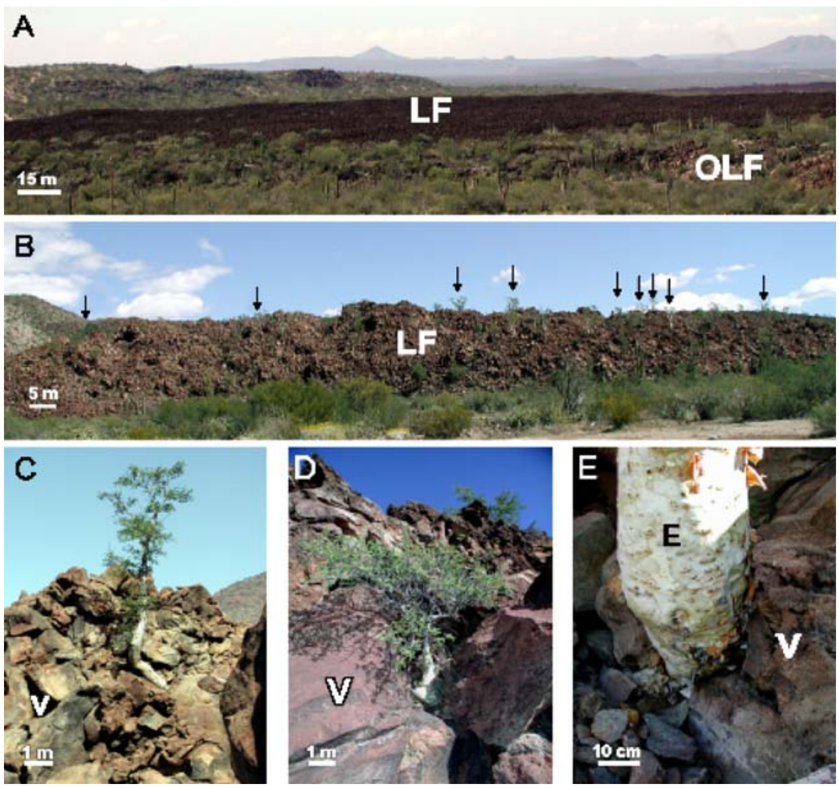

Fig. 2 Colonization of ancient lava flows at Tres Virgenes by elephant trees. **a** Typical “young” lava flow, almost devoid of flora. Older lava flows are partially degraded and covered with vegetation composed of elephant trees and common desert flora. **b** “Young” lava flow almost exclusively colonized by elephant trees (*arrows* indicate several specimens). **c** A typical elephant tree growing in small rocks on the lava flow. **d** Elephant tree growing inside a large boulder in the lava flow. **e** Enlargement of **d**. The tree is growing directly inside a volcanic rock. *E* elephant tree; *LF* lava flow; *OLF* old lava flow; *V* volcanic rock (photographs taken in March 2005)

peels off in papery layers, revealing a blue-green, waxy-smooth, spongy inner photosynthetic bark. The trunk is very thick in proportion to the size of the tree (Clark et al. 1993; Gibson 1981; Humphrey 1991; Roberts 1989).

A recent study of cardon cactus growing in an area similar to Tres Virgenes, La Purisima, about 150 km southwest (Bashan et al. 2002), showed that rock-weathering microorganisms associated with the roots allow cacti to develop and grow in bare rock volcanic environments by supplying it with nutrients (Puente et al. 2004a,b). It is not known, as yet, whether these "helper" microorganisms also exist in elephant tree roots. However, the tree is well adapted to scarce precipitation. Its green photosynthetic bark may be an adaptation for surviving prolonged drought and may function to recycle endogenous respiratory CO_2, thus maintaining the plant's energy reserves and permitting rapid production of leaves in response to infrequent rains (Franco-Vizcaino et al. 1990). The stem also acts as an important buffering mechanism during water deficit, allowing maintenance of leaf turgor in these succulent trees (Nilsen et al. 1990).

In summary, this field study records the first tree species capable of primary colonization of barren volcanic rocks in a hot desert.

Acknowledgements Yoav Bashan participated in this study in the memory of the late Messrs. Avner and Uzi Bashan from Israel. We thank J.L. Leon de la Luz of CIBNOR and C.Y. Li of USDA-Forest Service, Corvallis, Oregon for botanical information, Rocio Villalpando for collecting geographical information, and the editor at CIBNOR for improving the English text. This work was partially supported by Consejo Nacional de Ciencia y Tecnologia of Mexico (CONACYT contract U39520-Z) and partially by the Bashan Foundation, Oregon, USA. The stay of H. Vierheilig in Mexico was partially funded by a KUWI grant of the BOKU in Austria.

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