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SHORT COMMUNICATIONS

Wood Decomposition of *Cyrilla racemiflora* (Cyrillaceae) in Puerto Rican Dry and Wet Forests: A 13-year Case Study[1]

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ABSTRACT

We studied the decomposition of *Cyrilla racemiflora* logs over a 13-yr period in tropical dry and wet forests in Puerto Rico. The mean mass loss, ratio of soft to hard wood, nutrient concentrations, and the diversity of wood-inhabiting organisms were greater in logs decomposing in the dry forest than in the wet forest. Termites were also more abundant in the logs collected from the tropical dry forest than the tropical wet forest. High moisture content and a low animal diversity on the logs in the wet forest seem to retard wood decay in this habitat. Wood decay rates in the tropical dry forest can be related to the high diversity of species and functional groups of wood-inhabiting organisms.

RESUMEN

Efectuamos un estudio de la descomposición de troncos de *Cyrilla racemiflora* por un período de 13 años en bosques tropicales secos y húmedos en Puerto Rico. El promedio de pérdida de masa, la proporción de madera blanda a dura, la concentración de nutrientes y la diversidad de organismos en la madera fueron mayor en los troncos descompuestos en el bosque tropical seco que en los troncos del bosque tropical húmedo. El numero de termitas también fue más abundante en los troncos colectados en el bosque tropical seco que en el bosque tropical húmedo. Un alto contenido de humedad y una baja diversidad de organismos en los troncos en el bosque tropical húmedo parecen retardar la descomposición de madera en esta región. La rápida descomposición de madera en el bosque tropical seco puede estar relacionada a la alta diversidad de organismos y de grupos funcionales de los organismos que habitan en su madera.

Key words: Cyrilla racemiflora*; dry forest; Puerto Rico; soil fauna; termites; tropics; wet forest; wood decomposition.*

WOOD IS THE MAIN CONSTITUENT OF TROPICAL FORESTS, yet few studies focus directly on its decomposition (Torres 1994, Harmon *et al.* 1995, Delaney *et al.* 1998, Dajoz 2000). Dead wood is a temporary sink for atmospheric carbon, a source of soil organic matter, a substrate for nitrogen fixation and seedling establishment, and an important habitat for wildlife (*e.g.*, Franklin *et al.* 1987). Although studies dealing with canopy invertebrates in the tropics have received great attention, few deal with the diversity of invertebrates in the soil, leaf litter, or dead wood (Dajoz 2000, González & Seastedt 2000, Stork 2003). In 1976, Wallwork stated the participation of soil fauna in the decomposition of dry stumps is minimal while tree stumps undergoing wet decomposition are usually characterized by extensive growth of microfloral decomposers. Wallwork (1976) mentions as a general rule that conditions associated with white rot fungi (wet decay) do not favor many groups of fauna that try to avoid the meshwork of hyphae.

To examine these hypotheses, we studied the decomposition of *Cyrilla racemiflora (Cyrillaceae)* logs over a 13-yr period (1989–2002) in the Guánica Biosphere Reserve, a subtropical dry forest (17°58′N, 66°52′W) located in southwestern Puerto Rico and in the Icacos Valley located in the Luquillo Experimental Forest (18°15′N, 65°45′W) in northeast Puerto Rico. Our objective was to determine the relationship between wood decay, climatic conditions, and wood-inhabiting organisms.

C. racemiflora grows in temperate and tropical regions extending from Virginia (USA) to northern Brazil and reaches its maximum size and age in the montane forests of the West Indies. In the Luquillo Mountains, *C. racemiflora* may grow to 1 m or more in diameter (Weaver 1996). Its fresh, green wood is hard (specific gravity about 0.53 g/cm^3) and exhibits prominent growth rings (Little & Wadsworth 1964, Torres 1994). Detailed descriptions of *C. racemiflora* are provided elsewhere. Weaver (2000) presents a summary report on the habitat, life cycle, chemistry, genetics, and uses of *C. racemiflora.* Torres (1994) provides chemical data for different wood regions and decay classes of *C. racemiflora* in the Luquillo Mountains.

Mean annual precipitation in the Guánica dry forest is 860 mm and mean air temperature is 25.1°C. Elevation is 160 m and the plant communities are typical of a semi-deciduous forest (Murphy & Lugo 1986). Soils have developed from limestone

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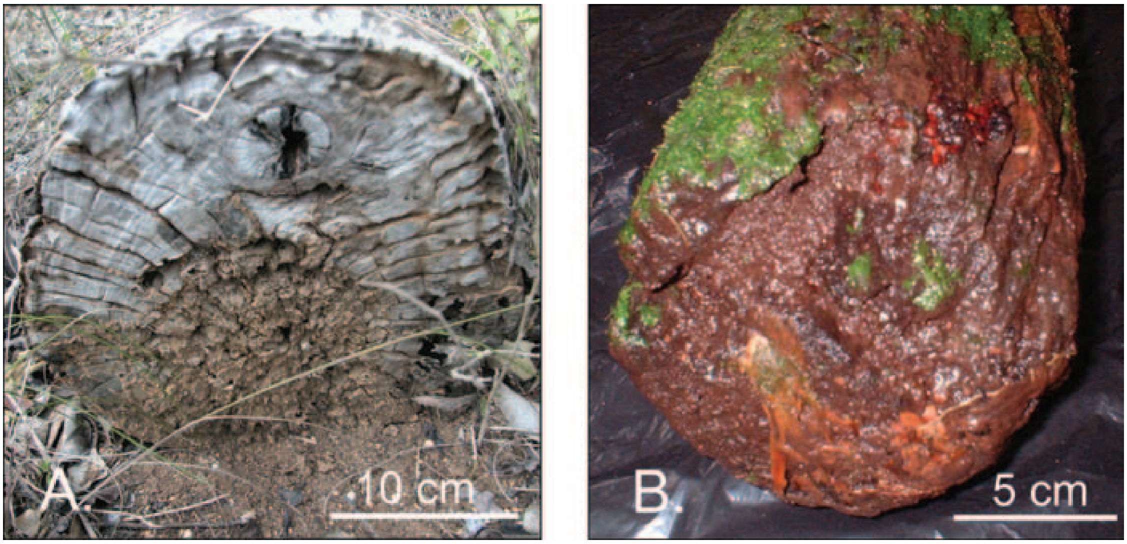

FIGURE 1. *Cyrilla racemiflora* logs decomposing in (a) a tropical dry and (b) a tropical wet forest after 13 yr. Notice the absence of bark, the presence of termite galleries and cracks, and how decay proceeds faster near the ground in the dry forest (a). In contrast, observe the occurrence of mosses, high-water saturation, and no cracks or animal galleries in logs decaying in the tropical wet forest (b).

bedrock and are categorized as stony, shallow, and dry (Carter 1965). The Icacos valley is located in the subtropical lower montane wet forest life zone at an elevation of approximately 800 m and is covered by a forest dominated by *C. racemiflora*. The *C. racemiflora* forest occurs above the cloud condensation level. The soil is at field capacity throughout most of the year (Ewel & Whitmore 1973), and this forest is classified as a freshwater wetland (Frangi 1983, Lugo & Brown 1988). The extreme wetness of the soil gives rise to an accumulation of incompletely decomposed organic matter (Lugo & Brown 1988). Mean annual rainfall averages 4000 mm in the Luquillo forest and annual mean air temperature is about 22°C with little monthly variation (Brown *et al.* 1983). Actual evapotranspiration values have been estimated for the Guánica Forest and Luquillo Forest at 891 and 1342 mm, respectively (González & Seastedt 2001).

Sixteen days after the passage of Hurricane Hugo over Puerto Rico (October 4, 1989) we cut 12 logs of approximately 1 m in length and about 30 cm in diameter from the hurricane-uprooted trees in the Icacos valley of the Luquillo Experimental Forest (LEF). Half of the logs were laid on the Guánica Forest floor and the other half were laid on the forest floor of the Icacos valley of the LEF. All logs were placed on flat ground in the valley topographic position. Measurements of the circumference at both ends of the logs and the length were taken. The initial dry weight was estimated by multiplying the log volume (assuming a cylindrical form and taking the average radius at the end points) by the density (0.58 g/cm^3, Torres 1994). Logs were observed during the first two years to determine the pattern of invertebrate (mainly insects) and fungal colonization. Fungal colonization referred only to the presence of fruiting bodies as no culturing and identification of fungi was performed. Therefore, we do not infer fungal activity and growth by the presence or absence of fruiting bodies, nor can we compare rot types in the logs placed in the two forests. The logs were collected from the field after 13 yr on December 21–25, 2002. All logs were recovered from the Guánica forest. The passage of Hurricane Georges on September 21, 1998 through Puerto Rico disturbed the Luquillo forest to the extent that that we could locate only two of the original logs.

During the first 2 yr of the study, mosses were present on the logs located in the Luquillo forest and the bark of these logs exhibited minor cracks. In Guánica, the mosses originally present in the logs died by June 6, 1990 and cracking was common throughout the bark and at the ends of the logs (Fig. 1a, b). Angiosperm seedlings germinated over three logs at Luquillo by February 9, 1991 and roots from the forest floor were growing on another log. Vines were found over a log at Guánica by February 2, 1991 and the bark was almost completely detached from two logs. Fruiting bodies of fungi were present at the cut ends of all the logs laid at the Luquillo forest by December 11, 1989, but were found in only the end of one log at Guánica. Bark beetle (Scolytidae) entrance orifices were found on March 31, 1990 in two logs at Luquillo, but the beetles could not establish a gallery system; bark beetles were not found at Guánica. Previous studies (Torres 1994) found that bark and ambrosia beetles are rare in *C. racemiflora* logs. The rarity of bark beetles in the Guánica forest may be related to the fast drying of logs (Bright & Torres, unpubl. data).

Termites (*Nasutitermes costalis, Heterotermes convexinotatus*) were established rather quickly on all logs in Guánica (December 20, 1989). Termites (*Parvitermes discolor*) arrived later at the Luquillo forest (in two logs by June 29, 1990) and larvae of a tenebrionid (*Arrhabeus* sp.) were penetrating the ends of another log at Luquillo. Larvae of this tenebrionid were attacking two additional logs by February 9, 1991.

After more than 13 yr in the field we collected the logs from the field by rolling them over a tarp. In the laboratory, we removed

TABLE 1. *Nutrient concentrations (mean ± SE) in wood regions of* C. racemiflora *located in the Guánica dry forest and Luquillo rain forest.* N = *6 for each wood section for the Guánica dry forest,* N = *1 for bark,* N = *2 for soft wood and* N = *2 for hard wood located in Luquillo wet forest. Concentrations of nutrients in different wood regions are significantly different in the Guánica dry forest (Kruskal–Wallis tests, df = 2,* P *< 0.01).*

Wood region	Ca (mg/g)	P (mg/g)	Al (mg/g)	Fe (mg/g)	Mn (mg/g)	K (mg/g)	Mg (mg/g)	C (%)	S (%)	N (%)
Guánica dry forest										
Bark	31.46 ± 5.41	0.27 ± 0.02	2.44 ± 0.56	2.01 ± 0.47	0.07 ± 0.02	3.27 ± 0.21	1.53 ± 0.18	49.45 ± 0.78	0.14 ± 0.01	0.94 ± 0.04
Soft wood	76.00 ± 13.16	0.48 ± 0.04	10.82 ± 2.29	9.92 ± 2.11	0.19 ± 0.03	6.59 ± 0.61	3.67 ± 0.59	34.85 ± 3.65	0.11 ± 0.01	0.85 ± 0.05
Hard wood	2.24 ± 0.49	0.03 ± 0.01	0.15 ± 0.05	0.15 ± 0.03	0.02 ± 0.01	1.57 ± 0.21	0.39 ± 0.07	51.38 ± 0.11	0.03 ± 0.01	0.11 ± 0.01
Luquillo wet forest										
Bark	3.54	0.14	3.38	4.35	0.10	0.57	0.74	55.58	0.11	0.75
Soft wood	2.14 ± 0.73	0.16 ± 0.02	5.53 ± 1.31	6.67 ± 2.01	0.05 ± 0.03	0.47 ± 0.03	0.49 ± 0.16	46.17 ± 3.93	0.11 ± 0.03	0.70 ± 0.12
Hard wood	0.64 ± 0.08	0.01 ± 0.01	0.13 ± 0.11	0.18 ± 0.13	0.01 ± 0.01	0.15 ± 0.03	0.16 ± 0.02	51.42 ± 0.07	0.02 ± 0.01	0.12 ± 0.02

by hand all the invertebrates, plants, lichens, and roots and divided the log material in three categories: bark, soft wood (pliable), and hard wood. We determined the oven-dry weight (constant weight at 65°C) of the total soft and hard wood regions. The soft and hard wood weights were combined to determine the mass loss in each log. The ratio of soft to hard wood was calculated as an indicator of the degree of wood decay.

Samples from bark, soft wood, and hard wood were ground with a Foss Tecator Cyclotec (model 1093) mill through a 1 mm stainless steel sieve. Total nitrogen, carbon, and sulfur were determined using the dry combustion method by means of a LECO CNS-200 analyzer (St. Joseph, MI, USA). P, Ca, K, Al, Fe, Mn, and Mg determinations were performed from digestions using a Beckman plasma emission spectrometer (Spectra V) (Luh Huang & Schulte 1985). Accuracy was assured by running control samples of known chemical composition.

The mean mass loss for the Guánica (dry forest) logs was 12.5 kg (SD = 6.93) and for the Luquillo (wet forest) logs 7.1 kg (SD = 2.3), representing an average of 61 and 54 percent of the original mass, respectively. The mean ratio of soft to hard wood for the Guánica forest was 0.37 (SD = 0.25) and 0.04 (SD = 0.02) for the Luquillo forest, indicating that logs in the Guánica site were in a more advanced stage of decomposition. Mass loss was greater in the Guánica dry forest even when the weather conditions (lack of rain) kept decay matter *in situ.* The heart wood of the two logs found in the Luquillo forest was almost intact (no animal galleries, but some fungi were present). These results are consistent with studies dealing with litter decomposition in desert and tropical dry ecosystems where decomposition is more rapid than predicted from actual evapotranspiration values (Whitford *et al.* 1981, González & Seastedt 2001).

The soft wood at Guánica was the richest in nutrient concentrations (except for C, S, and N) when compared to the bark and hard wood components. The bark had higher concentrations of C, S, and N than the soft wood (Table 1). The hard wood, in Guánica and Luquillo, contained the lowest nutrient concentrations. The C:N ratio of the bark and soft wood of all logs ranged between 41 and 67. The C:N ratio of the hard wood of all logs averaged 448. Although we did not conduct a statistical analysis due to the small sample size in the Luquillo logs, nutrient concentrations were greater for the majority of nutrients in the Guánica logs. The higher Ca concentration in the Guánica logs could be a reflection of the higher $CaCO_3$ in the soil of this forest (Torres *et al.* 1999) which decomposers could bring to the decomposing logs. The ability of surface growing fungal hyphae to accumulate Ca to concentrations greater than that of the litter has been previously reported by Todd *et al.* (1973) and Cromack *et al.* (1977). Also, the higher nutrient concentrations in the Guánica logs could be related to a lower leaching potential due to the low precipitation in this forest and the greater animal activity (termites particularly).

We found a total of 29 animal species (mean = 11) in the Guánica logs and 12 (mean = 7) in the Luquillo logs collected in December 2002 (Tables 2, 3). The subterranean termite, *H. convexinotatus*, was the most important decomposer at the Guánica site followed by the arboreal termite *N. costalis*. All logs at Guánica contained termites in great numbers, and animal galleries and millipede frass were common (Fig. 1a). Also, ant nests were more common at the Guánica logs. Only one species, *Portoricoscia richmondi* (an isopod) was present in the logs collected from both forests (Tables 2, 3). At the Luquillo forest the fungi and earthworms seem to have a greater role in wood decomposition and termites a lower role. While in Guánica, wood decay seems to be driven by the presence of a particular functional group (termites) and high faunal diversity.

Log decomposition was greatest in the upper half region of the logs in Luquillo (Fig. 1b) and logs contained roots in the lower parts, mosses on their sides, and the holes in the upper parts act as nutrient sinks (leaves and small branches accumulate here). Fungus (presence of fruiting bodies of ascomycetes and basidiomycetes) were found at the ends of the logs. In Luquillo, there were minor amounts of bark peeled away from the logs that were not entirely decomposed after more than 13 yr. The high moisture content of the logs in the Luquillo montane forest correlated with a lower animal diversity and lack of certain functional groups seems to slow decomposition in this habitat, which behaves in many places as an anaerobic wetland (Lugo & Brown 1988).

TABLE 2. *Number of times a taxonomic group was found in logs at the Guánica dry forest (N = 6).*

Class	Order	Family	Species	Frequency
Arachnida	Araneae	–[a]	sp. 1	2
		–	sp. 2	2
		–	sp. 3	1
		–	sp. 4	1
		–	sp. 5	1
	Pseudoscorpionida	–	–	4
	Scorpionida	Buthidae	immature	1
	Amblypygi	Phrynidae	Phrynus marginemaculatus	4
Chilopoda	Scolopendromorpha	–	–	2
	Scutigeromorpha	Scutigeridae	–	1
Diplopoda	Spirobolida	Rhinocricidae	Anadenobolus monilicornis	4
	Polyxenida	Lophoproctidae	Lophoturus niveus	2
Entognatha	Diplura	–	–	1
Insecta	Coleoptera	Curculionidae	–	1
		Staphylinidae	–	1
	Hymenoptera	Formicidae	Camponotus kaura	3
			Crematogaster steinheili	2
			Cyphomyrmex minutus	1
			Monomorium floricola	1
			Leptothorax torrei	3
	Lepidoptera	Geometridae	larvae	1
		Noctuidae	pupae	3
	Isoptera	Termitidae	Nasutitermes costalis	3
		Rhinotermitidae	Heterotermes convexinotatus	6
	Orthoptera	Blattellidae	–	2
	Zygentoma	Lepismatidae	Lepisma sp.	4
Malacostraca	Isopoda	Oniscidae	Portoricoscia richmondi	2
Reptilia	Squamata	Typhlopidae	Typhlops hypomethes	1
		Gekkonidae	Sphaerodactylus nicholsi	4

[a]Undetermined.

In Guánica, greater decomposition occurred in the lower regions of the logs, close to the ground (Fig. 1a), where moisture was retained longer, and apparently favoring colonization by decomposers. Fruiting bodies of fungi of macro-mycetes were present in five logs in the Guánica forest and were restricted to the lower regions of logs. Greater decay as evidenced by more cracking in the lower part of the log could be a result of brown rot fungi. Fruiting bodies of these basidiomycetes need high moisture to disperse their spores. Vines or roots were present on four of the logs and only one seedling of *Croton humilis* was seen growing out of a log. In Guánica, a great proportion of the detached bark from all logs was found partially undecomposed on the forest floor after more than 13 yr.

TABLE 3. *Frequency of occurrence taxonomic groups in logs at the Luquillo Forest (N = 2).*

Class	Order	Family	Species	Frequency
Arachnida	Araneae	–[a]	–	1
Chilopoda	Scolopendromorpha	Cryptopidae	Cryptos bivittatus	2
Diplopoda	Spirobolida	Spirobolellidae	Spirobolellus richmondi	1
Insecta	Coleoptera	Elateridae	larvae	1
		Scolytidae	larvae	1
	Hymenoptera	Formicidae	Pachycondyla stigma	1
			Strumigenys rogeri	1
	Isoptera	Termitidae	Parvitermes discolor	1
	Orthoptera	Gryllidae	–	2
Malacostraca	Isopoda	Oniscidae	Portoricoscia richmondi	1
Oligochaeta	–	–	–	1
Symphyla		Scolopendrellidae	–	1

[a]Undetermined.

We note that this preliminary information on the decay of *C. racemiflora* in two extreme habitats suggests interesting patterns of wood decomposition and nutrient mineralization processes. Wood decay in tropical wet and dry forests is related to the interacting factors of the species composition of wood-inhabiting organisms and the physico-chemical environment. A high moisture content and low animal diversity in the wood slows decay rates in tropical wet forests. However, wood decay rates in tropical dry forests can be related to the high diversity of species and functional groups of its wood-inhabiting organisms, which can overcome climatic constraints. Future studies on wood decay should try to tease apart the intertwined effects of climate and organisms as the relative importance of these regulating factors might differ given woods of different physical and chemical properties.

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