SOME LOW ELEVATION FOG FORESTS OF DRY ENVIRONMENTS: APPLICATIONS TO AFRICAN PALEOENVIRONMENTS

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MACARONESIAN ELFIN CLOUD FORESTS: CANARIAN EXAMPLES

We present some examples of cloud water and fog precipitation on vegetation following Kerfoot's pioneer work (1968). High fog frequency allows for the existence of forest communities in otherwise arid (low rainfall) conditions. Using the El Hierro fountain tree as an example, Macaronesian elfin forests are described, with special attention to the Garajonay National Park (La Gomera, Canary Islands) where very significant stands of fog/cloud forest remain.

The Macaronesian region includes the Azores, Canary, Cape Verde, and the Selvagens. Of these, the Canary Islands harbor the richest botanical diversity and most extensive remnant stands of fog/cloud forest.

El Hierro is the smallest island (280 km^2) of the Canarian archipelago (28° N; 13–18° W) (Figure 1). Under an arid climate, "fountain" trees (laurels, junipers, pine trees) have been used for centuries to provide freshwater. Water is naturally collected by such trees from the intense fog (*niebla*) that occurs often without any rainfall. From the leaves, the water drops on the soil where it can be collected and stored. One laurel tree (*Ocotea foetens*), the so-called *Garoé*, was used by the native pre-Hispanic populations until 1610, when it was uprooted by a hurricane (Figure 2). The following is an extract

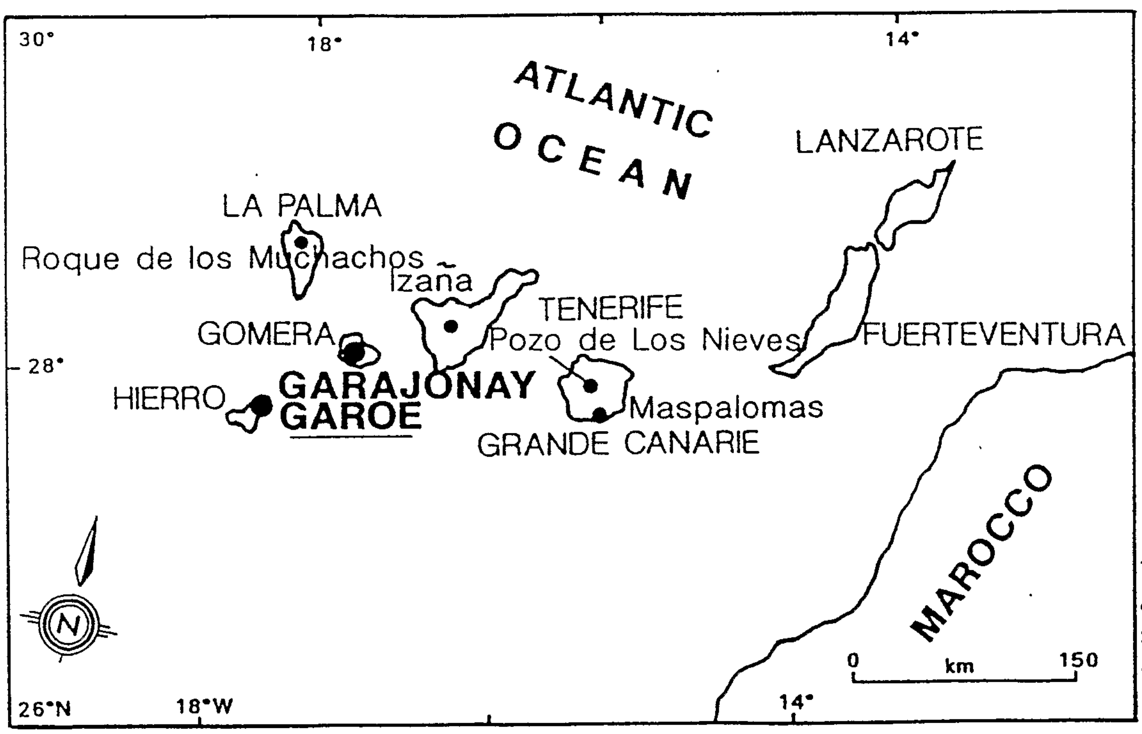

FIGURE 1. *Canary Islands, Spain, including the location of the Garoé and Garajonay National Park.* Drafted by M. Suavin.

FIGURE 2. *El Hierro coat of arms. The fountain tree, the so-called* Garoé, *is at the center of the escutcheon. This tree, which was uprooted in 1610 by a hurricane, is still visible symbolically, especially on taxi cabs that always carry stickers with El Hierro's arms on their doors.*

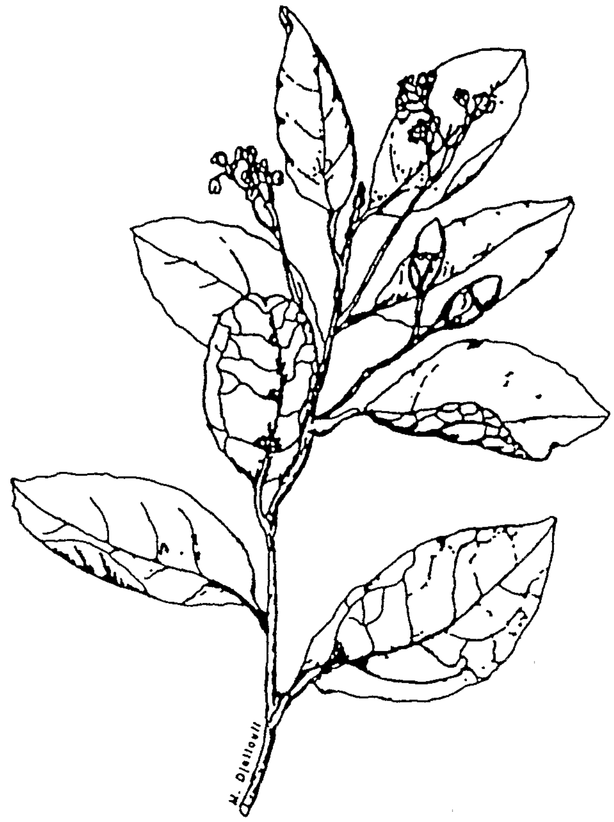

FIGURE 3. Ocotea foetens, *a Macaronesian laurel. The* Garoé *was an* O. foetens. Drawn by M. Djellouli.

from George Glas's *History of the Discovery and Conquest of the Canary Islands* (1764):

> On the top of this rock [≈1,000 m] grows a tree called, in the language of the ancient inhabitants, *Garoé* (sacred or holy tree), which for many years has been preserved sound, entire and fresh. Its leaves constantly distill such a quantity of water, as is sufficient to furnish drink to every living creature in Hierro; nature having provided this remedy for the drought of the island. It is distinct from other trees, and stands by itself. The circumference of its trunk is about twelve spans [1 span ≅ 22.8 cm], the diameter four, and in height from the ground to the top of the highest branch forty spans: the circumference of all the branches together is one and twenty feet [1 foot ≅ 30.5 cm]. The branches are thick and extended; the lowest commence about an ell [1 ell ≅ 120 cm] from the ground. Its fruit resembles the acorn, and tastes something like the kernel of a pineapple, but it is softer and more aromatic. The leaves of this tree resemble those of the laurel, but are larger, wider, and more curved; they come forth in perpetual succession, so that the tree always remains green.

In memory of the *Garoé*, another laurel (*Ocotea foetens*; Figure 3) was planted in 1945 at the same place as the old one by Don Zósimo Hernández Martin, who worked with ICONA (Instituto Nacional para la Conservación de la Naturaleza). By 1993, 48 years later, this laurel had become a new fountain tree producing high quantities of fog water like the ancient *Garoé* (Gioda et al. 1992; Gioda, Hernández Martin, and Gonzáles 1993). The average annual rainfall is 800 mm in this El Hierro region, according to data from *Consejeria de Obras Publicas*.

Another famous fountain tree, a juniper (*Juniperus phoenicea*) located at Cruz de los Reyes (1,353 m), was destroyed by a bush fire in 1990, but both the concrete collector under the plant and the water storage system, built on behalf of Don Zósimo Hernández Martin, are still in place (Acosta Baladón 1992). Plans have been made to transplant a new juniper tree in this location (Gioda 1993) with the concurrence of local authorities (island government, ICONA), who in the 1970s and 1980s supported construction of the concrete collector and fog water storage tanks. Today, cattle drink fog water collected from pine trees (*Pinus canariensis*) on Mirador de los Bascos (650 m) and on El Hierro (Gioda, Hernández Martin, and Gonzáles 1993).

Besides these Canarian examples, farmers have used fog water on Brava (Cape Verde Islands) since 1942, mainly collected from agaves (*Furcraea gigantea*) and palm trees (*Phoenix* sp.) (Reis F. Cunha 1964; Acosta Baladón and Gioda 1991, 1992).

Garajonay National Park (La Gomera Island): A Canarian Elfin Cloud Forest

The elfin cloud forest of Mount Garajonay on La Gomera Island has been classified a Spanish national park since 1981 (total area: 3,985 ha). Since 1986, it has been registered as a UNESCO World Heritage site (Pérez de Paz 1990).

Climate and Hydrology. The Canary Islands are essentially influenced by the subtropical high pressure systems of the north Atlantic Ocean, trade winds being the factor driving the atmospheric circulation. These winds from the NNE are humid (relative humidity 75–90 percent) and collide with the insular blocks, producing a "sea of clouds," the altitude of which usually ranges from 600 to 1,500 m. In the vicinity of Tenerife island, the average frequency of occurrence of the "sea of clouds" is 199 days per year. These clouds do not result in abundant rainfall because an upper-level temperature inversion restricts their vertical growth and the formation of a deep cloud layer necessary for raindrop formation. Mount Garajonay National Park (elevation 700–1,487 m) has an evergreen forest sustained by direct interception of cloud water. The mean annual rainfall in the area ranges from 600 to 800 mm. It is estimated that forest fog/cloud-water interception is more than double this amount (Santana Pérez 1990; Gischler 1991).

Vegetation and Flora. The laurel forest, the so-called *laurisilva*, is a luxuriant subtropical vegetation with a diverse structure of trees, shrubs, herbs, and climbers so dense that they prevent light penetration into the forest interior. The evergreen forest zone is dominated by four species of laurel (bay): *Laurus azorica, Appollonias barbujana, Persea indica*, and *Ocotea foetens*. These are all Macaronesian endemics and relicts of a now virtually extinct tertiary Mediterranean flora that occupied southern Europe and North Africa about 15–40 million years ago.

Many other Canarian endemic trees and shrubs occur in this forest, including *Appollonias barbujana* spp. *ceballosi, Ilex perado* spp. *lopez-lilloi* (specific to La Gomera), *Arbutus canariensis, Erica scoparia* spp. *platycodon, Gesnouina arborea, Ilex perado* spp. *platyphilla, Juniperus cedrus, Maytenus canariensis, Sambucus palmensis, Teline stenopetala* var. *microphylla, Viburnum tinus* spp. *rigidum*, and *Myrica rivas-martinezii* (Pérez de Paz 1990).

In the Canary Islands, the evergreen forest has vanished on Gran Canaria, where only 1 percent of the pre-Hispanic forest community still exists; and it is endangered on Tenerife where less than 10 percent of this forest type remains, concentrated in the Montes de las Mercedes region (White 1986; García Morales 1989).

SOUTH AMERICAN CLOUD COMMUNITY: THE LACHAY NATIONAL RESERVE, PERU

In 1977, the Lachay National Reserve, a woodland in a very dry and foggy formation, was declared by the Peruvian authorities (total area 5,070 ha). It is located 105 km north of Lima near the Panamerican Road (11° S; 77° W). It is representative of *lomas* (hill) formations located between ± 8° S (Peru) and ± 20° S (Chile). *Lomas* also refers to botanic formations. In central and southern Peru, not far away from the Pacific coast, many *lomas* such as Lachay are found, with ancient *pueblos* (pre-Colombian settlement ruins [Engel 1987]). Their inhabitants had preserved natural resources without any destructive pressure by grazing and exploitation of wood.

Climate and Hydrology

Based on 44 years of observation, the climate of Lachay is characterized by the following parameters: (1) rainfall, 173 mm; (2) fog (*garúa*) precipitation under the canopy: depth of rainfall multiplied by 3–8; (3) monthly average temperatures: 12.8°–20.8° C; (4) monthly average sunshine periods: 36–218 hours.

SENAMHI (Servicio Nacional de Meteorología e Hidrologia) has been working since the 1960s in the following *lomas*: Lachay, Pasamayo, Cerro Campana, Atiquipa, Cerro Orara (Ventanilla-Ancón), Cerro Colorado (Villa María de Triunfo), and Parque Recreacional de Cahuide (Ate-Vitarte). The aim of SENAMHI is to develop the use of fog catchers on *lomas* at altitudes between 400 and

1,000 m. SENAMHI obtains an average fog water production of up to 10 liters/m²/day using a mesh proposed by ESTRATUS Company.

Vegetation and Flora

The vegetation is characteristic of the central Peruvian hills (*lomas*) along the desertic Pacific coast (Weberbauer 1911). The most representative trees are two species: *tara* (*Caesalpina tinctoria*) and *pallilo* (*Capparis prisca*), growing at altitudes ranging from 500 to 700 m. Among the trees and shrubs, the following species are vanishing in the *lomas: Eupatorium sternbergianum, Cassia biflora, Carica candicans, Lobelia decurrens, Capparis prisca,* and *Caesalpina tinctoria* (Dourojeanni and Ponce 1978). The woodland contains few succulents. The trees are scattered, gnarled, and stunted. They are located on often skeletal soils between rocks where Bromeliaceae are growing. The most abundant are the genera *Pitcairnia* and *Puya*.

SOME ASPECTS OF AFRICAN QUATERNARY PALEOENVIRONMENTS

Tropical cloud forests help us to understand some paleoenvironmental paradoxes, such as lowland extensions of mountain ecosystems during Quaternary Ice Ages. The mountain ecosystems generally appear above 1,000 m. However, in tropical Africa we find today several lowland spots with mountain ecosystems, for example, on the southern border of the Zaire-Congo basin, in the Mayombe, Chaillu, and Monts de Cristal hills (White 1981; Maley Caballé, and Sita 1988) or in other areas such as the Freetown hills (Liberia), Mount Cameroon, the Angola plateau, and Mount Usambara (Maley 1989). Outside Africa, there are many examples of this phenomenon in the Antilles and around the Caribbean Sea (Baynton 1968; Howard 1970). In the northern tip of Colombia, Cavelier and Goldstein (1989) described the elfin forest of the Serrania de Macuira, which occurs at a maximum elevation of 865 m.

In fact, such communities can be found at elevations as low as 500 m, or even 300 m (Angola). They can occur on lower slopes of high mountains (Mount Cameroon, 4,070 m) (Serle 1964; Thomas 1986), on plateau escarpments (Angola, Sudan), or on hilltops as a result of crest effects (Peru, Chile). These communities are particularly numerous near the sea (Moreau 1966; Kerfoot 1968; Whitmore 1975; Blot 1991). However, cloud phenomena may be present at distances up to 800–1,000 km from the Atlantic Ocean in Gabon and the Congo (Maley 1991).

All studies concerning the history of the vegetation in Africa have concluded that during climate cooling, mountain vegetal species extended to relatively low elevations. Pollen analyses carried out in eastern Africa (Bonnefille et al. 1992) and in central and western Africa (Maley 1989, 1991) show that temperatures dropped by 3°–8° C during the last Ice Age maximum about 18,000 years BP. On the high mountains of east Africa, the observational evidence of the descent of glaciers by about 1,000 m has led to similar conclusions (Hamilton 1982). To understand the effect of lower temperatures, we can examine the composition of flora and fauna at elevations in the middle altitude range, between 1,000 and 3,000 m. For example, the percentages of plant species common to Mount Cameroon and the mountains of eastern Africa are 53 percent for mountain forests and 49 percent for mountain meadows. Similar percentages occur for mammals and birds (Moreau 1966). To explain these similarities, many authors have ventured that during the coldest periods of the Quaternary, mountain flora and fauna have spread to low altitudes, thus allowing migrations between mountain ranges. Indeed, pollen analyses for location sites far away from high mountains have supported this assumption. For example, a small depression at 600 m (Bois de Bilanko, about 35 km north of Brazzaville, Congo) has yielded a section with pollen types dominated (before the beginning of the Holocene) by mountain species: *Podocarpus latifolius* (50 percent), *Ilex mitis*, and *Olea capensis*, constituting 60 percent of the pollen spectra. Moreover, between the mountain ranges of eastern Africa and Cameroon, isolated occurrences of species typical of mountain areas still exist today (Maley, Caballé, and Sita 1988). These are benchmarks on a preferential path of migration, which probably operated intermittently during the coldest periods of the Quaternary, or before the Quaternary. This path joins eastern Africa to Angola, and through the hills of Mayombe, Chaillu, and Monts de Cristal, it reaches the mountains of Cameroon (Maley 1989, 1991).

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