Photo: Jacintha Vanbeveren

Rapid, recent and irreversible habitat loss: Scalesia forest on the Galapagos Islands

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Introduction

The Galapagos biota has suffered few extinctions, due mainly to the late colonization by humans and the high level of protection on most of the archipelago as an uninhabited national park. Thus, the same radiations of finches, mockingbirds, and giant tortoises that inspired Darwin in formulating his theory of evolution can still be observed today. However, land use change on the four inhabited islands (San Cristóbal, Santa Cruz, Floreana, and Isabela) has affected much of the natural vegetative cover in the highlands. It is estimated that on these islands 29,600 ha of the highlands (33% and 49% respectively of the humid and very humid vegetation zones) have been altered due to the combined presence of invasive plants and agriculture (Watson *et al.*, 2009).

In this paper we present all available spatial information on the Scalesia forest community to evaluate the impacts of human-induced changes on its distribution. In particular we reconstruct the historical range of the forest dominated by *S. pedunculata* and *S. cordata* (Lawesson *et al.*, 1987; Adsersen, 1990; Itow, 1995). Using available evidence we then document the current extent of these forests to estimate the proportion that remains and analyze reasons for the dramatic and rapid loss of this unique habitat type.

The genus Scalesia

Scalesia is one of the seven endemic plant genera of the Galapagos Islands. The genus includes 15 species, with 21 taxa distributed on all except four of the main islands (Eliasson, 1974). Some species are widely distributed whereas others are single island endemics. Most are shrubs found dispersed within the arid and transition zones, but three species, *S. pedunculata*, *S. cordata*, and *S. microcephala*, are trees that occur in dense forests as the dominant plant species. These forests are mainly found in the humid highlands and are structurally unique. Tree Scalesias have a very short life cycle. Seeds germinate in forest clearings, reaching 4-4.5 m in height in one year, and 10-15 m at maturity. They start to produce flowers and fruits at 1-2 years of age, and live for about 25 years (Itow, 1995). Cohort recruitment has been noted to be linked to El Niño events that affect the archipelago periodically. The increased rain appears to result in a massive dieback of adult plants and mass recruitment from the seedbank (Lawesson, 1988; Itow and Mueller-Dombois, 1988).

Scalesia forest

Scalesia pedunculata forests occur in the transitional and humid zones of Santa Cruz, San Cristóbal, Floreana, and Santiago, while *S. cordata* forests are restricted to Cerro Azul and Sierra Negra volcanoes on Isabela (Wiggins and Porter, 1971; Hamann, 1981). Santa Cruz, San Cristóbal, Floreana, and Sierra Negra volcano (Isabela) are the only inhabited regions of the archipelago (with the exception of military bases and an airport on Baltra), and the highlands of each have been severely affected by human presence due to agricultural activities and invasive species. While Cerro Azul volcano (Isabela) and Santiago Island are unpopulated, they have also been severely degraded by introduced herbivores and invasive plant species.

Scalesia forest distribution

Historical distribution (1915)

Information on the historical distribution of the Scalesia forest comes from observations of Stewart (1915) who described the vegetation as he walked along transects from the coast to the peaks of different islands. These surveys suggest that the upper slopes of San Cristóbal, Santa Cruz, Santiago, Floreana, and Isabela were all dominated by Scalesia forests. For example, on Santa Cruz, he reported that dense forests between 150 and 580 m were largely made up of *S. pedunculata*. This corresponds to an area of 9600 ha. Stewart also noted that above 80 m in elevation on Sierra Negra volcano (Isabela), the forest consisted mostly of *S. cordata* and *Sapindus saponaria*. He recorded that a considerable amount of *S. cordata* forest had already been cleared away on Sierra Negra, and estimated an original range of over 17,300 ha. On Santiago, Stewart (1915) estimated that the Scalesia forest covered at least 1000 ha of the island.

Distribution changes from 1960-1990

Ground surveys carried out between 1960 and 1980 indicate without exception the considerable decrease in area covered by Scalesia forest (Elliason, 1984; Hamann, 1984). Forest stands on the southern slopes of Santa Cruz have not existed since 1964, with the last trees cleared in the 1970s (Itow, 1995). In addition, studies in the 1980s (Adsersen, 1989) mention only one small area of humid Scalesia forest on the northern slope of the same island. By 1975 on Santiago, only a few trees remained due to intense grazing by introduced goats (van der Werff, 1978, 1979; Hamann, 1975). On San Cristóbal, the original *S. pedunculata* forest had been completely destroyed by 1986 with only a few trees on a steep and inaccessible cliff along a watercourse on the south side of the island remaining (Itow, 1995). The same study mentions that on Floreana there was still a good but small stand of *S. pedunculata* in 1991 (Itow, 1995). The first vegetation maps for the archipelago were compiled in 1987, using aerial photographs and field notes taken between 1980 and 1985 (INGALA *et al.*, 1989). For Santa Cruz, the area covered by *S. pedunculata* forest indicated on the maps can be estimated at 1852 ha or 19% of the original extent.

Current distribution (2009)

Recent information from field surveys and herbarium sample locations provide a current estimate of a maximum of 100 ha of Scalesia forest on Santa Cruz. This represents 1.1% of the original forest (Figure 1). In San Cristóbal, there is no Scalesia forest left (0% of the original distribution), while in Santiago the remaining area is restricted to within the five fenced areas that were constructed between 1974 and 1999 and covers a total of 1.1 ha (less than 0.1% of the original distribution). There may be a little more remaining on Floreana, but data collection there is not yet complete.

Studies of the distribution of *S. cordata* on southern Isabela carried out by Delgado (1997) and Shimizu

(1997) provide data on the location and size of current remnants on Sierra Negra volcano, which in total cover less than 10 ha, with only two of the forest remnants covering more than 2 ha. Moreover, Jaramillo *et al.* (2006) found that most of these remnants were heavily invaded by the introduced *Psidium guajava*. We estimate that there has been a loss of 99.9% of *S. cordata* forest on Sierra Negra (Figure 2).

Discussion

While extensive loss of forest in the highlands, due to habitat destruction, herbivory, and invasive plant species, is commonly recorded, this is the first time that the actual extent of habitat loss of *S. pedunculata* and *S. cordata* forest in Galapagos has been calculated. The results indicate an almost complete loss of an entire vegetation type on the inhabited islands of the archipelago.

The rapid reduction of Scalesia forest during the early 20th century occurred as a result of direct human destruction for wood and clearing of forests for agriculture on all the inhabited islands (Lundh, 2006). Water is a critical resource in Galapagos and the Scalesia forest zone occurs in the only zone of the islands with reliable water availability, due to garúa mists during the cold season. In addition, on southern Isabela, major fires in 1985 and 1995 led to the replacement of remaining fragments of *S. cordata* forest by the invasive *Psidium guajava* (Nowak *et al.*, 1990), due to the ability of the latter to resprout after fire (Delgado, 1997; Shimizu, 1997).

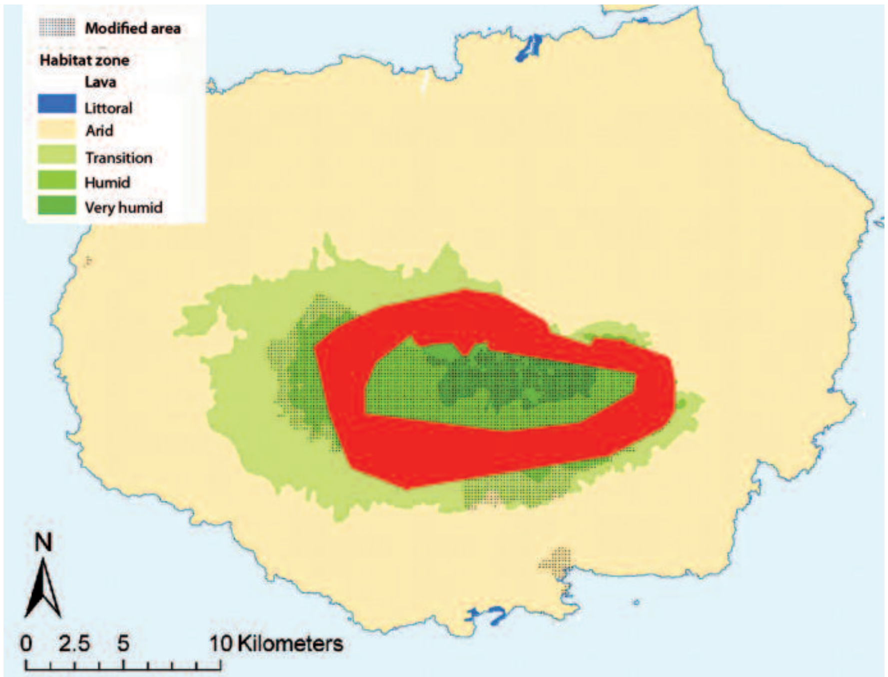
High densities of introduced goats were the main factor for the loss of the Scalesia forest zone on the uninhabited island of Santiago (de Vries and Calvopiña, 1977). Now that herbivores have been eradicated there (Cruz *et al*., 2005; Guo, 2006; Carrión *et al.*, 2007), the vegetation is recovering, even though invasive plants are beginning to become increasingly problematic (Atkinson *et al.*, 2008). However, since the eradication of goats in 2006, no regeneration of *S. pedunculata* has been observed outside the fenced areas despite the ability of Scalesia to reach maturity within one year of germination. However, it is hoped that in the future this species and the forests might regenerate.

On the inhabited islands, Scalesia forest has not returned to abandoned agricultural land due to the competitive ability of invasive plants. In Isabela many of these areas are now covered in dense *Psidium guajava* forests, while in Santa Cruz several farms are still dominated by introduced pasture 50 years after their abandonment. In addition, the small forest remnants that were never cleared are being invaded by introduced plant species, such as *Cedrela odorata*, *Cinchona pubescens*, and *Rubus niveus* (Rentería and Buddenhagen, 2006; Jaramillo *et al.*, 2006). While this review does not consider the *S. cordata* forest on Cerro Azul volcano as there is very little spatial information about this area, a recent field survey found a small forest of 18 ha on the flank of the volcano at an elevation of 200-300 m, surrounded by an extensive forest of *Psidium guajava* (Guezou, A. CDF, pers. obs.).

Active management to help restore these areas is complicated by the difficulties of controlling fast growing and competitive invasive plant species. This problem is compounded in the National Park areas of Cerro Azul and Sierra Negra, where ungulates continue to eat the bark and young of *S. cordata*, and disperse the seeds of the introduced *Psidium guajava*. Although weed control is carried out in priority sites, to date it has had little impact on forest regeneration due to the large and persistent seed banks of invasive species and their rapid growth rate (Gardener *et al.*, this volume). The invasion of these areas is made worse by the effect of El Niño events, which increase forest vulnerability to invasion by plants due to gap formation and heavy rainfall. It is likely that this threat will become more severe as these events increase in frequency and intensity as predicted under climate change models (Mitchell *et al.*, 2003).

Recommendations

A program of active and focused research as identified in Gardener *et al.* (this volume) needs to be initiated to inform and optimize the restoration of the remaining fragments of Scalesia forest, and to provide a sound methodology for the successful reestablishment of areas within the natural distribution.



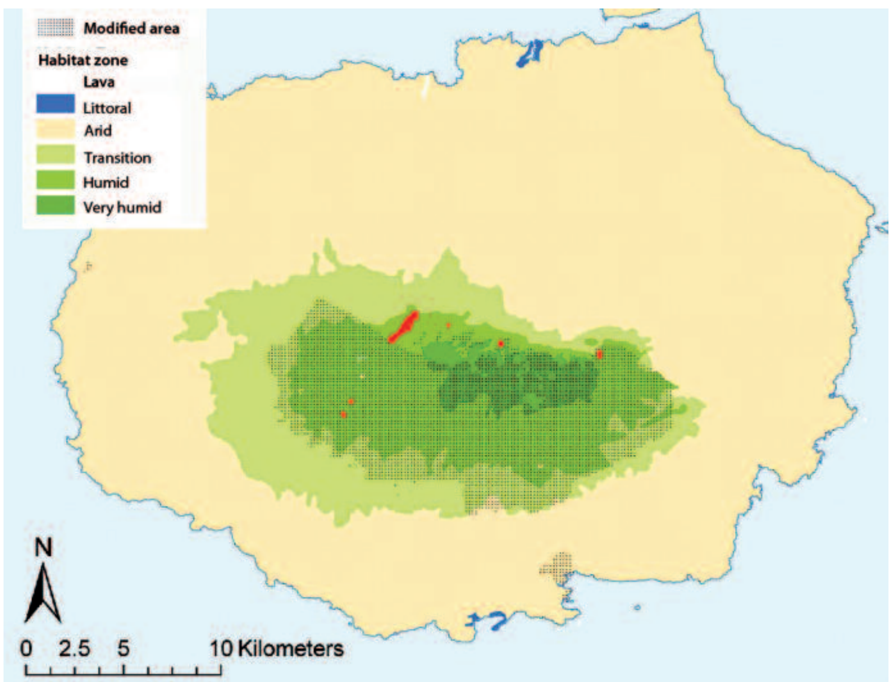


Figure 1. Maps of vegetation types showing the *Scalesia pedunculata* forest (in red) on Santa Cruz, with historical distribution above and current distribution below.

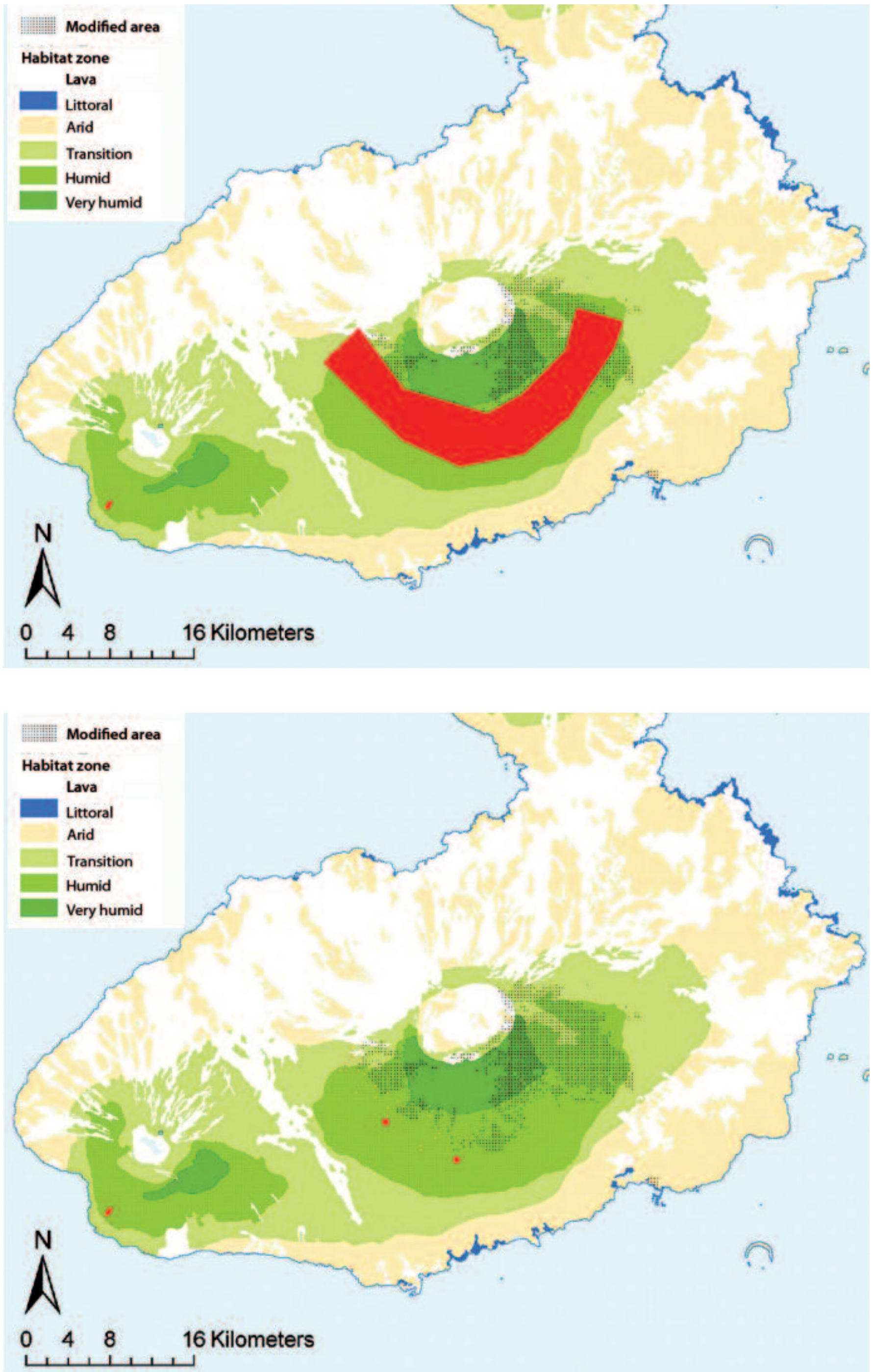


Figure 2. Maps of vegetation types showing the *Scalesia cordata* forest (in red) on southern Isabela, with historical distribution above and current distribution below. The largest red points represent remnants of forest of more than 2 ha. .