

Tropical tree diversity enhances light capture through crown plasticity and spatial and temporal niche differences

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Appendix A: Experimental design of the Sardinilla plantation.

Experimental design

The experimental plantation is located in Sardinilla, ca. 50 km north of Panama City (Panama,
2 Central America). Mean annual rainfall at the nearest meteorological station (Buena Vista) is
2351 mm with 25-50mm per month during the dry season (January to March) and *ca.* 250mm per
4 month during the rainy season (May to November). Daily and seasonal temperatures are relatively
constant ranging from a daily maximum of 34.3 C to a minimum of 21.1 C in January (STRI,
6 2009). The elevation of the site is on average 70 m, with a slightly undulating topography. In July
2001, 5566 seedlings of six native species were planted to establish a synthetic gradient of species
8 richness (Scherer-Lorenzen et al., 2007).

The species planted in Sardinilla were selected based on a range of traits including functional
10 traits, local usage and ecological importance. Species data available from the 50 ha dynamic plot
of nearby forest of Barro Colorado Island (BCI) served as a basis for selection (Condit *et al.*, 2006).
12 The species were chosen to cover a range of relative growth rates in diameter at breast height
(RGR) that is representative of BCI trees (Table A1). We however excluded from the selection

species with exceedingly high growth rates such as *Cecropia insignis* or *Trema micrantha* which have observed relative growth rate on BCI of respectively 19.5% and 43.95%. For results to be directly relevant to nearby afforestation initiatives, species were further chosen either for their timber value (*Anacardium excelsium*; Ae; *Cordia alliodora*, Ca; *Cedrela odorata*, Co and *Tabebuia rosea*, Tr) or because they are abundant in the Panama Canal watershed where the experiment is taking place (*Hura crepitans*, Hc and *Luehea seemanii*, Ls; Potvin & Gotelli, 2008). In sum, three functional groups were formed *a priori* based on relative growth rates observed in BCI: Ca and Ls are the fast-growers, Ae and Hc the intermediate species and Co and Tr the relatively slow-growers (Table A1).

Both Co and Tr have been classified as shade-intolerant and non-pioneer species (Elias & Potvin, 2003; Poorter & Bongers, 2006) but are also known to tolerate shade (Condit *et al.*, 1996; Hooper *et al.*, 2002). Hc, Ae, Ca and Ls have the fastest growth rates (Table A1) and are able to colonize relatively large forest gaps (Croat, 1978). Hc is shade tolerant (Sautu, 2002). Ca and Ls are the only species that have already been considered as a pioneer species per se (Lang & Knight, 1983; Welden *et al.*, 1991; Ellis *et al.*, 2000; Hooper *et al.*, 2002; Coll *et al.*, 2008). The species selected for the plantation also encompass a range of phenology representative of the tropical moist lowland forests. Ae and Co lose their leaves in the early dry season, Hc loses them in the middle of the dry season, Ls becomes deciduous at the end of the dry season while Ca loses its leaves in the early wet season. Tr has been reported to drop its leaves from March through June Flores & Marin (2003) but also to lose its leaves twice during the year both in the early dry season (January-February) then once more in July Croat (1978). More details on each species is provided in section *Species characteristics*.

Following standard reforestation practices in Panama, seedlings were planted at 3 m distance from each other in our $45 \times 45 \text{ m}^2$ plots. Each species was planted in two replicated monocul-

ture plots, in three 3-species-mixture plots and in six 6-species-mixture plots. Within each plot, trees were planted following a multiple Latin-square design to ensure that systematic environmental variation did not bias the results. Thus, the species identity of neighbours around trees of a given species remained the same within a plot, thereby forming a specific neighbourhood (Fig. A1). Because species composition changes over the 3-species plots while the 6-species plots are perfect replicates, trees from any given species experience, across the plantation, five different neighbourhoods: one in monoculture, three from 3-species plots and one from 6-species plots. *C. alliodora* failed to establish: of the 900 initially planted, only 51 individuals remained in 2011, all in mixtures. At year 9 after planting, there were thus 22 plots of interest: 10 monocultures (two per species), six 3-species mixtures (T1 to T6) and six 6-species mixtures (A1 to A6).

For analytical purposes and because spatial heterogeneity expressed itself at smaller scales, plots were partitioned in 4 subplots of equal size *ca.* 22.5m×22.5m) to capture heterogeneity within a plot (Healy *et al.*, 2008). Investigation are thus undertaken at the subplot scale in this study. The species identity of neighbours around trees of a given species remained the same within a subplot.

Species characteristics

Ae has a rounded and dense crown and grows at a medium rate to 45 m in height and 3 m d.b.h (Fournier, 2003a). Ae grows in a wide range of soils and climatic conditions. Many of the trees drop their leaves for a short period of time during late November and December and green flushes of new foliage appear in early January (Allen, 1956). Ae has simple, alternative, relatively large obovate (oblong in outline with a rounded apex) leaves. Its leaves have no stipules, are 15 to 35 cm long and between 5 to 15 cm wide.

Ca is generally a tall, thin tree with a narrow, open crown (Boshier, 2003). It grows under a

wide range of ecological conditions from very wet to seasonally dry. In seasonally dry, deciduous,
62 and semi-deciduous forest the species rarely grows more than 20 m in height and 30 cm dbh while
it may reach 40m in height and 1 m dbh in wetter environments. Mature trees are deciduous, even
64 in aseasonal climates, losing their leaves for 1 to 2 months per year.

66 Co is a deciduous tree that can reach 35 m in height and 60 cm dbh (Rocas, 2003). Co grows
in areas with an annual average of temperature of 22 to 32 C, average annual precipitation of 1600
68 to 2500 mm and a 3 to 4-month dry season. Co has a globose or rounded crown with a dense leaf
cover. The leaves of Co are paripinnate or imparipinnate, 15 to 50 cm long, made up of 10 to 22
70 oblong or lanceolate leaflets that are asymmetrical, 4.5 to 14 cm long and 2 to 4.5 cm wide (Rocas,
2003).

72
Hc can reach up to 45m in height and more than 2m in diameter (Sautu, 2002). It grows in areas
74 with at least 1,500 mm to 2,500 mm of rainfall. Young individuals are extremely shade tolerant and
saplings can survive up to two years completely shaded. The adult tree has a large rounded crown
76 usually formed out of three main branches. The leaves of Hc are simple, have long petioles and a
round base. They are ovate with cordate-shaped apex. They are 4 to 16 cm long and equal in width.

78
Ls is a fast-growing tree that can reach more than m in height and 2m dbh (Fournier, 2003b).
80 Ls grows on a wide range of soils and climate from 2000 mm to 4000 mm and annual average
temperatures of 23 to 25°C. The crown of Ls is round or oval. The species is gradually shedding its
82 leaves starting at the end of the dry season and usually remains with a low leaf cover for the first
weeks of the wet season (Kunert *et al.*, 2010). Leaves are alternate, stipulate, simple and thick-
84 petiolate (Fournier, 2003b). Blades are oblong, oblong-elliptic or slightly oblong-obovate, rounded

at the base, acuminate at the apex. Leaves are 7 to 40 cm long and 3 to 16 cm wide.

86

Tr is a tall, fast-growing tree reaching 25 o 30 m high and 1 m dbh (Flores & Marin, 2003).

88 The crown of Tr is wide, well stratified with a few thick branches that grow irregular and horizon-

tal. Although frequent in periodically inundated forests and soils with moderate or low drainage,

90 Tr grows in a wide range of habitat from sea level to 1200 m altitude, from 20 to 30C and an-

nual rainfall above 500 mm. Leaves are dropped March through June (Flores & Marin, 2003) but

92 Tr has also been reported to lose its leaves twice during the year both in the early dry season

(January-February) then once more in July (Croat, 1978). Tr has decussate, compound, digitale

94 leaves with a long petiole (Flores & Marin, 2003). Each leaf consists out of five leaflets that differ

in size, the center leaflet being the largest. Their shape ranges between elliptic-oblong, obovate

96 and oblong-ovate. The apex is acute or acuminate, has an entire margin, and an obtuse base. The

leaflets are between 6 and 20 cm long and between 3 and 10 cm wide. The crown of Tr is wide, well

98 stratified with a few thick branches that grow irregular and horizontal (Flores & Marin, 2003).

Table A1: Details on the selected native tree species in the Sardinilla plantation. Adapted from Delagrange *et al.* 2008.[†]; Relative growth rates in diameter at breast height observed in the forest of Barro Colorado Island (Scherer-Lorenzen *et al.*, 2007).

Species	Family	Distribution	Economic uses	RGR [†]
<i>Anacardium excelsum</i> (Ae)	Meliaceae	On the Pacific coast from Mexico to Argentina	High timber value	5.9%
<i>Cordia alliodora</i> (Ca)	Boraginaceae	From Mexico to Northern Argentina	furniture and housing High timber value	7.0%
<i>Cedrela odorata</i> (Co)	Bignonaceae	From Mexico to tropical South America (Venezuela)	furniture, ornamental High timber value	2.3%
<i>Hura crepitans</i> (Hc)	Euphorbiaceae	From Central America to northern Brazil and Bolivia	Medium timber quality heavy construction	4.9%
<i>Luehea seemanii</i> (Ls)	Anacardiaceae	From Mexico to tropical South America	Good timber value furniture, Canoes	9.1%
<i>Tabebuia rosea</i> (Tr)	Tiliaceae	From Mexico to Argentina	High timber value furniture and flooring	3.4%

Six-species planting design

Tr	Co	Ca	Ls	Ae	Hc	Tr	...
Co	Ca	Ls	Ae	Hc	Tr	Co	...
Ca	Ls	Ae	Hc	Tr	Co	Ca	...
Ls	Ae	Hc	Tr	Co	Ca	Ls	...
Ae	Hc	Tr	Co	Ca	Ls	Ae	...
Hc	Tr	Co	Ca	Ls	Ae	Hc	...
Tr	Co	Ca	Ls	Ae	Hc	Tr	...
...

Three-species planting design

Hc	Ca	Co	Hc	...
Ca	Co	Hc	Ca	...
Co	Hc	Ca	Co	...
...

Tr	Ae	Ls	Tr	...
Ae	Ls	Tr	Ae	...
Ls	Tr	Ae	Ls	...
...

Ls	Ae	Co	Ls	...
Ae	Co	Ls	Ae	...
Co	Ls	Ae	Co	...
...

Ls	Hc	Co	Ls	...
Hc	Co	Ls	Hc	...
Co	Ls	Hc	Co	...
...

Tr	Ca	Hc	Tr	...
Ca	Hc	Tr	Ca	...
Hc	Tr	Ca	Hc	...
...

Tr	Ae	Ca	Tr	...
Ae	Ca	Tr	Ae	...
Ca	Tr	Ae	Ca	...
...

Figure A1: Planting design in mixture plots. The composition of the six 3-species plots was defined by randomly choosing between Ca and Ls, Ae and Hc, and Co and Tr. These three groups of species cover the range of relative growth rates in diameter at breast height in the nearby forest of Barro Colorado Island from 2.3% (Co) to 9.1% (Ls) per year. Consequently, while species composition differed among the 3-species plots and subplots, faster and slower growing species were equally represented in any given plot or subplot.

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