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Biological Deterioration of Woods in Tropical Environments

Part 4 - Long-Term Resistance to Terrestrial Fungi and Termites

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ABSTRACT

This is the fourth report in a series describing the biodegradation of treated and untreated woods in the marine and terrestrial environments of the Panama Canal Zone. Presented here are the final results of the terrestrial studies for exposure periods up to 13 years at three jungle exposure sites. One hundred fifteen natural woods and five wood preservatives are evaluated for resistance to subterranean termites and to above-ground and below-ground fungal decay.

Thirty seven of the 115 species of untreated wood survived the full 158-month exposure; of these only five were considered to be highly resistant to all the wood-degrading organisms present. Fungi below and near the groundline were the most universally destructive organisms. Subterranean termites more rapidly destroyed susceptible woods, but eventually many more wood species were found to have higher natural resistance to termites than to fungi.

Wood density seemed to be an important factor in durability but was not the only requirement. Certain chemical constituents in the woods were definitely contributory to high resistance; one of the most effective seems to be a naturally occurring quinone. Silica, an important chemical in marine environments, showed no significant effect on terrestrial durability. In other respects also, terrestrial and marine durability were unrelated, although a few untreated woods, especially those containing natural quinones, and one treated wood, creosoted pine, were resistant in both environments.

PROBLEM STATUS

This is a final report on one phase of a continuing NRL problem.

AUTHORIZATION

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BIOLOGICAL DETERIORATION OF WOODS IN TROPICAL ENVIRONMENTS

Part 4 — Long-Term Resistance to Terrestrial Fungi and Termites

INTRODUCTION

In the last few years the deleterious effects of toxic chemical treatments on soils and waters have begun to be appreciated, and investigations of alternate methods of controlling destructive organisms are being initiated. With this awareness the importance of using woods naturally resistant to such organisms in lieu of wood treated with toxic preservatives has taken on new significance. A long-term NRL study to evaluate the natural resistance of a large number of tropical woods and to compare their durability to that of woods treated with the best available chemical preservatives has been completed. This investigation included 115 wood species and 10 selected wood preservatives. Exposures for up to 158 months were made in five different marine and terrestrial sites in the very bioactive environments of the Panama Canal Zone. A first interim report, Part 1 of this series (1), covered the collection and identification of wood species, exposure conditions, test procedures, and the initial test results for the exposure of the first 14 to 18 months. Part 2 of this series (2) presented the data for all the natural woods for the 90 month marine exposure, and Part 3 of this series (3) discussed the long-term marine durability of chemically treated nonresistant coniferous woods and combinations of selected naturally resistant tropical woods and chemical preservatives.

This report, Part 4, will finish this series by presenting the final results through 158 months for the terrestrial exposures of both natural and chemically treated woods. With these completed results it is also now feasible to make comparisons between marine and terrestrial durability. This facet will be discussed for both natural and treated woods.

SELECTION OF TEST MATERIALS

The tropical rain forests of the world contain a countless variety of trees, a great number of which yield excellent timbers unmatched by most of those from the temperate zones. Many of these fine woods are known only in restricted localities, and very little scientific data on their resistance to biological deterioration have been collected. On the Isthmus of Panama, where this investigation was conducted, the flora of the Pacific and Caribbean coasts meet and mingle; in this relatively small area a great variety of forest trees is found.

Most of the wood species tested were collected in Panama, but many represent timbers available throughout tropical America. The study was initiated to evaluate the marine durability of these woods, and most of the species were selected with this in mind; however, in marine structures it is usually necessary to use timbers or piles both in and out of the water, and a knowledge of their resistance to terrestrial wood-destroying organisms is also needed. Therefore, most of the untreated woods and some of the treated woods were tested in both the marine and terrestrial environments.

EXPERIMENTAL PROCEDURES

Exposure Conditions

Because of the ideal conditions for growth of wood-destroying organisms, materials exposed in the hot, humid tropics are much more susceptible to biological attack than in temperate climates. Earlier reports by the authors (4,5) compared the destructiveness of tropical vs temperate-climate termite species; it was shown that a much more rapid and uniform attack occurred with the tropical species. In wood durability studies such as these, exposures in the highly active, nonseasonal tropical environments offer the best possible conditions for obtaining reliable data.

In the present study, specimens were placed at three jungle locations in the Panama Canal Zone. One was on the Caribbean side of the Isthmus, at Fort Sherman, where the samples were sheltered from the weather; another was at an unsheltered jungle location near Galeta Point, also on the Caribbean side; and the third was an unsheltered area on the Pacific side of the Isthmus at Fort Clayton. The climatic conditions for the Caribbean and Pacific sides of the Canal Zone are given in Appendix A.

Samples exposed at both Galeta Point and Ft. Clayton were stakes 1.5 in. by 1.5 in. by 18 in. These were exposed vertically with one-half the length of the stake buried. Three replicates of each species of wood and wood treatment were dispersed in each of the stake test plots. For control and comparison, 68 stakes of a nonresistant wood, southern yellow pine, were randomly distributed at each of the two areas. These two areas and the type of specimens used were selected to insure maximum attack by fungi.

At the Ft. Sherman site, samples were panels 0.5 in. by 2 in. by 5 in. attached to oak splines. Five specimens and an untreated southern pine control panel were attached to each spline, with a 0.5-in. clearance between panels. Six replicates of each wood species and each preservative treatment tested were dispersed throughout the exposure area. The splines were placed in contact with the soil, and test panels were then about 1 in. above the ground. A pine control panel was included on each spline. The purpose of this exposure method was to prevent ground-line fungal attack while permitting free access to subterranean termites. The entire exposure area was roofed, with open sides.

Methods of Evaluation

Specimens in all exposures were rated for both fungal decay and termite damage. In the stake test, above- and below-ground fungal activity varied considerably, and these two conditions were rated separately; for termites the difference was not significant, and only one termite rating per stake was given. The same rating system was used for both termites and fungi, as follows:

0 - no visible damage
1 - trace of damage
2 - slight damage
3 - moderate damage
4 - heavy damage
5 - very heavy damage
X - sample destroyed or missing

Specimens were inspected at approximate periods of 6, 12, 18, 30, 90, 109, and 158 months. However, the Fort Sherman termite panels were all removed at the end of four years because of closure of the access road to the site, and all the Albrook stakes were removed after five years because of a new construction project in the area. The stake specimens at Galeta Island remained on exposure for over 13 years before being removed; they then were brought to NRL for a final detailed inspection. All data were carefully considered to obtain the resistance rankings for the different wood species; however, results for the more durable woods and wood treatments are based primarily on the 90- and 158-month data from the Galeta Point exposures.

RESULTS AND DISCUSSION

Untreated Tropical Woods

The 115 untreated woods included in the investigation are listed in Table 1. One hundred four of these species were from Panama; nine species were reputedly resistant woods from other tropical areas; and two U.S. woods, Douglas fir and southern yellow pine, were used for controls, comparisons, and wood-treatment evaluations. Woods in Table 1 are listed alphabetically by botanical name with author citations and most-used common names from the area of procurement. The wood density is also given for each of the species, followed by a summary of results showing the overall numerical resistance rating at each inspection period. Ratings for both termites and fungi for each of the four major inspection periods are given. An integrated alphabetical listing of the woods studied by common and botanical names is included in Appendix B.

Resistance to Fungal Decay — Decay of wood is the result of the activity of certain wood-destroying fungi. Under favorable conditions of moisture and temperature, the fungi thrive on the cellulosic substrate, the hyphae spreading throughout the wood, enzymatically degrading the cellulose and releasing nutritional elements locked up in the tissues of the wood. This is a very important scavenging mechanism in nature which simultaneously disposes of debris and enriches the soil for future plant generations. In the jungle soil, where conditions of temperature and moisture are ideal for growth, there exist great numbers of fungi. However, few if any of the wood-destroying fungi are capable of attacking all wood species, and some woods seem to be practically immune to most of these fungi.

The subterranean portion of the stake specimens usually received the heavier attack, with the maximum generally occurring close to the groundline. Thirty nine of the 115 woods exposed had rateable portions remaining after 158 months (Table 1); all of these woods are considered to be highly resistant to fungi. Those species showing exceptional resistance to fungi are listed in Table 2 for above-ground durability and in Table 3 for the groundline and below.

The first four woods in Table 2 received only a trace of fungal damage (numerical rating 1) at any site and for any exposure period. The remainder of the woods in this table all received a maximum rating of slight (numerical rating 2), indicating only slight attack above ground. Generally at groundline or below the woods were more heavily damaged by about one rating step than were the above-ground portions of the stakes. The first six species listed in Table 3 had a maximum damage rating of 2 (slight), and the remainder had a maximum rating of 3 (moderate).

Table 1
Damage to Untreated Woods Exposed to Termites and Fungi in Tropical Rain Forests

Botanical Name	Common Names in Area of Procurement†	Density‡	Degree of Damage*											
			Subterranean Termites				Fungi							
							Above Ground				Groundline and Below			
			12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo
Anacardium excelsum	Expavé (1)	E	1	2	x	x	0	3	x	x	2	4	x	x
Andira inermis	Cocú (2)	D	0	1	3	x	1	3	3	x	1	4	5	x
Aspidosperma megalocarpon	Carreto, Alcarreto (1)	B	1	3	4	x	1	2	3	x	2	3	5	x
Avicennia marina	Mangle salado (2)	B	3	x	x	x	0	4	x	x	¶	x	x	x
Bombscopsis quinata	Cedro espino (1)	F	0	1	1	1	0	1	2	4	1	2	2	5
B. sessilis	Ceibo (2)	F	5	x	x	x	¶	x	x	x	¶	x	x	x
Brosimum sp.	Berba, Guayabo blanco (1)	D	1	2	x	x	2	4	x	x	2	5	x	x
Bursera simaruba	Almácigo, Indio desnudo (2)	F	5	x	x	x	¶	x	x	–	¶	x	–	–
Byrsonima crasslfolia	Nance (2)	D	0	2	4	x	2	3	4	x	2	3	4	x
Callitris glauca	Australian cypress pine (3)	E	0	1	2	1	0	1	1	2	0	2	3	4
Calophyllum brasiliense	Maria (1)	D	0	3	4	x	0	2	2	x	0	3	5	x
Calycophyllum candidissimum	Alazano, Lemonwood, lancewood (2)	C	0	2	3	x	0	2	4	x	2	3	5	x
Carapa slateri	Cedro macho, Tangare (4,5)	E	0	4	x	x	1	2	3	x	3	4	5	x
Carapa sp.	Cedro vino (1)	E	0	3	5	x	1	2	3	x	3	4	5	x
Cariniana pyriformis	Chibugá, Albarco (5)	B	0	1	1	3	1	2	2	4	2	3	4	5
Caryocar costaricense	Henené (5)	B	0	0	1	1	0	1	2	2	1	2	3	3
Caryocar sp.	Ajo (5)	B	0	1	1	2	0	2	3	4	2	2	4	5
Cassia moschata	Bronze shower (2)	C	1	1	2	2	1	1	2	3	1	2	3	4
Cedrela mexicana	Cedro amargo (1)	F	0	1	2	x	1	2	5	x	3	3	5	x
Cedrela sp.	Cedro granadino (6)	F	1	4	x	x	0	2	x	x	2	4	x	x
Centrolobium orinocense	Amerillo de Guayaquil (5)	D	0	0	1	2	0	1	1	3	1	2	2	4
Chlorophora tinctoria	Mora (1)	E	0	1	1	1	0	1	2	2	0	2	4	5
Chrysophyllum cainito	Caimito, Star apple (2)	B	0	1	5	x	1	3	5	x	2	4	5	x
Colubrina glandulosa	Carbonero de amunición (2)	B	0	0	1	1	0	1	1	2	0	1	2	3
Conocarpus erectus	Zaragosa (2)	B	0	1	1	1	0	1	1	3	1	2	3	4
Copaifera aromatica	Cabimo (1)	D	0	1	1	2	0	0	2	3	2	2	3	4
Cordia alliodora	Laurel negro (4)	F	0	1	1	x	1	2	4	x	1	3	5	x

Table 1 (Continued)
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Cornus disciflora	Mata hombro (6)	D	1	4	5	x	1	4	5	x	3	4	5	x
Coumarouna oleifera	Almendro (1)	B	0	0	2	2	0	1	2	4	1	2	2	5
Croton panamensis	Sangre (2)	E	5	x	x	x	4	x	x	x	4	x	x	x
Dalbergia retusa	Cocobolo (1)	A	0	0	0	0	0	0	1	1	0	1	2	2
Dialyanthera otoba	Miguelario (4)	F	5	x	x	x	¶	x	x	x	¶	x	x	x
Dicorynia paraensis	Angélique, Basra locus (7)	C	0	1	1	2	0	1	1	3	1	2	3	4
Diphysa robinoides	Macano, (2)	B	0	0	0	1	0	0	1	2	1	1	2	3
Enterolobium cyclocarpum	Corotú (2)	E	0	0	1	x	0	1	3	x	0	1	4	x
Erythrina glauca	Gallito (2)	F	4	x	x	x	5	x	x	x	5	x	x	x
Eschweilera sp.	Guayabo macho (1)	D	1	1	1	x	1	2	2	x	2	2	3	x
Genipa americana	Jagua (2)	D	1	3	x	x	1	4	x	x	2	5	x	x
Gliricidia sepium	Bala, Mata ratón (2)	A	0	0	1	1	0	1	1	2	0	1	2	3
Guajacum officinale	Lignum vitae (8)	A	0	0	0	0	0	0	0	1	0	1	1	2
Guarea longipetiola	Chuchupate (6)	E	0	1	2	x	0	2	4	x	1	3	5	x
G. guara	Guaragao (1)	C	0	1	1	2	0	1	1	3	1	2	2	3
Hura crepitans	Nuño (2)	F	4	5	x	x	4	4	x	x	4	5	x	x
Hyeronima alchorneoides	Pantano (6)	B	0	1	3	x	0	3	4	x	1	4	5	x
Hymenaea courbaril	Algarrobo (2)	C	0	0	1	1	0	1	2	4	0	2	2	4
Lafoënsia punicifolia	Amarillo negro (2)	C	0	1	1	2	0	1	2	4	2	3	4	5
Laguncularia racemosa	Mango blanco (2)	D	1	3	4	x	1	2	3	x	2	4	5	x
Lecythis ampla	Coco (5)	C	0	1	1	2	0	1	2	3	1	2	3	3
Lecythis or *Manilkara*	Coco (5)	A	0	1	3	x	1	1	3	x	1	2	4	x
Licania arborea	Raspa (1)	D	0	1	x	x	1	5	x	x	3	5	x	x
Licaria pittieri	Jigua negra (5)	E	0	1	2	x	1	3	4	x	2	3	5	x
Lonchocarpus sp.	Iguanillo (2)	B	1	2	3	x	1	3	4	x	2	3	5	x
Lophira procera	Bongassi (9)	A	0	0	1	2	0	1	2	3	0	2	3	5
Luehea seemannii	Guácimo (1)	E	2	3	x	x	1	4	x	x	3	5	x	x
Magnolia sororum	Vaco, Baco (6)	E	0	2	3	x	1	2	3	x	1	3	5	x
Manikara bidentata	Níspero balata (5)	B	0	0	1	1	1	1	1	3	1	2	2	3
M. chicle	Níspero zapote (2)	A	0	1	2	2	0	1	3	3	0	2	4	5
Manilkara sp.	Rasca (1)	A	0	1	4	x	0	1	4	x	1	2	5	x
Minquartia guianensis	Crillo, Manwood (4)	C	0	0	1	1	0	1	2	2	1	2	3	3
Mora oleifera	Alcornoque (5)	D	1	3	x	x	1	2	x	x	1	3	x	x
Myroxylon balsamum	Bálsamo (5)	A	1	1	2	2	0	1	1	3	0	2	2	4
Nectandra whitei	Bambito (1)	D	1	3	5	x	1	1	3	x	2	2	4	x

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Ocotea dendrodaphne	Ensiva, Insibe (5)	C	0	0	1	1	0	1	1	3	1	2	3	3
O. rodiei	Greenheart (10)	B	0	0	1	1	0	1	1	1	0	1	2	2
Paramachaerium gruberi	Sangrillo negro (6)	C	0	0	2	3	0	1	2	4	1	2	3	5
Pelliciera rhizophorae	Palo de sal (1)	D	2	4	x	x	2	5	x	x	3	5	x	x
Peltogyne purpurea	Nazareño (1)	B	0	0	2	x	0	1	2	x	1	2	3	x
Pentaclethra macroloba	Gavilán (4)	C	0	0	1	x	0	2	3	x	1	3	5	x
Phoebe johnstonii	Aguacatillo (2)	E	1	3	x	x	3	4	x	x	4	5	x	x
Pinus caribaea	Nicaraguan pine (11)	E	4	5	x	x	1	¶	x	x	1	¶	x	x
Pinus sp.	Southern yellow pine (12)	F	5	x	x	x	1	x	x	x	2	x	x	x
Pithecellobium mangense	Uña de gato (2)	E	0	0	1	1	0	1	1	2	0	2	2	2
Platymiscium pinnatum	Quirá (1)	B	0	0	1	1	0	1	1	3	0	1	2	3
Pouteria campechiana	Mamecillo (2)	A	1	2	5	x	1	2	4	x	2	3	5	x
P. chiricana	Níspero de monte (2)	B	1	2	4	x	1	3	5	x	2	4	5	x
Prioria copaifera	Cativo (2)	E	4	x	x	x	4	x	x	x	5	x	x	x
Pseudotsuga menziesii	Douglas fir (12)	E	4	5	x	x	1	¶	x	x	1	¶	x	x
Quercus sp.	Oak, Roble (6)	B	4	5	x	x	0	¶	x	x	3	¶	x	x
Rhizophora brevistyla	Mangle rojo (Pacific) (1)	A	3	4	¶	x	1	2	4	x	2	3	5	x
R. mangle	Mangle rojo (Atlantic) (2)	B	2	3	x	x	1	3	x	x	2	4	x	x
Sterculia apetala	Panamá (2)	F	4	5	x	x	4	5	x	x	4	5	x	x
Swartzia panamensis	Cutarro (5)	B	0	0	1	1	0	1	2	3	1	2	3	4
S. simplex	Naranjito (2)	B	1	1	3	x	1	3	5	x	3	4	5	x
Sweetia panamensis	Malvecino (1)	B	0	1	4	x	0	2	3	x	1	3	5	x
Swietenia macrophylla	Mahogany, Caoba (1)	E	0	1	1	1	0	1	2	3	0	2	3	4
Symphonia globulifera	Sambogum, Cerillo (4)	E	1	3	x	x	0	2	x	x	2	4	x	x
Tabebuia chrysantha	Guayacán negro (1)	A	0	0	1	1	0	1	1	3	0	1	2	5
T. guayacan	Guayacán (6)	A	0	0	1	0	0	1	1	2	0	1	2	3
T. pentaphylla	Roble de sabana (1)	E	0	1	4	x	0	2	5	x	2	4	5	x
Tectona grandis	Teak (Canal Zone) (2)	E	0	1	1	1	1	1	1	2	1	3	3	3
T. grandis	Teak (Burma) (13)	E	0	0	1	1	0	1	1	3	0	3	3	4
Terminalia amazonia	Armarillo (1)	C	0	1	3	x	0	1	3	x	1	3	4	x
T. catappa	Almond (2)	E	1	2	4	x	2	3	4	x	3	4	5	x
T. myriocarpa	Dalienze (2)	E	0	2	x	x	1	3	x	x	3	4	x	x
Ternstroemia seemannii	Manglillo (2)	E	2	3	x	x	1	3	x	x	2	5	x	x
Tetragastris panamensis	Anime (5)	B	0	1	4	x	0	2	3	x	1	3	5	x
Tetrathylacium Johansenii	Macho (2)	D	2	3	x	x	1	4	x	x	4	5	x	x

Table 1 (Continued)
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Botanical name	Common Names in Area of Procurement†	Density‡	Degree of Damage*											
			Subterranean Termites				Fungi							
							Above Ground				Groundline and Below			
			12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo
Trattinickia aspera	Caraño (2)	F	5	x	x	x	2	x	x	x	2	x	x	x
Trichilia tuberculata	Alfaje (2)	C	1	4	x	x	1	3	x	x	3	4	x	x
Vatairrea sp.	Amargo-amargo (1)	E	0	1	4	x	1	3	3	x	2	3	4	x
Virola koschnyi	Bogamani (6)	F	5	x	x	x	¶	x	x	x	¶	x	x	x
V. sebifera	Mancha (6)	E	5	x	x	x	2	x	x	x	4	x	x	x
Vitex floridula	Cuajado (2)	D	1	3	4	x	2	3	5	x	3	4	5	x
Vochysia ferruginea	Mayo (2)	F	2	4	x	x	2	3	x	x	3	4	x	x
Vouacapoua americana	Acapú (14)	B	0	0	0	0	0	1	1	1	0	1	2	2
Zanthoxylum belizense	Acabú (1)	F	1	2	x	x	2	3	x	x	2	4	x	x
Unidentified	Macano blanco (1)	A	0	0	0	0	0	0	1	2	1	1	2	2
Unidentified	Vasca (5)	E	1	3	x	x	3	4	x	x	4	5	x	x
Unidentified	Sigua (1)	E	4	¶	x	x	2	5	x	x	3	5	x	x
Unidentified	Naranjillo (6)	D	1	2	4	x	1	3	4	x	3	4	5	x

* 0–none, 1–trace, 2–slight, 3–moderate, 4–heavy, 5–very heavy, x–all specimens were removed or destroyed before this inspection because of low resistance to fungi or termites or both.

† (1) Province of Panama, Republic of Panama; (2) Panama Canal Zone; (3) Australia; (4) Province of Bocas del Toro, Republic of Panama; (5) Province of Darien, Republic of Panama; (6) Province of Chiriqui, Republic of Panama; (7) Surinam; (8) Central America; (9) Africa; (10) Guyana; (11) Nicaragua; (12) United States; (13) Burma; (14) Brazil.

‡ Density (g/cm^3 air-dry): A: >1.0; B: 0.9 to 1.0; C: 0.8 to 0.9; D: 0.7 to 0.8; E: 0.5 to 0.7; and F: <0.5.

¶ Could not be rated.

Table 2
Natural Woods Showing Highest Resistance to Fungi Above Groundline
(In Descending Order of Merit Based on all Exposures)

Botanical Name	Common Name*	Source	Specific Gravity (air-dry)
Guajacum officinale†	Lignum vitae	Central America	1.2
Dalbergia retusa	Cocobolo	Panama, R.P.‡	1.1
Vouacapoua americana	Acapú	Brazil	0.9 - 1.0
Ocotea rodiei	Greenheart	Guyana	0.9 - 1.0
Gliricidia sepium	Mata raton	Panama Canal Zone	>1.0
Unknown genus	Macano blanco	Panama, R.P.	>1.0
Pithecellobium mangense	Uña de gato	Panama Canal Zone	0.50
Tabebuia guayacan	Guayacan	Chiriqui, R.P.	>1.0
Minquartia guianensis	Manwood	Bocas, R.P.	0.8 - 0.9
Tectona grandis	Teak	Panama Canal Zone¶	0.58
Callitris glauca	Australian cypress pine	Australia	0.69
Centrolobium orinocense	Amarillo de guayaquil	Darien, R.P.	0.7 - 0.8
Caryocar costaricense	Henené	Darien, R.P.	0.9 - 1.0
Colubrina glandulosa	Carbonero	Panama Canal Zone	0.9 - 1.0

* Common name from area of source.
† Woods in the same group showed practically equal resistance.
‡ Province of Panama, Republic of Panama.
¶ Not endemic to Panama—grown in the Panama Canal Experimental Gardens.

Table 3
Natural Woods Showing Highest Resistance to Fungi at Groundline and Below
(In Descending Order of Merit Based on all Exposures)

Botanical Name	Common Name*	Source	Specific Gravity (air-dry)
Dalbergia retusa†	Cocobolo	Panama, R.P.‡	1.1
Ocotea rodiei	Greenheart	Guyana	0.9 - 1.0
Vouacapoua americana	Acapú	Brazil	0.9 - 1.0
Guajacum officinale	Lignum vitae	Central America	1.2
Unknown genus	Macano blanco	Panama, R.P.	>1.0
Pithecellobium mangense	Uña de gato	Panama Canal Zone	0.50
Platymiscium pinnatum	Quirá	Panama, R.P.	0.9 - 1.0
Ocotea dendrodaphne	Ensiva	Darien, R.P.	0.8 - 0.9
Lecythis ampla	Coco	Darien, R.P.	0.8 - 0.9
Minquartia guianensis	Manwood	Bocas, R.P.	0.8 - 0.9
Manilkara bidentata	Níspero balata	Darien, R.P.	0.9 - 1.0
Guarea guara	Guaragao	Chiriqui, R.P.	0.8 - 0.9
Colubrina glandulosa	Carbonero	Panama Canal Zone	0.9 - 1.0
Caryocar costaricense	Henené	Darien, R.P.	0.9 - 1.0
Tectona grandis	Teak	Panama Canal Zone¶	0.58

* Common name from area of source.
† Woods in the same group showed practically equal resistance.
‡ Province of Panama, Republic of Panama.
¶ Not endemic to Panama–grown in the Panama Canal Experimental Gardens.

Most woods, even when resistant to other wood-destroying organisms, eventually succumb to some fungus for which the growing conditions are optimal. The surprise in these studies is that any of these woods were able to survive for over 13 years in the jungle stake exposures. The four species that remained almost intact for the full exposure period, *Dalbergia retusa*, *Guajacum officinale*, *Ocotea rodiei* and *Vouacapoua americana*, are truly exceptionally durable woods.

Resistance to Subterranean Termites — Termites are wood-destroying insects found throughout the tropics and much of the temperate zone. They are usually divided into two groups, drywood termites and subterranean termites. The drywood species live solely in the wood; their colonies are relatively small, and they are a serious problem in only a few places. By contrast, the subterranean species must maintain contact with the earth or other sources of water; they form large colonies which can cause serious damage to unprotected structures in a very short time. In the tropics, where the more vigorous subterranean termites of the genera *Coptotermes* and *Heterotermes* are active, destruction of unprotected wooden structures can be spectacularly rapid. On the U.S. mainland the genus *Reticulitermes* has been in the past the only subterranean genus of consequence. In recent years, however, the tropical species *Coptotermes formosanus* has become established in the southern U.S. port areas (6) and is damaging structures and infesting species of wood that were formerly considered immune to attack.

Termites attacked susceptible woods much more rapidly than fungi. In fact, a few species of soft woods seemed to be particularly attractive to termites. All of the dispersed replicates of the species *Dialyanthera otoba, Busera simaruba, Virola koschnyi,* and *Trattinickia aspera* were attacked in all exposure beds before most of the other woods were appreciably damaged. Southern pine, the control wood, and Douglas fir were only slightly less susceptible to termites; the pine control stakes which were distributed generously throughout the test areas were attacked rapidly and consistently.

On the other hand, many more of the woods showed higher resistance to termites than to fungi. Table 4 lists in a general descending order of merit those woods that had the best termite resistance. The first three were completely resistant to termite attack in all exposures. The remaining 16 woods were only slightly lower in resistance, ending the 158-month exposures with only traces of termite damage.

Wood Density in Relation to Durability — An approximate density range for each of the woods has been included for all species in Table 1, and the air-dry specific gravities are shown for the superior woods listed in Tables 2 - 4.

Inspection of the data in Tables 2 - 4 shows that most of the highly resistant woods were very heavy, hard species. However, many other heavy, hard woods were not resistant; of the 36 species with specific gravity greater than 0.9, 19 were susceptible to fungal or termite attack or both. These susceptible species showed at least moderate attack by 30 months or heavy to very heavy attack by 90 months. Conversely, of the 41 woods of medium-to-low density (specific gravity less than 0.7), six species were found highly resistant to termites, and two of these, *Tectona grandis* and *Pithecellobium mangense*, were highly resistant to fungi. This resistance to terrestrial organisms was exceptional, considering the relatively low densities. Especially noteworthy is *P. mangense*, which despite a density of only 0.50 had high resistance rankings in all exposures.

During the course of the study, attention was focused on the natural screening of tropical woods that has taken place in Gatun Lake over the last 60 years. As the lake filled, large areas of the tropical forest, with its tremendous variety of species, were submerged or partially submerged. Most of these trees, with their upper portions exposed to airborne fungi, swarming termites, and 60 years of weathering, have now been reduced to below-water-level stumps. A few lonely survivors, however, still stand; some even remain with their branches intact almost down to twig size, attesting to the exceptional durability of their wood. Figure 1 is a view of several of these sturdy trees that have outlasted the forest that once surrounded them. A sampling of the wood of twenty five standing trees from various parts of the lake was made, and the wood was identified by the Yale School of Forestry. *Tabebuia guayacan* (guayacan) was predominant; 22 of the 25 trees sampled were of this species. The guayacans also appeared to be the best preserved of the trees examined. Two other species were identified as *Swartzia panamensis* (cutarro) and *Manilkara dariensis* (níspero). All the trees inspected had extremely hard and dense wood, with air-dry specific gravities greater than 1.0.

From the results of all exposures, it is obvious that density plays a very important role in conferring terrestrial durability to the untreated woods. Besides the few exceptions mentioned, it seems to be a first requirement for long-term durability; however, it is also evident that density alone does not assure protection. A combination of density and certain natural chemical repellants in the wood tissues seems to be the requisite condition for superior long-term durability.

Table 4
Natural Woods Showing Highest Resistance to Subterranean Termites
(In Descending Order of Merit Based on all Exposures)

Botanical Name	Common Name*	Source	Specific Gravity (air-dry)
Tabebuia guayacan†	Guayacan	Chiriqui, R.P.	>1.0
Dalbergia retusa	Cocobolo	Panama, R.P.‡	1.1
Guajacum officinale	Lignum vitae	Central America	1.2
Vouacapoua americana	Acapú	Brazil	0.9 - 1.0
Unknown genus	Macano blanco	Panama, R.P.	>1.0
Swartzia panamensis	Cutarro	Darien, R.P.	0.9 - 1.0
Tabebuia chrysantha	Guayacan negro	Panama, R.P.	>1.0
Callitris glauca	Australian Cypress Pine	Australia	0.69
Platymiscium pinnatum	Quirá	Panama, R.P.	0.9 - 1.0
Ocotea rodiei	Greenheart	Guyana	0.9 - 1.0
Pithecellobium mangense	Uña de gato	Panama Canal Zone	0.50
Minquartia guianensis	Manwood	Bocas, R.P.	0.8 - 0.9
Ocotea dendrodaphne	Ensiva	Darien, R.P.	0.8 - 0.9
Gliricida sepium	Mata raton	Panama Canal Zone	>1.0
Colubrina glandulosa	Carbonero	Panama Canal Zone	0.9 - 1.0
Tectona grandis	Teak	Burma and C.Z.	0.58
Swietenia macrophylla	Mahogany	Panama, R.P.	0.5 - 0.7
Bombacopsis quinata	Cedro espino	Bocas, R.P.	0.47
Manilkara bidentata	Níspero balata	Darien, R.P.	0.9 - 1.0
Cordia alliodora	Laurel negro	Bocas, R.P.	0.42

* Common name from area of source.
† Woods in the same group showed practically equal resistance.
‡ Province of Panama, Republic of Panama.

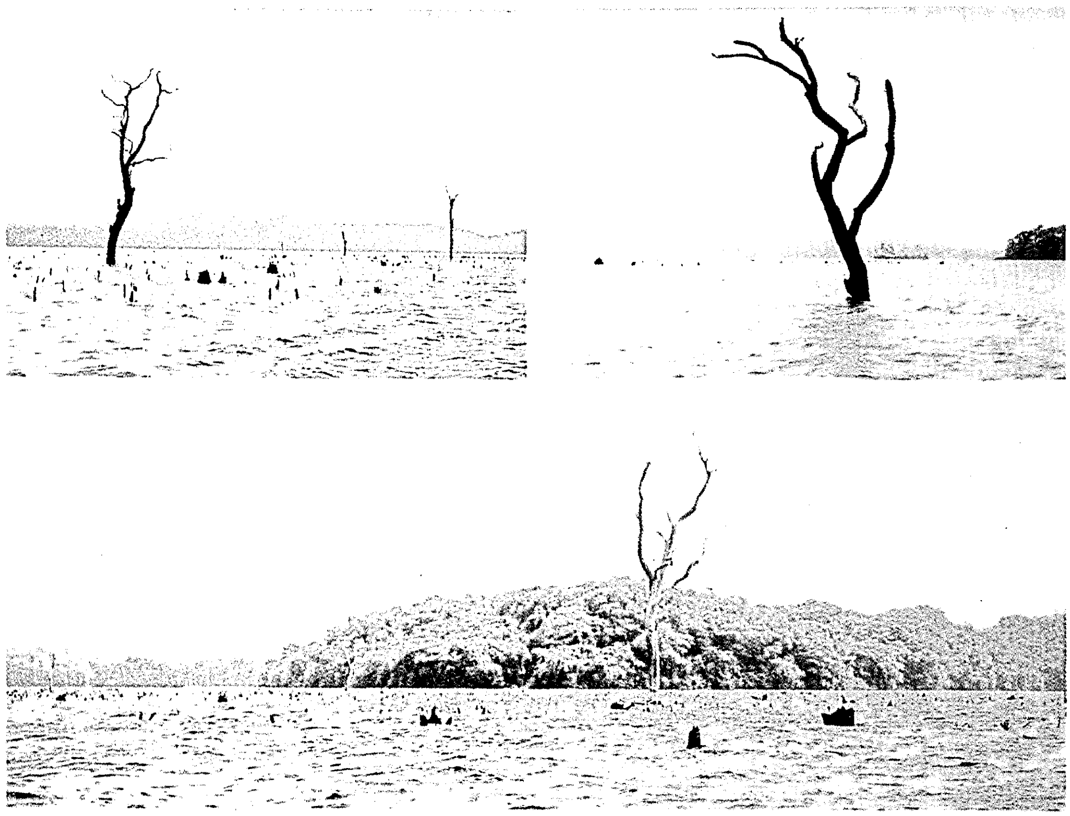


Fig. 1 — A few of the surviving trees in Gatun Lake after 60 years of partial submersion. Photographs taken during a period of extreme low water show the stumps of less resistant trees.

Importance of Naturally Occurring Chemicals — The chemical constituents in a wood have a very important role in its resistance to biological attack. Many of the woods tested have been analyzed quantitatively for silica content, and a complete spectrographic analysis for other inorganic elements has also been made (2). The silica, which is of considerable importance in marine durability, seems to have little influence on the wood's resistance to terrestrial organsims. The three woods with highest silica content, *Licania arborea* (2.2%), *Pouteria chiricana* (2.1%), and *Pouteria campechiana* (1.9%), all exhibited low resistance to both fungi and termites in the terrestrial exposures. Further, *Tectona grandis* (teak) from Burma, with 1.4% silica, was less resistant in contact with the ground than the *T. grandis* grown in the Canal Zone, which had only 0.01% silica.

In relation to resistance, organic compounds in the woods play a much more important role than inorganics. Isolation and identification of these organic constituents which provide high resistance for certain woods is an important goal. Some work on a few of the best woods from the marine studies is now in progress at NRL, and a first, interim report on this work has been issued (7).

Dalbergia retusa was the wood most resistant toward marine boring organisms (2), and it has been equally impressive in its exposure to terrestrial organisms. It is interesting to note that other species of *Dalbergia* have also been cited as being resistant to terrestrial organisms; the species *D. nigra* of Brazil is highly regarded for its durability (8), as is the Indian species *D. sisso* (9). The active ingredient in *D. nigra* has been identified as a dalbergione (10), and that in *D. sisso* is thought to be a related compound, a 4-arylcoumarin dalbergin (11). These compounds and their derivatives coexist in *Dalbergia* species and represent a new class of naturally occurring quinones, the neoflavonoids (12). Also present in the wood tissue with the neoflavonoids is another new class of natural products, the cinnamylphenols (13), which are isomeric with the quinols of dalbergiones and may be intermediates in the biosynthesis of the neoflavonoids. It has been shown recently that some of the cinnamylphenols, notably obtusastyrene, possess antimicrobial properties (14). These cinnamylphenols and other closely related neoflavonoids are among the compounds being assayed for antiborer properties.

The work on *Dalbergia* is providing much more knowledge concerning the natural chemical preservatives in this wood than is known for the other high-resistance woods in this study; however, organic constituents in the other wood tissues are probably contributory to their high biological resistance as well. Some of these materials have been identified by other investigators, such as the alkaloids in *Ocotea rodiei* (15), anthraquinones in *Tectona grandis* (16), lapachol in *Tabebuia guayacan* (8), guaiacol in *Guajacum officinale* (17), and the cordiachromes in a related *Cordia* species, *Cordia millenii* (18).

Preservative-Treated Woods

As part of this study, a few of the best known or most promising chemical wood preservatives were used to treat domestic southern pine and in one case the tropical softwood *Prioria copaifera* (cativo). These wood treatments were included primarily for comparison with the naturally durable tropical woods under identical conditions of exposure over long periods in extremely bioactive environments. The results also provide comparative data on the effectiveness of the different treatments when used in southern pine. Table 5 lists the different preservatives used in the terrestrial exposures and compares exposure results for the treated woods with results for five of the best naturally resistant woods.

Comparison of the different preservatives shows that whole creosote at 8 to 10 lb/ft^3 was the most effective of the five preservatives tried. Above ground there was no trace of termite damage or fungal attack on any creosoted specimen during the full 158-month exposure. This was slightly superior to any of the five best naturally resistant woods and slightly to considerably better than the other treated woods. In the below-ground tests the creosoted wood also was slightly better than any other wood so exposed. Through 90 months it received only trace attack (numerical rating 1); however, by 158 months the damage had increased to slight (numerical rating 2). The copper formate treated pine and all five of the top-rated untreated tropical woods were on a par with creosoted pine at this final 158-month inspection. A further extension of exposure time may have weighed in favor of the natural woods, in which the active constituents are more homogeneously distributed throughout the specimens. By contrast, the induced toxics are usually concentrated at the surface of the wood, where they can become depleted with time until the concentration decreases to a level at which they are no longer able to provide protection. After initiation, biological attack at this latter stage would proceed more rapidly.

Table 5

Comparison of Treated and Untreated Woods Exposed to Termites and Fungi in Tropical Rain Forests

Materials			Degree of Damage*											
			Subterranean Termites				Fungi							
							Above Ground				Groundline and Below			
			12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo
Preservative-Treated Woods Exposed in Terrestrial Environments														
Preservatives	Retention (lb/ft^3)	Wood Treated												
Whole creosote, grade 1, medium residue	8.4 - 10.1	Southern pine	0	0	0	0	0	0	0	0	0	0	1	2
Copper formate (water base, thermal reacted)	0.59 - 0.65	Southern pine	0	0	1	1	0	0	1	1	0	0	2	2
Pentachlorophenol, AWPA P9 (5% in Navy Standard fuel oil)	0.45 - 0.53	Southern pine	0	0	1	1	0	0	1	2	0	1	2	4
Tributyltin oxide (0.3% in #2 fuel oil)	0.027 - 0.029	Southern pine	0	1	2	x	0	1	5	x	0	2	5	x
Tributyltin oxide (0.6% in #2 fuel oil)	0.072 - 0.077	Southern pine	0	1	5	x	0	0	5	x	0	1	5	x
Osmose Salts, AWPA P5 (2% in H_2O)	0.59 - 0.65	Southern pine	0	0	1	1	0	1	2	4	0	2	2	5
Osmose Salts, AWPA P5 (3% in H_2O)	0.70 - 0.78	Cativo	0	1	x	x	2	3	x	x	3	5	x	x
Five of the Most Resistant Natural Woods Exposed in Terrestrial Environments														
Botanical Name	Common Name	Source												
Guajacum officinale	Lignum vitae	Central America	0	0	0	0	0	0	0	1	0	1	1	2
Dalbergia retusa	Cocobolo	Panama	0	0	0	0	0	0	1	1	0	1	2	2
Vouacapoua americana	Acapú	Brazil	0	0	0	0	0	1	1	1	0	1	2	2
Ocotea rodiei	Greenheart	Guyana	0	0	1	1	0	1	1	1	0	1	2	2
Tabebuia guayacan	Guayacan	Panama	0	0	1	0	0	1	1	2	0	1	2	3

*0-none, 1-trace, 2-slight, 3-moderate, 4-heavy, 5-very heavy, x-all specimens were removed or destroyed before this inspection because of low resistance to fungi or termites or both.

Correlation of Marine and Terrestrial Durability

With the completion of this study, a look at the comparative resistances of the woods in the terrestrial and marine environments is now possible. Such a comparison should be of considerable interest, for if there is a close correlation and the same woods show the same relative resistance in both envrionments, then it should be feasible to use the simpler land exposures to screen other natural woods or to evaluate the effectiveness of compounds extracted from durable natural woods. Furthermore, since marine structures often extend into the atmosphere or contact the soil, woods of universal resistance in all environments would have much greater worth as construction timbers or as source materials for chemical-extraction studies.

Most of the woods showing very low resistance in the terrestrial environment were also low in the marine environments; however, those showing very high resistance in terrestrial environments, were not necessarily high in marine envrionments. This response has already been discussed in relation to silica, but some of the low-silica woods also exhibited variable resistance, when all the wood-destroying organsims are considered. For example, *Guajacum officinale* and *Ocotea rodiei*, though highly resistant to most wood destroyers, were not very resistant to teredos in the ocean. Also, some of the highly-teredo-resistant woods in the marine exposures, such as *Chryosphyllum canito* and *Licania arborea*, showed low resistance to both termites and decay in the terrestrial studies. Of the two preservatives tried in marine and terrestrial exposures, creosote was consistently good in both environments, whereas copper formate was good only in the terrestrial exposures, giving poor results in the marine studies (3). There was sufficient disagreement in all groups to negate any possibility of identifying marine-durable woods on the basis of terrestrial exposures.

A number of the tropical woods were highly resistant to all organisms both on the land and in the sea. The most outstanding wood in this respect is *Dalbergia retusa*, and to date this species has received the most attention in NRL's extraction studies. Other woods that were highly durable in both marine and terrestrial exposures are *Tabebuia guayacan*, *Vouacapoua americana*, and *Platymiscium pinnatum*, of the heavy woods; *Tectona grandis* and *Pithecellobium mangense*, of the moderate-density species; and *Cordia alliodora* and *Bombacopsis quinata*, of the relatively light woods.

Of these, only *Tectona grandis**, *Cordia alliodora*, and possibly *Bombacopsis quinata* are of sufficient size and frequency to provide timbers for general construction use, but another application of the results of this study should be even more valuable: this will be to identify the constituents in the woods providing such high broad-spectrum resistance and to use these materials for treatment of available domestic timbers. With this objective, four of the multiresistant woods have been included in NRL's investigation of extractable materials. The four selected species are: *Dalbergia retusa*, chosen because of its highest overall resistance; *Tabebuia guayacan*, included because of its high resistance in most exposures and its predominance among the surviving trees in Gatun Lake; and *Bombacopsis quinata* and *Cordia alliodora*, chosen because of their high resistant-to-density ratios. These last two, with seemingly much lower quantities of interstitial constituents, were relatively high in overall resistance, suggesting the presence of very potent repellents to wood-destroying organisms.

**Tectona grandis* is dependent on high silica content to protect against teredos, and this constituent has been observed to vary considerably in this species.

SUMMARY OF RESULTS

- The Panama jungle sites used for this study are heavily infested with wood-destroying organisms, and conditions are ideal for their activity. The preservatives and natural wood species exposed under these conditions were subjected to a very rigorous screening test.

- Damages caused by subterranean termites, fungi at groundline and below, and above-ground fungi were rated separately, Of these, termites are the most rapidly destructive, but many more woods were resistant to termites than to fungi; by 158 months more than 37 species had received only slight or less termite attack.

- Certain soft woods were especially attractive to termites; all replicates of four species were selectively and rapidly destroyed before most of the other nonresistant woods had been appreciably damaged.

- The fungal attack at groundline and below was the most inevitable, and after 158 months of this exposure just five woods remained with only slight attack.

- The above-ground fungal damage was also severe, but specimens were usually less damaged than below ground by about one rating step. Fifteen woods were evaluated highly resistant above ground, with final ratings of slight attack or less.

- Wood density seemed to be an important factor in wood durability; most of the highly durable woods were hard and heavy. However, density alone did not assure resistance, since some of the very dense woods were nonresistant.

- Naturally occurring chemicals that provide repellency are the keys to the highest durability. Although silica inclusions that give protection against teredos in seawater were of no significance in the nonaqueous environments, certain organic chemicals seem to be very important. Only a few of these have been identified; among the most effective are the natural quinones, which have been identified as the active ingredients in a few of the most resistant woods in the study.

- Two of the wood preservatives used in southern pine–copper formate and whole creosote–provided resistance through 158 months that was equivalent to the resistance of the best natural woods. As used, tributyltin oxide and pentachlorophenol were less effective. Of the preservative systems tried, only creosote provided high resistance in both marine and terrestrial exposures.

- There was very little relation between durability in the marine and in the terrestrial environments, although a few woods such as *Dalbergia retusa* which contain natural quinones, seem to be exceptional in this respect and showed good durability in both environments.

ACKNOWLEDGMENTS

This study could not have been accomplished without the cooperation of a large number of people. Especially noteworthy was the interest and assistance of Mr. B.W. Forgeson, Dr. J.M. Leonard, and Dr. A.L. Alexander, all formerly of NRL. Mr. T.R. Price of the

Chemistry Division of NRL and Dr. T.R. Sweeney, formerly of the Chemistry Division, did much of the work on the selection of preservatives to be tested and the actual treating of the pine and fir specimens.

Botanical identification of the woods required the participation of expert botanists and wood anatomists. The Yale School of Forestry and the Smithsonian Institution supplied the people with the necessary knowledge and ability, principally Dr. W.L. Stern from the Smithsonian and Dr. K.L. Chambers and the late Dr. G.K. Brizicky from Yale. Mrs. C.R. Southwell of the Index Nominum Genericorum Project at the Smithsonian reviewed all botanical and common names of the woods studied to assure correct listing in Appendix B.

Finally, many organizations and individuals assisted in the tropical wood collection phase of the study, especially the Panama Canal Company and the former head of the Canal Zone experimental gardens, Mr. W. Lindsay. The United Fruit Company and numerous lumber dealers and boat builders of Panama supplied valuable assistance and materials.

REFERENCES

1. C.R. Southwell, C.W. Hummer, Jr., B.W. Forgeson, T.R. Price, T.R. Sweeney, and A.L. Alexander, "Natural Resistance of Woods to Biological Deterioration in Tropical Environments, Part 1 — Screening Tests of a Large Number of Wood Species," NRL Report 5673, Feb. 1962.

2. C.R. Southwell, J.D. Bultman, B.W. Forgeson, and C.W. Hummer, Jr., "Biological Deterioration of Wood in Tropical Environments, Part 2 — Marine Borer Resistance of Natural Woods over Long Periods of Immersion," NRL Report 7123, Dec. 1970.

3. C.R. Southwell and J.D. Bultman, "Biological Deterioration of Woods in Tropical Environments, Part 3 — Chemical Wood Treatments for Long-Term Marine Borer Protection," NRL Report 7345, Dec. 1971.

4. J.D. Bultman, C.R. Southwell, and R.H. Beal, "Termite Resistance of Polyvinyl Chloride Plastics in Southern Temperate and Tropical Environments, Final Report of Phase 1 — Effect of Plasticizers and Insecticides," NRL Report 7417, June, 1972.

5. C.R. Southwell, J.D. Bultman, and R.H. Beal, "Termite Resistance of Polymeric Materials, Phase 2 — Nontoxic Polymers," NRL Report 7418, July 1972.

6. R.H. Beal, "Formosan Invader," Pest Control Journal 35, No. 2, 13 (1967).

7. J.D. Bultman and C.R. Southwell, "A Preliminary Investigation of the Marine Borer Resistance of the Tropical Wood *Dalbergia Retusa*," NRL Report 7416, June 1972.

8. B.F. Kukachka, "Properties of Imported Tropical Woods," USDA Forest Service Research Paper FPL 125, Mar. 1970.

9. V.K. Ahluwalia, P.L. Sawhney, and T.R. Seshadri, "Constitution of Dalbergin," J. Sci. Industr. Res. 15B, 66 (1956).

10. O. Gonçalves de Lima, M.H. Dália Maia, I. Leoncio d' Albuquerque, M. Machads, F. de Albuquerque, M.A. Pereira Borba, "Substancias Antimicrobianas de Plantas Superiores," Revista do Instituto de Antibioticos 3, 61 (1961).

11. N.R. Krishnaswamy and T.R. Seshadri, *Recent Progress in the Chemistry of Natural and Synthetic Coloring Matters*, T.S. Gore et al., editors, Academic Press, New York, 1962, p. 235.

12. W.B. Eyton, W.D. Ollis, I.O. Sutherland, O.R. Gottlieb, M. Taveira Magalhaes, and L.M. Jackman, "The Neoflavonoid Group of Natural Products – I. Dalbergiones – A New Class of Quinones," Tetrahedron 21, 2683 (1966).

13. M. Gregson, K. Kurosawa, W.D. Ollis, B.T. Redman, R.J. Roberts, I.O. Sullivan, A. Braga de Oliviera, W.B. Eyton, O.R. Gottlieb, and H.H. Dietrichs, "The Natural Occurrence of *dis*- and *trans*-Cinnamylphenols," Chem. Communications 1390 (1968).

14. L. Jurd, A.D. King, K. Mihara, and W.L. Stanley, "Antimicrobial Properties of Natural Phenols and Related Compounds I. Obtusastyrene," Applied Microbiology 21, 507 (1971).

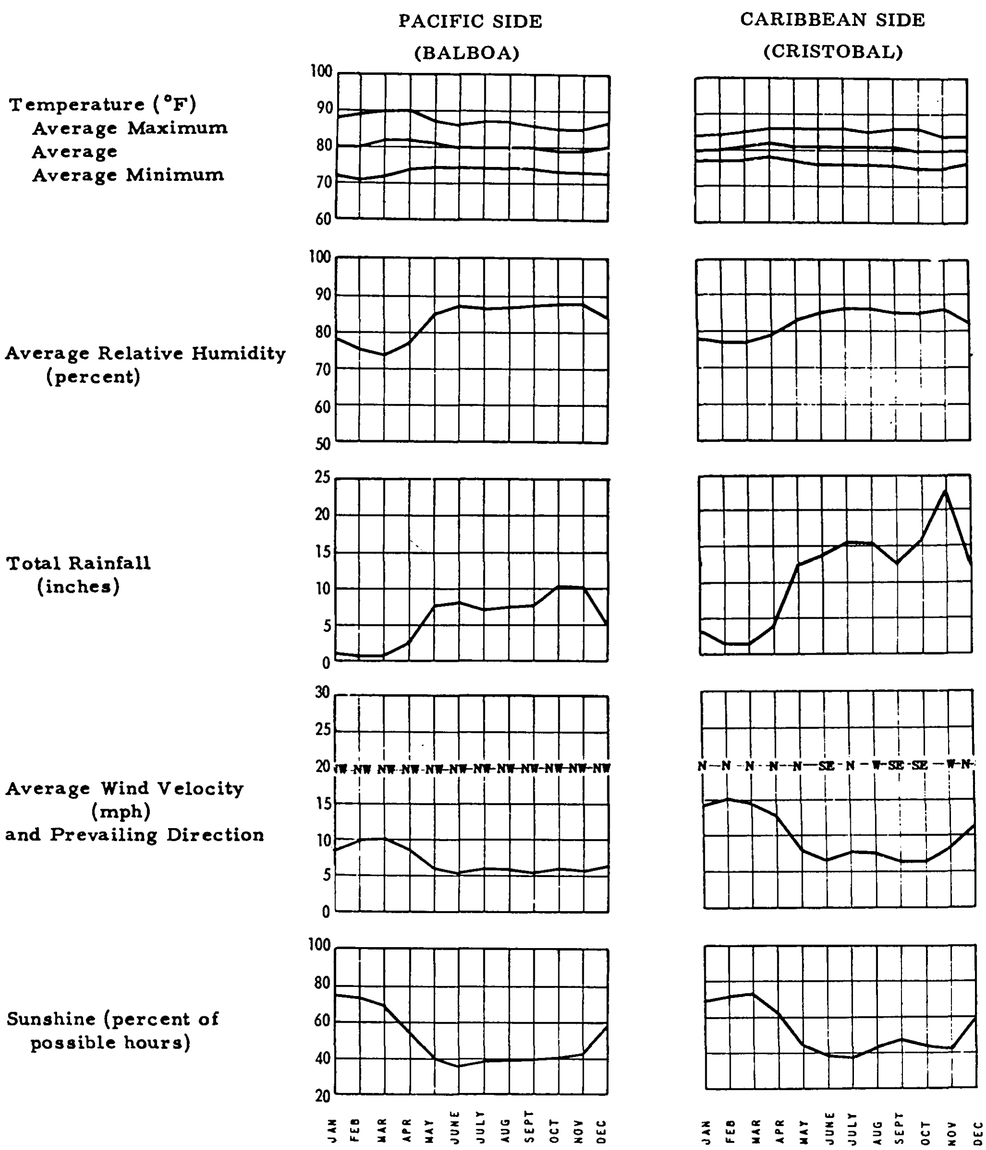
15. F.F. Wangaard, "The Natural Marine Borer Resistance of Tropical American Woods," Tropical Woods 105, 38 (1956).

16. P. Rudman and F.J. Gay, "The Causes of Natural Durability in Timber, Part VII – The Causes of Decay Resistance in Teak (*Tectona grandis* L. f.)," Holzforschung 15, 151 (1961).

17. S.J. Record and R.W. Hess, *Timbers of the New World*, Yale University Press, New Haven, 1943, p. 555.

18. M. Moir and R.H. Thomson, "Cordiachromes: A New Group of Terpenoid Quinones from *Cordia* spp," J. Chem. Soc. (London) Chem. Communications, 363 (1972).

Appendix A
CANAL ZONE CLIMATIC CONDITIONS—20 YEAR AVERAGES



Appendix B
BOTANICAL AND COMMON NAMES OF WOODS STUDIED

Acabú, *Zanthoxylum belizense*
Acapú, *Voucapoua americana*
Aguacatillo, *Phoebe johnstonii*
Ajo, *Caryocar* sp.
Alazano, *Calycophyllum candidissmum*
Albarco, *Cariniana pyriformis*
Alcarreto, *Aspidosperma megalocarpon*
Alcornoque, *Mora oleifera*
Alfaje, *Trichilia tuberculata*
Algarrobo, *Hymenaea courbaril*
Almácigo, *Bursera simaruba*
Almendro, *Coumarouna oleifera*
Almond, *Terminalia catappa*
Amargo-amargo, *Vatairea* sp.
Amarillo, *Terminalia amazonia*
Amarillo de guayaquil, *Centrolobium orinocense*
Amarillo negro, *Lafoënsia puncifolia*
Anacardium excelsum, (H.B.K.) Skeels, expavé
Andira inermis, (Swartz) H.B.K. ex A.P. DC., cocú
Angélique, *Dicorynia paraensis*
Anime, *Tetragastris panamensis*
Aspidosperma megalocarpon, J. Muell. Arg., carreto, alcarreto
Astronium graveolens, N.J. Jacq., zorro, zorillo, or ron-ron
Australian cypress pine, *Callitris glauca*
Avicennia marina, (Forssk.) Vierh., mangle salado
Azobe, *Lophira procera*

Bala, *Lophira procera*
Bálsamo, *Myroxylon balsamum*
Bambito, *Nectandra whitei*
Basra locus, *Dicorynia paraensis*
Berba, *Brosimum* sp.
Bogamani, *Virola koschnyi*
Bombacopsis quinata, N.J. Jacq. Dugand, cedro espino
Bombacopsis sessilis, (Benth) Pittier, ceibo
Bongassi, *Lophira procera*
Bronze shower, *Cassia moschata*
Brosimum sp., berba guayabo blanco
Bursera simaruba, (L.) Sarg., almácigo, indio desnudo
Byrsonima crassifolia, (L.) H.B.K., nance

Cabimo, *Copaifera aromatica*
Caimito, *Chrysophyllum cainito*
Callitris glauca, R.Br. ex Mirb., Australian cypress pine
Calophyllum brasiliense, Camb., maria
Calycophyllum candidissimum, (Vahl) A.P. D.C., alazano, lemonwood, lancewood
Coabo, *Swietenia macrophylla*
Caraño, *Trattinickia aspera*
Carapa slateri, Standl., cedro macho, tangaré
Carapa sp., cedro vino
Carbonero de amunición, *Colubrina glandulosa*
Cariniana pyriformis, Miers, chibaugá, albarco
Carreto, *Aspidosperma megalocarpon*
Caryocar costaricense, Donn. Sm., henené
Caryocar sp., ajo
Cassia moschata, H.B.K., bronze shower
Cativo, *Prioria copaifera*
Cedrela mexicana, M. Roem., cedro amargo
Cedrela sp., cedro granadino
Cedro amargo, *Cedrela mexicana*
Cedro espino, *Bombacopsis quinata*
Cedro granadino, *Cedrela* sp.
Cedro macho, *Carapa slateri*
Cedro vino, *Carapa* sp.
Ceibo, *Bombacopsis sessilis*
Centrolobium orinocense, (Benth) Pittier, amarillo de Guayaquil
Cerillo, *Symphonia globulifera*
Chibugá, *Cariniana pyriformis*
Chlorophora tinctoria, (L.) Gaud. ex Benth., mora
Chrysophyllum cainito, L., caimito, star apple
Chuchupate, *Guarea longipetiola*
Coco, *Lecythis ampla*
Coco, *Lecythis* or *Manilkara*
Cocobolo, *Dalbergia retusa*
Cocú, *Andira inermis*
Colubrina glandulosa, Perk., carbonero de amunición
Conocarpus erectus, L., zaragosa
Copaifera aromatica, Dwyer, cabimo
Cordia alliodora, (Ruiz & Pavon) Cham. ex Oken, laurel negro

Cornus disciflora, Sessé & Moc. ex A.P. DC., mata hombro
Corotú, *Enterolobium cyclocarpum*
Coumarouna oleifera, (Benth.) Taub., almendro
Crillo, *Minquartia guianensis*
Croton panamensis, J. Muell. Arg., sangre
Cuajado, *Vitex floridula*
Cutarro, *Swartzia panamensis*

Dalbergia retusa, Hemsl., cocobolo
Dalienze, *Terminalia myricarpa*
Dialium guianense, (Aubl.) Sandw. in A.C. Smith, tamarindo
Dialyanthera otoba, (Humb. & Bonpl. ex Willd.) Warb., miguelario
Dicorynia paraensis, Benth, angélique, basra locus
Diphysa robinioides, Benth, macano
Douglas fir, *Pseudotsuga menziesii*

Ekki, *Lophira procera*
Ensiva, *Ocotea dendrodaphne*
Enterolobium cyclocarpum, (N.J. Jacq.) Griseb., corotú
Erythrina glauca, Willd., gallito
Eschweilera sp. (probably), guayabo macho
Espavé, *Anacardium excelsum*

Gallito, *Erythrina glauca*
Gavilán, *Pentaclethra macroloba*
Genipa americana, L., jagua
Gliricidia sepium, (N.J. Jacq.) Kunth ex Walp., bala, mata ratón
Gorogán, *Virola koschnyi*
Greenheart, *Ocotea rodiei*
Guácimo, *Luehea seemannii*
Guaragao, *Guarea guara*
Guajacum officinale, L., lignum vitae
Guarea longipetiola, C. DC., chuchupate
G. guara, (N.J. Jacq.) P. Wils., guaragao
Guayabo blanco, *Brosimum* sp.
Guayabo macho, *Eschweilera* sp.
Guayacán, *Tabebuia guayacan*
Guayacán negro, *Tabebuia chrysantha*

Henené, *Caryocar costaricense*
Hippomane mancinella, L., manzanillo
Hura crepitans, L., nuno
Hyeronima alchorneoides, Allem., pantano
Hymenaea courbaril, L., algarrobo

Iguanillo, *Lonchocarpus* sp.
Indio desnudo, *Bursera simaruba*
Insibe, *Ocotea dendrodaphne*
Ironwood, *Lophira procera*

Jagua, *Genipa americana*
Jigua negra, *Licaria pittieri*

Lafoënsia punicifolia, A.P. DC., *amarillo* negro
Laguncularia racemosa, (L.) C.F. Gaertn, mangle blanco
Lancewood, *Calycophyllum candidissimum*
Laurel negro, *Cordia alliodora*
Lecythis ampla, Miers, coco
Lecythis sp., coco
Lemonwood, *Calycophyllum candidissimum*
Licania arborea, B.C. Seem., raspa
Licaria pittieri, (Mez) C.K. Allen, jigua negra
Lignum vitae, *Guajacum officinale*
Lonchocarpus sp., iguanillo
Lophira procera, A.Chev., bongassi, ekki, azobe, bala, ironwood
Luehea seemannii, Planch. & Triana, guácimo

Macano, *Diphysa robinioides*
Macano blanco, unknown genus
Macho, *Tetrathylacium johansenii*
Magnolia sororum, Seib., vaco
Mahogany, *Swietenia macrophylla*
Malvecino, *Sweetia panamensis*
Mamecillo, *Pouteria campechiana*
Mancha, *Virola sebifera*
Mangle blanco, *Laguncularia racemosa*
Mangle rojo (Atlantic), *Rhizophora mangle*
Mangle rojo (Pacific), *Rhizophora brevistyle*
Mangle salado, *Avicennia marina*
Manglillo, *Ternstroemia seemannii*
Manilkara bidentata, (A.DC.) A. Chev., níspero balata
M. chicle, (Pittier Gilly, níspero zapote
Manilkara sp., rasca
Manwood, *Minquartia guianensis*
Manzanillo, *Hippomane mancinella*
María, *Calophyllum brasiliense*
Mata hombro, *Cornus disciflora*
Mata ratón, *Gliricidia sepium*
Mayo, *Vochysia ferruginea*
Miguelario, *Dialyanthera otoba*
Minquartia guianensis, Aubl., crillo, manwood

Mora, *Chlorophora tinctoria*
Mora oleifera, (Triana) Ducke, alcornoque
Myroxylon balsamum, (L.) Harms, bálsamo

Nance, *Byrosonima crassifolia*
Naranjillo, unknown genus
Naranjito, *Swartzia simplex*
Nazareño, *Peltogyne purpurea*
Nectandra whitei, (Woods.) C.K. Allen, bambito
Nicaraguan pine, *Pinus caribaea*
Níspero balata, *Manilkara bidentata*
Níspero de monte, *Pouteria chiricana*
Níspero zapote, *Manilkara chicle*
Nuno, *Hura crepitans*

Oak, *Quercus* sp.
Ocotea dendrodaphne, (Derul.) Mez, ensiva or insibe
O. rodiei, (Schomb.) Mez, greenheart

Palo de sal, *Pelliciera rhizophorae*
Panamá, *Sterculia apetala*
Pantano, *Hyeronima alchorneoides*
Paramachaerium gruberi, Brizicky, sangrillo negro
Pelliciera rhizophorae, Planch. & Triana, palo de sal
Peltogyne purpurea, Pittier, nazareño
Pentaclethra macroloba, (Willd.) Runtze, gavilán
Phoebe johnstonii, C.K. Allen, aguacatillo
Pinus caribaea, Morel., Nicaraguan pine
Pinus sp. southern yellow pine
Pithecellobium mangense, (N.J. Jacq.) Macbr., uña de gato
P. saman, (Willd.) Benth., rain tree
Platymiscium pinnatum, (N.J. Jacq.) Dugand., quirá
Pouteria campechiana, (H.B.K.) Baehni, mamecillo
P. chiricana, níspero (Standl.) Baehni, de monte
Prioria copaifera, Griseb., cativo
Pseudotsuga menziesii, (Mirb.) Franco, Douglas fir

Quercus sp., roble de monte, oak
Quirá, *Platymiscium pinnatum*

Rain tree, *Pithecellobium saman*
Rasca, *Manilkara* sp.
Raspa, *Licania arborea*
Rhizophora brevistyla, Salvosa, mangle rojo (Pacific)
R.Mangle, L., mangle rojo (Atlantic)
Roble de monte, *Quercus* sp.
Roble de sabana, *Tabebuia pentaphylla*
Ron-ron, *Astronium graveolens*

Sambogum, *Symphonia globulifera*
Sangre, *Croton panamensis*
Sangrillo negro, *Paramachaerium gruberi*
Sigua, unknown genus
Southern yellow pine, *Pinus*, sp.
Star apple, *Chrysophyllum cainito*
Sterculia apetala, (N.J. Jacq.) H. Karst., panamá
Swartzia panamensis, Benth., cutarro
S. simplex, (Vahl) K.P.J. Spn., narajito
Sweetia panamensis, Benth., malvecino
Swietenia macrophylla, G.King, mahogany, caoba
Symphonia globulifera, L.f., sambogum, cerillo

Tabebuia chrysantha, G. Nichols, guayacán negro
T. guayacan, (B.C. Seem.) Hemsl., guayacán
T. pantaphylla, (A.L. Juss.) Hemsl, roble de sabana
Tamarindo, *Dialium guianense*
Tangaré, *Carapa slateri*
Teak (Burma), *Tectona grandis*
Teak (Canal Zone grown), *Tectona grandis*
Tectona grandis, L.f., teak (Burma)
T. grandis, teak (Canal Zone grown)
Terminalia amazonia, (J.F. Gmel.) Exell, amarillo
T. catappa, L., almond
T. myriocarpa, Heurck & J. Muell. Arg., dalienze (Panamanian grown)
Ternstroemia seemannii, Triana & Planch., manglillo
Tetragastris panamensis, (Engl.) Kuntze, anime
Tetrathylacium johansenii, Standl., macho
Trattinickia aspera, (Standl.) J.J. Swart., caraño
Trichilia tuberculata, C. DC., alfaje

Uña de gato, *Pithecellobium mangense*

Vaco, *Magnolia sororum*
Vasca, unknown genus
Vatairea sp. (probably), amargo-amargo
Virola koschnyi, Warb., bogamani, gorogán
V. sebifera, Aubl., mancha
Vitex floridula, Duchass. & Walp. ex Walp., cuajado
Vochysia ferruginea, C.F. Mart., mayo
Vouacapoua americana, Aubl., acapú
Zanthoxylum belizense, Lundell, acabú
Zaragosa, *Conocarpus erectus*
Zorillo, *Astronium graveolens*
Zorro, *Astronium graveolens*

Unidentified, macano blanco
Unidentified, naranjillo
Unidentified, sigua
Unidentified, vasca

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13. ABSTRACT

This is the fourth report in a series describing the biodegradation of treated and untreated woods in the marine and terrestrial environments of the Panama Canal Zone. Presented here are the final results of the terrestrial studies for exposure periods up to 13 years at three jungle exposure sites. One hundred fifteen natural woods and five wood preservatives are evaluated for resistance to subterranean termites and to above-ground and below-ground fungal decay.

Thirty seven of the 115 species of untreated wood survived the full 158-month exposure; of these only five were considered to be highly resistant to all the wood-degrading organisms present. Fungi below and near the groundline were the most universally destructive organisms. Subterranean termites more rapidly destroyed susceptible woods, but eventually many more wood species were found to have higher natural resistance to termites than to fungi.

Wood density seemed to be an important factor in durability but was not the only requirement. Certain chemical constituents in the woods were definitely contributory to high resistance; one of the most effective seems to be a naturally occurring quinone. Silica, an important chemical in marine environments, showed no significant effect on terrestrial durability. In other respects also, terrestrial and marine durability were unrelated, although a few untreated woods, especially those containing natural quinones, and one treated wood, creosoted pine, were resistant in both environments.

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Fungi						
Subterranean termites						
Natural resistance						
Wood preservatives						
Natural chemicals						
Wood density						
Marine durability						