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Biological Deterioration of Wood in Tropical Environments

Part 2 - Marine Borer Resistance of Natural Woods Over Long Periods of Immersion

C. R. SOUTHWELL AND J. D. BULTMAN

Marine Biology and Biochemistry Branch
Ocean Sciences Division

B. W. FORGESON

Metallurgy Division

and

C. W. HUMMER

Panama Canal Company

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C.R. Southwell, J.D. Bultman, B.W. Forgeson, and C.W. Hummer

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13. ABSTRACT

One hundred and fifteen wood species have been exposed to marine borers in three different tropical waters for periods up to 90 months. Underwater sites were in the Panama Canal Zone and included two oceans and a brackish-water lake. Over 30 species of marine-boring organisms were identified from these waters; their extreme activity in the warm tropical environments provided a very thorough screening test for the woods. Samples have been evaluated separately for resistance to the three principal borer classes—teredo, pholad, and limnoria.

Several of the woods were resistant to one or more of the borer types. Some of these resistant species are relatively unknown as marine construction timbers, and in some instances they proved to be more durable than Greenheart, Teak, and other commercial marine woods. The species most resistant to all borers was Dalbergia retusa (Cocobolo), whose oily extract may provide leads to a satisfactory wood preservative.

The woods most resistant to each of the different classes of borers are tabulated, with their respective silica content and density included. Silica was shown to be significant only in relation to teredine borers, while wood density was important only with pholads. Woods considered to be of special interest because of findings in the study are discussed individually.

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CONTENTS

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PROBLEM STATUS

This is a final report on one phase of the project; work is continuing on other phases.

AUTHORIZATION

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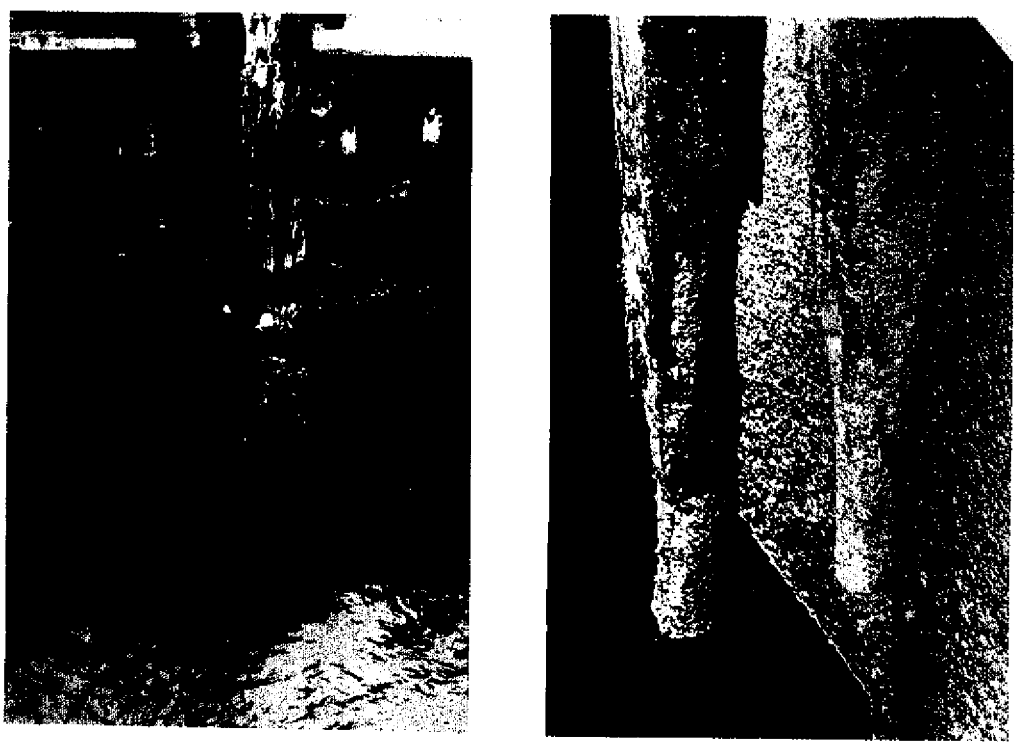
BIOLOGICAL DETERIORATION OF WOOD IN TROPICAL ENVIRONMENTS, PART 2 - MARINE BORER RESISTANCE OF NATURAL WOODS OVER LONG PERIODS OF IMMERSION

INTRODUCTION

As man extends his activities into the sea, a knowledge of the biological, chemical, and physical effects of the marine environment on the materials of his equipment and structures becomes increasingly important. Of the structural materials, wood, one of the oldest, is still and foreseeably will continue to be of great usefulness. This position is maintained because of wood's unique combination of properties; high strength-to-weight ratio, resiliency, flexural strength, and economy of use. In the absence of marine boring organisms, the durability of wood under water is high. When exposed to marine borers, however, wooden structures are subject to severe damage, particularly in lower-temperate and tropical waters. It has been estimated that damage caused by these organisms in the U.S. alone may average 200 to 250 million dollars annually (1).

Many procedures have been tried in an effort to deter marine borers, but most have failed because of the divergent methods of attack and wide tolerance range of different classes of borers. The most frequently used method of borer protection is pressure treatment with whole creosote. But as pointed out by several investigators (2-4), in waters infested with *Limnoria tripunctata*, the treatment is much less effective, and in



(a) Coco Solo Harbor on the Caribbean coast of the Panama Canal Zone (average tidal range 1 ft)

(b) Balboa harbor at the Pacific entrance of the Panama Canal (average tidal range 13 ft)

Fig. 1 - Typical marine borer damage to creosoted pilings in the tropics

tropical waters where limnoria is continuously active, creosoted timbers are often destroyed in a few years. Examples of attack on creosoted pilings in the tropical waters of the Panama Canal Zone are shown in Fig. 1 for (a) Coco Solo harbor on the Caribbean coast and (b) Balboa harbor on the Pacific coast. Replacement of creosoted timbers at the latter site, alone, costs 100 to 200 thousand dollars annually.

Another protective measure sometimes used is sheathing of pilings with borer-proof material, such as plastic, concrete, or metal. This sheathing procedure is effective as long as the cover is intact. Any small opening, however, will afford access to teredine borers (*Teredo, Bankia*), and intensive internal damage to the pilings can occur. Such damage usually goes undetected for some time while the large area of unaffected sheathing gives a false appearance of soundness.

The use of naturally resistant wood species is still another approach to borer control. Some woods are reputed to have a high natural resistance to certain borers. A few of these, such as *Ocotea rodiei* (Greenheart) and *Dicorynia paraensis* (Angelique), have been marketed worldwide on this basis. These naturally resistant woods have been very successful in some installations while giving poor results in others, indicating that here, as in the case of creosote, environmental variability probably exercises a telling influence.

On the Isthmus of Panama, the flora from North and South America and from the Pacific and Atlantic watersheds all meet and mingle, and a great variety of timber species is found. Hence, among the most abundant natural products of Panama are large stands of these tropical woods. In accordance with a treaty between the Republic of Panama and the United States which specifies the use of Panamanian products wherever feasible, the Panama Canal Company was faced with the prospect of having to use local woods for its construction needs. After a serious failure of a reputedly borer-resistant native wood, NRL was requested by the Panama Canal Company to investigate the marine borer resistance of a number of Panamanian wood species. The value of such a study was readily apparent. First, very few controlled investigations of the natural environmental resistance of woods in general had been made and, second, there were many potentially useful tropical woods completely untested for resistance to marine borers. In fact, very little was known about these woods - even the common names in many cases were uncertain. In addition to these points, it was evident that the Canal Zone would provide an ideal environment for marine borer studies. In this narrow strip of land, secure underwater exposure facilities are available in two oceans and in a brackish-water lake, each of which harbors different marine borers. In all, the opportunity to add to the general knowledge concerning marine borers and structural timbers was excellent. Realizing the potential usefulness of data obtainable from such a study, NRL accepted the project. With the support of the Panama Canal Company and the Office of Naval Research an all-out effort was made to obtain as many promising tropical timber species as possible. In addition, a small number of reputedly resistant woods exogenous to the area was included, as well as non-resistant North American pine and fir. Samples of pine, fir, and selected tropical woods which had been pressure-treated with various standard and experimental wood preservatives were also exposed. They are the subject of a separate report.

Exposure studies have now been completed through 90 months. One interim report covering the initial screening phase for exposure of 14 months in Pacific seawater and 14 months in brackish lake water has been published (5). This report will cover the long-term exposure results for the most resistant natural wood species in three underwater environments.

EXPERIMENTAL CONDITIONS

Selection and Identification of Wood Species

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 to exist only in restricted localities, and their reputation for resistance to marine exposure is based mainly on native lore and the limited experience of local boat builders. The few completed scientific studies of tropical woods (6-8) have shown a great range of borer resistance for the woods investigated, with some of the tropical species having very high resistance. It was planned originally to investigate only those woods which were well known in Panama and which were considered suitable for marine construction, based on local knowledge and experience. About 40 woods were selected on this basis; however, in the collection of these woods many additional species were uncovered whose potential usefulness was apparently as great as that of the original group. These specimens were added to the list, so that ultimately 104 wood species from Panama were exposed, along with 9 reputedly high-resistance woods from other parts of the world. Southern Yellow Pine and Douglas Fir, both low-resistant woods, were included as controls to evaluate distribution and intensity of borer attack in the exposure areas.

While many of the woods were collected locally, many others were obtained from remote regions of Panama by a collecting team composed of representatives from the Yale School of Forestry* and NRL. In addition to the timber specimens, herbarium collections were made to aid in the botanical classification of the many woods - a most important phase of this study. Without correct identification the investigation would have had little value. These identifications were made by examining the herbarium material and/or by anatomical methods. Identifications based on the herbarium collections were used wherever possible. A complete list of the botanical and common names of the woods studied is presented in Table A1 in the Appendix. Spelling of all generic names and most of the specific epithets conforms to that in the original publications as determined by the Index Nominum Genericorum Project at the Smithsonian Institution.

The majority of the identifications were made by Stern et al. at Yale (9,10), under an Office of Naval Research contract. Most of the commercially obtained timbers, for which there was no herbarium material, were relatively well known, and the woods were readily matched to positively identified species in the Yale collection. In some instances, however, all identification efforts were unsuccessful; Table A1 contains several woods for which only the genus could be determined and four for which no identification was possible. In the course of the collecting phase of the study one new species of tree was discovered, and its description was added to the botanical literature (11). Several other species were reported from Panama for the first time.

Exposure Conditions

Marine borer studies were conducted in the Canal Zone at three locations: one in the Pacific Ocean, one in Miraflores Lake, and one in the Caribbean Sea. Views of these three test locations are presented in Fig. 2. The Pacific site was the NRL marine exposure pier adjacent to the Ft. Amador Causeway on Naos Island, about 1-1/2 miles seaward from the natural shoreline. The water is normal tropical ocean water with a tidal range averaging 13 feet and a water depth averaging 22 feet. Brackish-water exposures were made from a spare canal lock gate moored near the center of Miraflores Lake. This body of water, which is approximately 2 square miles in area, is located between the second and third Pacific-side locks of the Panama Canal. The average elevation of the lake is 58 feet and the salinity varies with season, rainfall, and the number of lockages through the canal. Normally, the annual salinity range is between 0.2 and 0.5 ‰.

*Dr. W. L. Stern, now Professor of Botany, University of Maryland, and Dr. K. L. Chambers, now Professor of Botany, University of Oregon.

(a) Pacific Ocean site, Panama Bay,
Naos Island, C.Z.

(b) Brackish-water site, Miraflores Lake, C.Z.

(c) Caribbean Sea site, Manzanillo Bay,
Coco Solo, C.Z.

Fig. 2 - Views of the three test locations

The third exposure site was on the Atlantic side of the Isthmus in Manzanillo Bay of the Caribbean Sea, at the Coco Solo Naval Station. Here the tidal range averages about 1 foot.

Samples were suspended vertically at 1-1/2 to 3 feet below mean low tide at the Naos Island pier and 8 to 12 feet below the water surface at the Miraflores exposure site. Four replicates cut from each of two logs of each species were distributed in the respective areas. For the followup exposures conducted at Coco Solo, eight 1-1/2-by-1-1/2-by-9-in. replicate specimens were exposed to represent each log. The specimens were immersed vertically at a depth of 2 to 3 feet below mean low tide.

Methods of Evaluation

All specimens exposed to marine borer attack at Naos Island and Miraflores Lake were inspected after 7, 14, 37, and 90 months of immersion, while samples immersed at Coco Solo were inspected after 14, 37, and 51 months.* Normally, one specimen of each log was removed after each exposure period, but this procedure was modified as required during field inspections. If careful visual inspection indicated a panel was heavily infested, it was removed from the rack. In many cases this procedure resulted in the removal of all samples of a given species after a relatively short exposure. Because of the nature of teredo damage, the extent of this damage was often difficult to assess accurately by such visual inspection. When uncertainty existed one panel of a set was removed and sectioned longitudinally to determine the extent of damage. Subsequently, all specimens removed from exposure were sectioned in this manner so a more positive rating could be assigned. On the other hand, if it appeared that none of the repilicates of a given species were damaged, all were allowed to remain, thereby providing a broader base for rating these more resistant woods after longer periods of immersion. The X-ray comparison shown in Fig. 3 illustrates the great difference in appearance typically found between the exterior and interior of a piece of teredo-infested wood. During the field inspections a rating system similar to that developed by Clapp Laboratories (12) was used. For ease in handling the large volume of data collected, the Clapp rating system has been reduced in this report to a simpler numerical one: 0 - none apparent, 1 - slight, 2 - moderate, and 3 - heavy. Damage from each of the major families of borers, the Teredinidae, the Pholadidae, and the Limnoriidae, was rated separately. Examples of typical 1, 2, and 3 ratings for teredos are shown in Fig. 4.

RESULTS WITH NATURAL WOODS

Screening Phase - 115 Species of Wood

Preliminary results (14 months) of the screening phase of the study have been reported in Part 1 of this series (5). A comprehensive summary of the complete data through 90 months for all the 115 different wood species exposed in the Pacific Ocean and Miraflores Lake is presented in Table 1. In the first column of this table the botanical names of the woods are listed alphabetically, and in the second column the common names from the region of procurement are given. Many of these woods possess a large number of common names, which results in considerable confusion. No attempt has been made here to list more than one, or perhaps two, for each species; however, for those interested, the literature on tropical forestry and botany (13-15) will provide a cross reference of source material containing other common names for many of these wood species. The density of each wood, based on the air dry specific gravity, is given in Column 3. Ratings are then given for degree of attack for teredo in the Pacific Ocean and in the brackish water of Miraflores Lake and by pholads in the Pacific Ocean.

*These exposures were terminated before 90 months because the NRL Corrosion Laboratory was transferred to Key West, Florida.

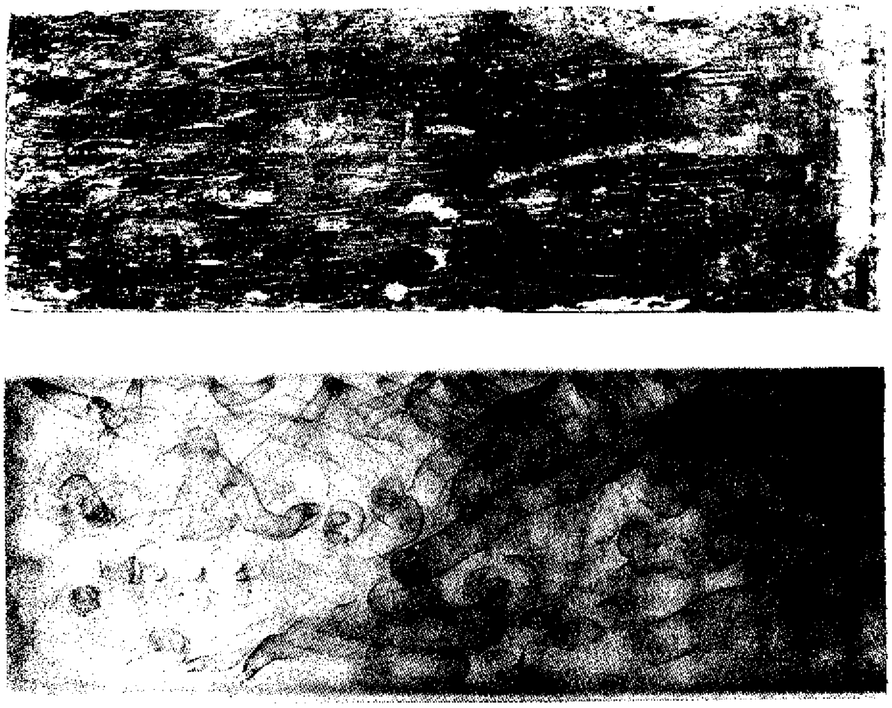


Fig. 3 - Extreme difference in appearance typically found between the exterior of a heavily teredo-infested piece of wood (top) and its interior (bottom) as revealed by x-ray photography

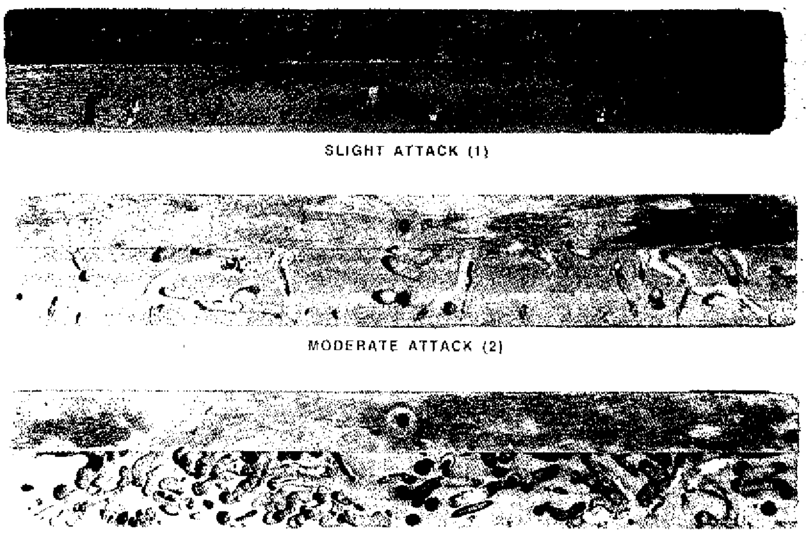


Fig. 4 - Examples of slight (1), moderate (2), and heavy (3) attack ratings for teredos

Selected Woods Exposed to High-Incidence Attack

The same comprehensive tabulation of data for the 44 selected wood species exposed to high-incidence borer attack in the Caribbean Sea at Coco Solo is presented in Table 2. In this case, ratings are also given for limnoria.

Resistance to Teredinidae

The teredine borers, also known as shipworms, belong to the Phylum Mollusca, Order Myoida. These are the best known of the marine boring organisms, being the most widespread and destructive. The genera *Teredo* and *Bankia* cause the most damage, although other genera are also implicated, including *Psiloteredo* and *Nausitora*, both of which were encountered in this investigation. In their mode of attack there is little difference between these genera. All settle from the plankton while in the larval stage, penetrate the wood, and spend the rest of their lives imprisoned therein. They continuously lengthen their burrows and do extensive internal damage to the wood in the process. Thirty species of teredine borers have been found in Canal Zone waters—20 species in the Caribbean Sea at Coco Solo, 13 species in the Pacific Ocean at Naos Island, and 4 species in Miraflores Lake. Some species are common to more than one location. A list of all Canal Zone borer species and location of occurrence is given in Table A2 in the Appendix (12).

At the Naos Island site in the Bay of Panama very rapid attack by teredos was observed for all of the pine and fir controls, with most specimens heavily damaged within 7 months. In the brackish water of Miraflores Lake the borer population developed more slowly, but eventually damage reached and exceeded that for the ocean, and by 14 months most of the lake controls were heavily infested. No difference in resistance could be detected between the Southern Pine and Douglas Fir at either of these exposure sites.

Many of the tropical woods were also rapidly destroyed by teredos. In the Pacific Ocean 36 of the 115 species were heavily damaged at the end of 7 months and another 15 species had reached the "heavy" rating in the ensuing 7 months, so that 44% of the woods were heavily infested by the end of 14 months in this marine environment. In Miraflores Lake by the end of 14 months 61% of the tropical woods were heavily damaged.

Although many of the wood species proved to be completely lacking in natural resistance to teredine borers, such negative results are not unimportant in investigations of this nature. The knowledge that these woods are susceptible to marine borer attack can be a decided asset, saving costly misapplication. A case in point concerns the Mangroves, some of which are hard, dense, and straight-trunked trees. Because they grow in the salt marshes, these woods have been considered by many people to be resistant to the depredations of marine borers. This misinformation has caused some very costly mistakes in using Mangrove wood in waterfront structures. Of the five Mangrove species tested, *Laguncularia racemosa, Rhizophora mangle, Rhizophora brevistyla, Avicennia marina,* and *Conocarpus erectus*, only *C. erectus* showed any natural resistance to teredine borers. The heavy damage sustained by *Rhizophora* (Red Mangrove) after only 14 months of exposure in the Pacific Ocean can be seen in Fig. 5.

For longer periods of exposure, only a few of the natural woods showed extended resistance potential. In Tropical Pacific ocean water, 11 species were rated "slight" or less with respect to teredo damage after 37 months, and after 90 months of exposure only two species, *Dalbergia retusa* and *Dialium guineense*, were still rated in the high-resistance category. None of the woods were completely immune to teredo damage through the full 7-1/2 years. *Dicorynia paraensis* was free from any teredo attack through 37 months; but all samples were removed at that inspection because of heavy pholad damage; thus, no 90-month teredo ratings were obtained.

Table 1
Natural Woods Exposed to Marine Borers in Tropical Waters
Screening Phase for 115 Wood Species

Botanical Name	Common Name in Area of Procurement	Density* A–Heaviest B, C, D, E, F–Lightest*	Degree of Damage†										
			Teredo							Pholad			
			Pacific Ocean–Naos Is., C.Z.				Brackish Lake–Miraflores, C.Z.			Pacific Ocean–Naos Is., C.Z.			
			7 mo	14 mo	38 mo	90 mo	14 mo	38 mo	90 mo	7 mo	14 mo	38 mo	90 mo
Anacardium excelsum	Espavé–Panama, R.P.	E	2	3	–	–	3	–	–	1	2	–	–
Andira inermis	Cocú–Panama Canal Zone	D	2	3	–	–	3	3	–	1	2	–	–
Aspidosperma megalocarpon (prob.)	Carreto, Alcarreto–Panama, R.P.	B	2	2	–	–	3	–	–	0	2	–	–
Astronium graveolens	Zorro, Zorrillo, Ron-ron–Panama, R.P.	C	2	3	–	–	2	3	–	1	1	–	–
Avicennia marina	Mangle Salado–Panama Canal Zone	B	3	–	–	–	3	–	–	‡	–	–	–
Bombacopsis quinata	Cedro Espino–Panama, R.P.	E	0	1	2	–	2	3	–	1	1	2	–
Bombacopsis sessilis	Ceibo–Panama Canal Zone	F	1	2	2	2	2	3	–	1	2	–	–
Brosimum sp.	Berba, Guayabo Blanco–Panama, R.P.	D	2	3	–	–	3	–	–	0	2	–	–
Bursera simaruba	Almácigo, Indio Desnudo–Panama Canal Zone	F	3	–	–	–	3	–	–	1	–	–	–
Byrsonima crassifolia	Nance–Panama Canal Zone	D	1	2	2	–	3	–	–	1	2	2	–
Callitris glauca	Australian Cypress Pine–Australia	D	0	1	2	–	2	2	–	1	2	3	–
Calophyllum brasiliense	María–Panama, R.P.	D	2	2	–	–	3	–	–	0	2	–	–
Calycophyllum candidissimum	Alazano, Lemonwood, Lancewood–Panama Canal Zone	C	2	2	2	3	2	3	–	0	0	2	2
Carapa slateri	Cedro Macho, Tangare–Bocas Del Toro and Darien, R.P.	E	3	3	–	–	3	–	–	1	2	–	–
Carapa sp.	Cedro Vino–Panama, R.P.	E	3	3	–	–	3	–	–	1	2	–	–
Cariniana pyriformis	Chibugá, Albarco–Darien, R.P.	E	1	1	2	–	2	3	–	1	2	2	–
Caryocar costaricense	Henené–Darien, R.P.	B	3	3	–	–	3	–	–	1	1	–	–
Caryocar sp.	Ajo–Darien, R.P.	E	3	3	–	–	3	–	–	1	1	–	–
Cassia moschata	Bronze Shower–Panama Canal Zone	C	2	2	2	–	2	3	–	0	2	2	–
Cedrela mexicana	Cedro Amargo–Panama, R.P.	F	2	2	3	–	3	–	–	1	1	1	–
Cedrela sp.	Cedro Granadino–Chiriquí, R.P.	F	3	3	–	–	3	–	–	1	1	–	–
Centrolobium orinocense	Amarillo de Guayaquil–Darien, R.P.	D	1	2	3	–	3	–	–	1	1	–	–
Chlorophora tinctoria	Mora–Panama, R.P.	E	1	1	2	3	2	3	–	1	1	1	–
Chrysophyllum cainito	Caimito, Star Apple–Panama Canal Zone	B	0	0	1	§	2	2	3	1	0	1	2
Colubrina glandulosa	Carbonero de Amunición–Panama Canal Zone	B	1	2	2	–	3	3	–	1	1	1	–
Conocarpus erectus	Zaragosa–Panama Canal Zone	B	1	1	2	–	2	3	–	1	1	1	–
Copaifera aromatica	Cabimo–Panama, R.P.	D	3	3	–	–	3	–	–	0	1	–	–
Cordia alliodora	Laurel Negro–Bocas Del Toro, R.P.	F	1	1	2	–	2	3	–	1	1	2	–
Cornus disciflora	Mata Hombro–Chiriqui, R.P.	D	3	3	–	–	3	–	–	‡	–	–	–
Coumarouna oleifera	Almendro–Panama, R.P.	B	2	2	2	–	3	3	–	1	1	–	–
Croton panamensis	Sangre–Panama Canal Zone	E	3	3	–	–	3	–	–	–	–	–	–
Dalbergia retusa	Cocobolo–Panama, R.P.	A	1	1	1	1	1	2	2	0	0	0	2
Dialium guineense	Tamarindo–Panama, R.P.	A	0	0	1	1	2	3	2	0	0	1	2
Dialyanthera otoba	Miguelario–Bocas Del Toro, R.P.	F	3	–	–	–	3	–	–	‡	–	–	–
Dicorynia paraensis	Angelique, Basra Locus–Surinam	C	0	0	0	–	1	2	2	1	1	2	–
Diphysa robinioides	Macano–Panama Canal Zone	B	2	2	¶	–	3	3	–	1	2	¶	–
Enterolobium cyclocarpum	Corotú–Panama Canal Zone	E	2	2	3	–	3	–	–	1	2	2	–
Erythrina glauca	Gallito–Panama Canal Zone	F	2	3	–	–	3	–	–	2	3	–	–
Eschweilera (prob)	Guayabo Macho–Panama, R.P.	D	1	2	2	–	2	3	–	1	1	2	–
Genipa americana	Jagua–Panama Canal Zone	D	3	3	–	–	3	–	–	1	1	–	–
Gliricidia sepium	Bala, Mata Ratón–Panama Canal Zone	A	1	2	2	–	2	3	–	1	2	2	–
Guajacum officinale	Lignum Vitae–Central America	A	0	2	2	3	2	3	–	1	1	2	2
Guarea longipetiola	Chuchupate–Chiriqui, R.P.	E	1	1	2	–	3	3	–	0	1	2	–
Guarea guara	Guaragao–Panama, R.P.	C	2	2	2	–	2	3	–	1	2	2	–
Hippomane mancinella	Manzanillo–Panama Canal Zone	E	1	3	–	–	2	3	–	0	1	–	–
Hura crepitans	Nuno–Panama Canal Zone	F	3	–	–	–	3	–	–	0	–	–	–
Hyeronima alchorneoides	Pantano–Chiriqui, R.P.	B	1	1	2	3	2	3	–	1	1	2	2
Hymenaea courbaril	Algarrobo–Panama Canal Zone	C	3	3	–	–	3	–	–	0	0	–	–
Lafoensia punicifolia	Amarillo Negro–Panama Canal Zone	C	2	2	3	–	3	–	–	1	1	–	–
Laguncularia racemosa	Mangle Blanco–Panama Canal Zone	D	2	3	3	–	3	–	–	0	1	1	–
Lecythis ampla	Coco–Darien, R.P.	C	2	3	3	–	3	3	–	1	2	–	–
Lecythis or Manilkara	Coco–Darien, R.P.	A	2	2	3	–	3	3	–	2	2	2	–
Licania arborea	Raspa–Panama, R.P.	D	0	0	1	–	2	2	–	0	0	1	–
Licaria pittieri	Jigua Negra–Darien, R.P.	E	1	2	3	–	3	3	–	1	2	2	–
Lonchocarpus sp.	Iguanillo–Panama Canal Zone	B	3	3	–	–	3	–	–	1	1	–	–

Lophira procera	Bongassi, Ekki, Azobe, Iron Wood–Africa	A	1	1	1	2	2	3	–	1	1	2	3
Luehea seemannii	Guácimo–Panama Canal Zone	E	2	2	–	–	2	3	–	1	2	–	–
Magnolia sororum	Vaco, Baco–Chiriqui, R.P.	E	2	3	–	–	3	–	–	1	2	–	–
Manilkara bidentata	Níspero Balata–Darien, R.P.	B	2	3	3	–	3	–	–	0	1	1	–
Manilkara chicle	Níspero Zapote–Panama Canal Zone	A	2	3	3	–	3	3	–	0	1	‡	–
Manikara sp.	Rasca–Panama, R.P.	A	1	2	2	–	2	3	–	0	1	1	–
Minquartia guianensis	Crillo, Manwood–Bocas Del Toro, R.P.	C	1	2	2	–	2	3	–	1	1	1	–
Mora oleifera	Alcornoque–Darien, R.P.	D	3	–	–	–	3	–	–	0	–	–	–
Myroxylon balsamum	Bálsamo–Darien, R.P.	A	2	3	–	–	3	–	–	0	1	–	–
Nectandra whitei	Bambito–Panama, R.P.	D	3	3	–	–	3	–	–	1	1	–	–
Ocotea dendrodaphne	Ensiva, Insibe–Darien, R.P.	C	1	2	2	3	2	3	–	1	2	2	3
Ocotea rodiei	Greenheart–British Guiana	B	1	1	2	¶	2	3	–	1	1	2	¶
Paramachaerium gruberi	Sangrillo Negro–Chiriqui, R.P.	C	1	2	2	3	3	3	–	1	2	2	2
Pelliciera rhizophorae	Palo de Sal–Panama Canal Zone	D	3	–	–	–	3	–	–	‡	–	–	–
Peltogyne purpurea	Nazareño–Panama, R.P.	B	3	3	–	–	3	–	–	0	0	–	–
Pentaclethra macroloba	Gavilán–Bocas Del Toro, R.P.	C	2	2	3	–	3	–	–	1	1	1	–
Phoebe johnstonii	Aguacatillo–Panama Canal Zone	E	3	–	–	–	3	–	–	0	–	–	–
Pinus caribaea	Nicaraguan Pine–Nicaragua	E	§	§	–	–	3	–	–	1	2	–	–
Pinus sp.	Southern Yellow Pine–U.S.A.	F	§	§	–	–	3	–	–	‡	–	–	–
Pithecellobium mangense	Uña de Gato–Panama Canal Zone	E	0	1	2	–	2	3	–	0	0	1	–
Pithecellobium saman	Rain Tree–Panama Canal Zone	E	3	3	3	–	3	–	–	1	1	2	–
Platymiscium pinnatum	Quirá–Panama, R.P.	B	1	1	2	–	2	3	–	0	0	1	–
Pouteria campechiana	Mamecillo–Panama Canal Zone	A	0	0	0	2	1	2	2	0	0	0	2
Pouteria chiricana	Nispero de Monte–Panama Canal Zone	B	1	1	1	2	2	2	3	0	0	1	2
Prioria copaifera	Cativo–Panama Canal Zone	E	3	–	–	–	3	–	–	0	–	–	–
Pseudotsuga taxifolia	Douglas Fir–U.S.A.	E	3	–	–	–	3	–	–	1	–	–	–
Quercus sp.	Native Oak, Roble–Chiriqui, R.P.	B	3	–	–	–	3	–	–	0	–	–	–
Rhizophora brevistyla	Mangle Rojo (Pacific)–Panama, R.P.	A	3	3	–	–	3	–	–	1	1	–	–
Rhizophora mangle	Mangle Rojo (Atlantic)–Panama Canal Zone	B	3	3	–	–	3	–	–	‡	‡	–	–
Sterculia apetala	Panama–Panama Canal Zone	F	3	–	–	–	2	3	–	‡	–	–	–
Swartzia panamensis	Cutarro–Darien, R.P.	B	2	2	3	–	3	–	–	1	1	–	–
Swartzia simplex	Naranjito–Panama Canal Zone	B	3	3	–	–	3	–	–	1	1	–	–
Sweetia panamensis	Malvecino–Panama, R.P.	B	2	2	3	–	3	3	–	1	1	1	–
Swietenia macrophylla	Mahogany, Caoba–Panama, R.P.	E	2	2	–	–	3	–	–	2	2	–	–
Symphonia globulifera	Sambogum, Cerillo–Bocas Del Toro, R.P.	E	3	–	–	–	3	–	–	‡	–	–	–
Tabebuia chrysantha	Guayacán Negro–Panama, R.P.	A	2	2	2	–	3	3	–	1	1	1	–
Tabebuia guayacan	Guayacán–Chiriqui, R.P.	A	1	1	2	2	2	3	–	1	1	1	2
Tabebuia pentaphylla	Roble de Sabana–Panama, R.P.	E	1	2	–	–	2	3	–	1	2	–	–
Tectona grandis	Teak (Canal Zone)–Panama Canal Zone	E	1	2	2	–	2	3	–	1	2	2	–
Tectona grandis	Teak (Burma)–Burma	E	0	0	0	–	2	2	–	1	2	3	–
Terminalia amazonia	Amarillo–Panama, R.P.	C	2	2	–	–	3	–	–	2	2	–	–
Terminalia catappa	Almond–Panama Canal Zone	E	1	1	1	–	2	3	–	1	2	2	–
Terminalia myrio čarpa	Dalienze–Panama Canal Zone	E	2	2	¶	–	2	3	–	2	2	¶	–
Ternstroemia seemannii	Manglillo–Panama Canal Zone	E	3	3	–	–	3	–	–	1	1	–	–
Tetragastris panamensis	Anime–Darien, R.P.	B	2	3	¶	–	3	3	–	1	2	¶	–
Tetrathylacium johansenii	Macho–Panama Canal Zone	D	2	3	–	–	3	–	–	1	1	–	–
Trattinickia aspera	Caraño–Panama Canal Zone	F	3	3	–	–	3	–	–	0	1	–	–
Trichilia tuberculata	Alfaje–Panama Canal Zone	C	1	2	2	–	2	3	–	1	1	2	–
Vatairea sp. (Prob.)	Amargo-Amargo–Panama, R.P.	E	3	3	–	–	3	–	–	0	1	–	–
Virola koschnyi	Bogamani, Gorogań–Chiriqui, R.P.	F	3	–	–	–	3	–	–	‡	–	–	–
Virola sebifera	Mancha–Chiriqui, R.P.	E	3	3	–	–	3	–	–	1	1	–	–
Vitex floridula	Cuajado–Panama Canal Zone	D	2	3	–	–	3	3	–	1	2	–	–
Vochysia ferruginea	Mayo–Panama Canal Zone	F	3	–	–	–	3	–	–	‡	–	–	–
Vouacapoua americana	Acapú–Brazil	B	0	1	1	2	2	3	–	0	0	1	2
Zanthoxylum belizense	Acabú, Arcabu–Panama, R.P.	F	3	3	–	–	3	–	–	1	2	–	–
Unidentified	Macano Blanco–Panama, R.P.	A	1	1	2	–	2	3	–	0	0	1	–
Unidentified	Vasca–Darien, R.P.	E	1	2	2	–	2	3	–	1	2	2	–
Unidentified	Sigua–Panama, R.P.	E	2	3	–	–	3	–	–	2	2	–	–
Unidentified	Naranjillo–Chiriqui, R.P.	D	1	2	3	–	2	3	–	1	1	1	–

* Density: A–air dry specific gravity > 1 (heaviest), B–0.9 to 1.0 a.d.s.g., C–0.8 to 0.9 a.d.s.g., D–0.7 to 0.8 a.d.s.g., E–0.5 to 0.7 a.d.s.g., and F– < 0.5 a.d.s.g. (lightest).
† 0–none apparent, 1–slight, 2–moderate, and 3–heavy.
‡ Very heavy teredo attack prevented assessment of pholad activity.
§ Some limnoria damage (1-2) at time indicated.
¶ Specimens missing, probably destroyed by combined action of teredos and pholads.
–Indicates all specimens removed or destroyed before this inspection.

Table 2
Selected Wood Species Exposed to High-Incidence Marine Borer Attack in the Caribbean at Coco Solo, Canal Zone
Exposure Periods to 51 Months

Botanical Name	Common Name in Area of Procurement	Density* A–Heaviest to F–Lightest	Degree of Damage† Teredo 14 mo	Teredo 37 mo	Teredo 51 mo	Pholad 14 mo	Pholad 37 mo	Pholad 51 mo	Limnoria 14 mo	Limnoria 37 mo	Limnoria 51 mo	Specimens Destroyed‡
Anacardium excelsum	Espavé–Panama, R.P.	E	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Bombacopsis quinata	Cedro Espino–Panama, R.P.	E	1	2	2	1	2	3	2	2	1	
Bombacopsis sessilis	Ceibo–Panama Canal Zone	F	1	–	–	1	–	–	3	–	–	7/8 by 14 months
Callitris glauca	Australian Cypress Pine–Australia	D	2	2	3	2	3	3	0	1	1	
Calophyllum brasiliense	María–Panama, R.P.	E	3	–	–	1	–	–	2	–	–	
Carapa slateri	Cedro Macho–Bocas del Toro, R.P.	E	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Cariniana pyriformis	Chibugá–Darien, R.P.	E	3	–	–	2	–	–	2	–	–	4/4 between 14 and 37 months
Cedrela mexicana	Cedro Amargo–Panama, R.P.	F	3	–	–	2	–	–	2	–	–	4/4 between 14 and 37 months
Cedrela sp.	Cedro Granadino–Chiriqui, R.P.	F	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Chlorophora tinctoria	Mora, Mora Amarilla–Panama, R.P.	E	3	–	–	1	–	–	2	–	–	5/5 between 14 and 37 months
Chrysophyllum cainito	Caimito–Panama Canal Zone	B	0	1	1	0	2	3	0	2	2	
Conocarpus erectus	Zaragosa–Panama Canal Zone	B	2	3	3	1	1	2	1	1	1	
Copaifera aromatica	Cabimo–Panama, R.P.	D	3	3	–	1	–	–	2	2	–	2/4 between 15 and 37 months
Cordia alliodora	Laurel–Panama, R.P.	F	1	1	1	2	3	3	1	1	1	
Cordia allidora	Laurel Negro–Bocas del Toro, R.P.	F	1	1	2	2	3	3	1	1	2	
Coumarouna oleifera	Almendro–Panama, R.P.	B	2	3	3	1	2	2	1	2	2	
Dalbergia retusa	Cocobolo–Panama, R.P.	A	0	0	0	1	1	1	0	0	0	
Dialyanthera otoba	Miguelario–Bocas del Toro, R.P.	F	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Dicorynia paraenis	Angelique–Surinam	C	0	0	1	2	3	3	0	1	2	
Enterolobium cyclocarpum	Corotú–Panama Canal Zone	E	2	2	–	0	3	–	2	2	–	1/8 14 months 2/2 between 37 and 51 months
Guajacum officinale	Lignum Vitae–Central America	A	0	3	3	1	1	2	0	0	0	
Hura crepitans	Nuno–Panama Canal Zone	F	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Hyeronima alchorneoides	Pantano–Chiriqui, R.P.	B	1	1	2	1	2	2	0	1	2	
Licaria pittieri	Jigua Negra–Darien, R.P.	E	2	3	3	2	2	3	0	2	2	
Lophira procera	Bongassi–Africa	A	2	2	2	2	2	2	0	1	1	
Luehea seemannii	Guácimo–Panama Canal Zone	E	3	–	–	1	–	–	1	–	–	1/8 by 14 months 4/4 between 14 and 37 months
Ocotea dendrodaphne	Ensiva–Darien, R.P.	C	2	3	–	2	–	–	1	2	–	
Ocotea rodiei	Greenheart–British Guiana	B	2	2	2	1	2	2	1	2	2	
Paramachaerium gruberi	Sangrillo Negro–Chiriqui, R.P.	C	1	2	3	1	2	2	1	1	2	
Pinus sp.	Southern Yellow Pine–U.S.A.	F	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Platymiscium pinnatum	Quirá–Panama, R.P.	B	2	3	3	1	1	2	1	1	1	
Pouteria campechiana	Mamecillo–Panama Canal Zone	A	1	1	1	1	1	2	1	2	2	
Pouteria chiricana	Níspero de Monte–Panama Canal Zone	B	1	1	1	1	2	2	2	3	3	
Prioria copaifera	Cativo–Panama Canal Zone	E	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Pseudotsuga taxifolia	Douglas Fir–U.S.A.	E	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Tabebuia guayacan	Guayacán–Chiriqui, R.P.	A	1	1	1	1	2	2	0	0	1	
Tectona grandis	Teak (C.Z. grown)–Panama Canal Zone	E	2	2	3	2	2	2	1	2	3	
Tectona grandis	Burma Teak–Burma	E	1	1	2	2	2	3	2	2	2	
Terminalia amazonia	Amarillo–Panama, R.P.	C	2	3	–	1	3	–	2	2	–	2/6 between 14 and 37 months
Terminalia catappa	Almond–Panama Canal Zone	E	3	3	–	2	2	–	1	2	–	
Vatairea sp. (prob.)	Amargo-Amargo–Panama, R.P.	E	3	–	–	1	–	–	2	–	–	1/8 by 14 months 5/5 between 14 and 37 months
Vochysia ferruginea	Mayo–Panama Canal Zone	F	–	–	–	–	–	–	–	–	–	8/8 by 14 months
Vouacapoua americana	Acapú–Brazil	B	2	2	2	1	2	2	1	1	1	
Unidentified	Vasca–Darien, R.P.	E	0	2	–	2	3	–	2	2	–	2/5 between 14 and 37 months

*Density: A–air dry specific gravity > 1, B–0.9 to 1.0 a.d.s.g., C–0.8 to 0.9 a.d.s.g., D–0.7 to 0.8 a.d.s.g., E–0.5 to 0.7 a.d.s.g., and F – < 0.5 a.d.s.g.
†0–none apparent, 1–slight, 2–moderate, and 3–heavy.
‡Eight specimens were exposed; one or more was removed, cut open, and rated at each period. The figures shown represent the number destroyed/number exposed at start of period.
– Indicates all specimens removed or destroyed before this inspection.

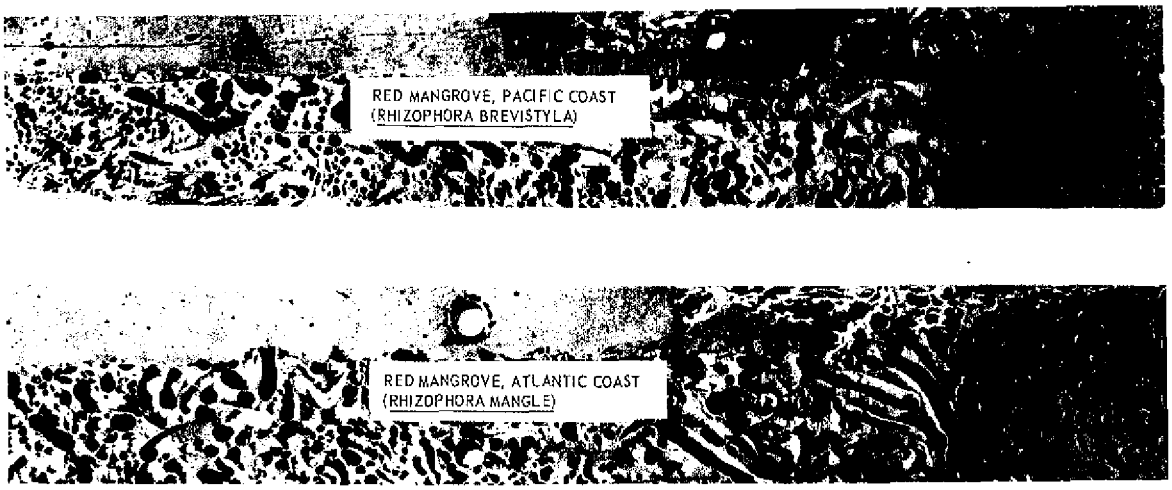


Fig. 5 - Heavy marine borer damage sustained by two different species of Red Mangrove during the first 7 months of immersion in tropical seawater, Naos Island, C.Z.

Even fewer wood species retained high resistance in the brackish water of Miraflores Lake. The surprising vigor of the brackish-water teredo in this low-salinity lake water was one of the interesting developments of the study. Only four species of borers have been found in the lake, and at the test platform in the center of the lake all the damage was done by one species, *Psiloteredo healdi*, a borer which has caused considerable damage to the Panama Canal locks. An example of the destruction caused by this lake borer can be seen in Fig. 6, which shows a section of a fender timber from the upper Miraflores locks. This same species is known to be a source of trouble in other brackish tropical waters, such as Lake Maracaibo in Venezuela. At the end of 14 months, many woods that were still unattacked in the ocean were infested at Miraflores by *P. healdi*. Examples of this damage can be seen in Fig. 7, which shows cross sections of two borer-resistant commercial timbers after 14 months in the lake and in the sea. After 37 months in the lake, not a single wood could be rated highly resistant (rating 0 to 1), while only eight of the original 115 species were considered even moderately resistant (rating 2). After 90 months in the lake, four of the eight were still in the "moderate" category.

The second phase of this program, exposure of certain woods in the extremely bioactive waters of the Caribbean Sea at Coco Solo, was primarily setup to evaluate resistance to high-incidence activity of *Limnoria tripunctata*. However, as shown in Table A2, a wider spectrum of teredine borers was present at this site; consequently, the data presented in Table 2, which show all the results of the Caribbean exposures through 51 months, provided additional information on teredo infestation for a number of woods in this study. From inspection of this table it can be seen that six wood species were only slightly attacked by teredo after 51 months and that *Dalbergia retusa* showed no visible evidence of teredo damage. Generally, the results of the exposure at Coco Solo reinforce those of Naos Island and Miraflores Lake. Based on the combined exposure data from both ocean water sites, a tabulation of 12 of the most naturally resistant woods with respect to teredine borers in tropical oceans is presented in Table 3. Also included in this table are the four woods most resistant to teredo attack in the brackish waters of Miraflores Lake. The wood species in both lists are arranged in an order of decreasing ability to resist teredo attack. Two properties, specific gravity and silica content, are included because of their possible relationship to marine borer resistance in many woods.

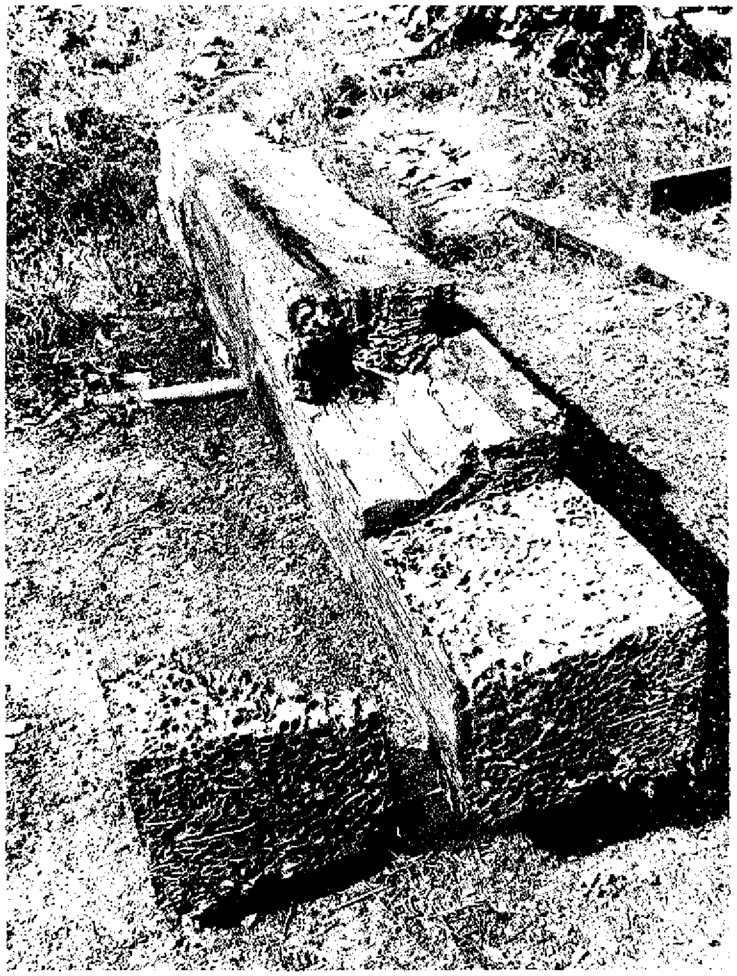


Fig. 6 - Damage to Panama Canal fender timber by brackish-water teredos in Miraflores Lake, untreated Southern Pine

Probably the wood most naturally resistant to damage by teredine borers under all environmental variations encountered and for long periods of exposure was *Dalbergia retusa*. This species is a low-silica, hard, heavy, very oily wood. It is scattered widely and has a poor timber form, which is most unfortunate from a commercial standpoint. However, the constituents providing such effective protection should be of considerable interest to wood preservation chemists. Almost equally resistant to teredine borers is the commercial South American species, *Dicorynia paraensis*; the wood is high in silica, and its teredo resistance may be related to this constituent. This correlation between silica content of the wood and its resistance to teredo activity was also apparent for other wood species. All seven woods in this study with more than 0.5% silica content are among the 12 most teredo-resistant woods in the marine environment listed in the upper portion of Table 3; three of the four best performing woods in brackish water listed in the lower section of the table were also high in silica. Thus, the presence of silica seems to contribute significantly to natural teredo resistance, although, obviously, it is not the only constituent that can protect.

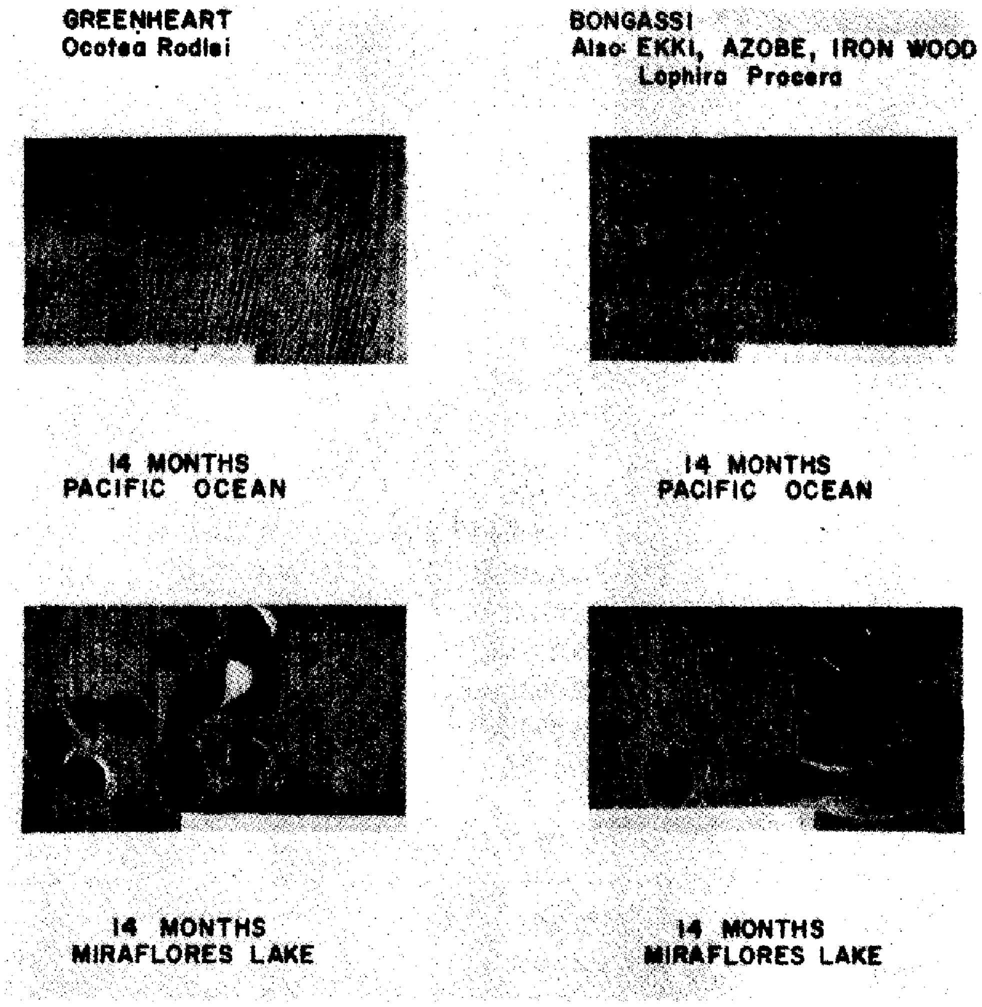


Fig. 7 - Cross section of two teredo-resistant wood species showing the more destructive effects of brackish-water teredos, exposure time 14 months

Density does not seem to be very important. While the majority of the resistant woods were high-density species, many other hard, dense woods were heavily attacked, including the heaviest of all, *Guajacum officinale* (1.23 air dry specific gravity). Furthermore, two species showing high natural resistance to teredos in the marine environment, *Cordia alliodora* and *Bombacopsis quinata*, were light woods of less than 0.5 specific gravity.

Resistance to Pholadidae

The family, Pholadidae, belongs to the same phylum as that of the teredine borers. Although the family is distributed worldwide, most of the individual genera contain very few species, have a limited range of distribution, and have not been of practical concern in U.S. harbors on the Pacific and northeast Atlantic coasts. These bivalves, known as stone borers, also begin life as larval members of the plankton. The larvae eventually settle on a suitable substrate, penetrate it, and spend the rest of their lives imprisoned in a burrow of their own making, which they continuously enlarge to accommodate growth requirements. The normal habitats for many of these animals are the naturally occurring mud banks, shale, limestone, and other soft rocks in the marine environment; however, they have been found in many construction materials, including poor grades of concrete, soft metals (16), and wood, which is the natural substrate for *Xylophaga* and *Martesia*. It is the latter genus which is most destructive to wooden marine structures. Because it has not been destructive along our temperate coasts, it has received little attention, and the true menace posed by this wood-boring clam in tropical and warmer

Table 3
Tropical Woods Showing High Natural Resistance to Teredos

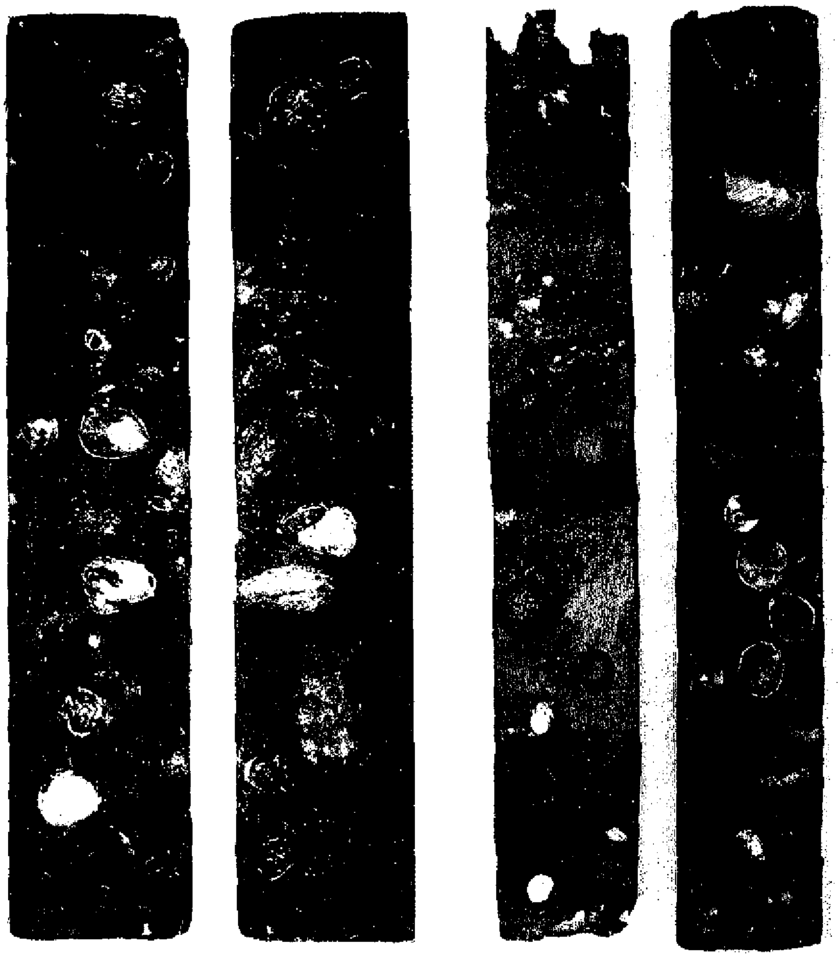
Botanical Name*	Source	Specific Gravity (air dry)	SiO_2 (%)
Most Resistant Woods in Tropical Seas			
Dalbergia retusa	Panama	1.1	0.004
Dicorynia paraensis	Surinam	0.88	0.72
Pouteria campechiana	Panama	>1.0	1.88
Chrysophyllum cainito	Panama	0.9-1.0	0.67
Tectona grandis	Burma	0.58	1.44
Dialium guineense	Panama	>1.0	2.55
Pouteria chiricana	Panama	0.9-1.0	2.07
Licania arborea	Panama	0.7-0.8	2.18
Cordia alliodora	Panama	0.42	0.01
Bombacopsis quinata	Panama	0.47	0.004
Tabebuia quayacan	Panama	>1.0	0.007
Vouacapoua americana	Brazil	0.9-1.0	0.002
Most Resistant Woods in Miraflores Lake (Brackish)			
Dalbergia retusa	Panama	>1.1	0.004
Pouteria campechiana	Panama	1.0	1.88
Dicorynia paraensis	Surinam	0.88	0.72
Dialium guineense	Panama	>1.0	2.55

*Listed in order of decreasing resistance.

temperate waters is not generally recognized. Pholads are capable of boring into the hardest of woods and completely destroying underwater timbers. Many woods with high natural resistance to teredos are susceptible to pholad attack.

In the Canal Zone, heavy *Martesia* activity occurs in both oceans but not in the low-salinity water of Miraflores Lake. Table 1 shows the extent of pholad damage sustained by each of the 115 different wood species immersed in the Pacific Ocean at Naos Island; Table 2 presents the same information for the 44 selected species of wood exposed in Caribbean water at Coco Solo.

A somewhat higher incidence of *Martesia* activity was found at Coco Solo than at Naos Island, but in both oceans the pholad population developed much more slowly than that of the shipworms. Of the 115 wood species exposed in the Pacific Ocean, none were heavily damaged by pholads during the first 7 months and only five reached a "moderate" attack level. By contrast, contemporaneous teredo attack resulted in moderate to heavy damage for 70 of these wood species. As exposure time increased, the more rapid attack of teredos destroyed all the teredo-susceptible woods, so that the pholad attack rates for these woods could not be completely evaluated. But it also became apparent from the long-term exposure data that many woods showing continued high resistance to the Teredinidae were slowly but surely attacked by *Martesia*. An example of this selective damage is presented in Fig. 8, which shows longitudinal sections of two of the most teredo-resistant woods, *Dicorynia paraensis* and *Chrysophyllum cainito*, after 51 months of exposure in the Caribbean. All damage observed was caused by pholads. The woods



(a) Dicorynia paraensis (b) Chrysophyllum cainito

Fig. 8 - Sectional views of two high-silica woods that exhibited excellent resistance to teredo but which were severely attacked by pholads *(Martesia sp.)*

showing the highest natural resistance to pholad activity are listed in Table 4 in order of decreasing merit.

From the specific gravity data included in Table 4, it can be seen that density seems to play a more significant role in rendering a wood resistant to pholads than it does with teredo or limnoria. Although high density did not assure resistance, all of the woods that were found highly resistant to these borers were extremely hard and dense. (>0.9 sp gr). Four woods of lower specific gravity, *Cordia alliodora* (0.42), *Bombacopsis quinata* (0.47), *Ocotea rodiei* (0.58), and *Dicorynia paraensis* (0.88), which had all shown high resistance to teredo, were heavily damaged by pholads within 37 to 51 months.

On the other hand, high silica content, which seems to contribute to teredo resistance, was apparently not important with respect to pholad attack. While three of the resistant woods listed in Table 4 had a high silica content, the other eight did not, including the two best: *Dalbergia retusa*, with only 0.004% silica, and *Platymiscium pinnatum*, with only 0.003% silica.

Table 4
Woods Showing High Natural Resistance to Pholads in Tropical Seas

Botanical Name*	Source	Specific Gravity (air dry)	SiO_2 (%)
Dalbergia retusa	Panama	1.1	0.004
Platymiscium pinnatum	Panama	0.9-1.0	0.003
Pouteria campechiana	Panama	>1.0	1.88
Pouteria chiricana	Panama	0.9-1.0	2.07
Dialium guineense	Panama	>1.0	2.55
Guajacum officinale	Central America	1.2	0.003
Conocarpus erectus	Panama	0.9-1.0	0.005
Calycophyllum candidissium	Panama	0.8-0.9	0.004
Ocotea rodiei	British Guiana	0.9-1.0	0.12
Vouacapoua americana	Brazil	0.9-1.0	0.002
Tabebuia guayacan	Panama	>1.0	0.007

*Listed in order of decreasing resistance.

The exposure results for one species, *Tectona grandis* (Teak), provided the most revealing information on the effects of silica. During the collection phase Teak from Burma was obtained, along with wood from a 15-year old Teak tree grown in Panama. Interestingly, these two woods, which were very similar in density, appearance, and terrestrial durability, were found to have a quite different silica content. The Burma Teak contained 1.44% silica, while the Panama-grown Teak contained only 0.01% silica. This difference was reflected in a considerably higher resistance to teredo for the Burma Teak; however, pholad resistance was about the same for the two woods.

Two aspects of pholad attack which make pholads seem not as serious a threat as teredo are that their presence is more easily detected because of their larger entrance holes and that they do not penetrate the wood so deeply. On the other hand, they seem to be the hardiest and most persistent of the marine wood-boring organisms. Evaluation of these studies and those of others (6,16,17) leave the impression that few, if any, untreated woods are completely resistant to *Martesia*. None of the many otherwise resistant woods tested retained zero pholad rating throughout the study. A dependence on natural resistance where there is a heavy *Martesia* population will probably result in eventual failure of the timber.

Resistance to Limnoriidae

The third major group of marine wood-boring organisms is composed of the small (up to 4-mm) crustaceans of the family, Limnoriidae, of which the genus *Limnoria*, commonly called "gribble," is the most destructive. Unlike the molluscan borers, these marine animals do not become members of the plankton during their early life but instead are hatched within the parental burrow, from which they begin to bore side tunnels within a few hours. The boring habits of the gribble also differ from those of the molluscan borers. These organisms burrow shallowly beneath and parallel to the wood surface, forming a maze of interconnecting tunnels. Then, as the weakened surface of the wood is exposed to wave action in the tidal zone and begins to wash away, the animals are forced to burrow deeper, thus beginning another cycle of attack. On vertical pilings this action results in the familiar hour-glass effect. Limnoria action has been found to be much more rapid in tropical waters because of the constant high temperature and the presence of a newly described species, *L. tripunctata* (18), which is of special significance because it is creosote-tolerant (2) and therefore the species most damaging to pressure-creosoted timbers. Vind et al. (19) have reported that *L. tripunctata* is active only at temperatures above 19°C. A graphic example of limnoria activity is presented in Fig. 1, which shows the effects of these organisms on creosoted pilings in Balboa Harbor at the Pacific end of the Panama Canal and in the Coco Solo harbor at the Caribbean end. These two locations have extreme differences in tidal range, which are indicated on the piles by the length of the damaged area. At Balboa very high tides (up to 22 ft) occur, which result in a very long taper on the pilings, while at Coco Solo the tide range is small, rarely exceeding 1.5 ft, and the hour-glass taper is very abrupt.

In the present study the 115 species of untreated woods were evaluated for limnoria damage for periods up to 90 months at Naos Island. However, at this location *L. tripunctata* has not been observed, and L. *lignorum*, which has been identified by the Clapp Laboratories as being the species present at our Naos site, was rated only moderately active (12). Out of the many hundreds of samples exposed at the Naos pier during the course of the NRL study, only a small percentage of the specimens of tropical woods were attacked by limnoria. Such data cannot be considered a valid comparative test for limnoria resistance; therefore, no limnoria results have been included in the Pacific Ocean exposure data in Table 1.

One bit of information concerning limnoria did derive from the Pacific exposures—that was the relatively low resistance of pine. Thirty pieces of Southern Yellow Pine, *Pinus sp.*, were dispersed throughout the exposure area as controls. In addition, eight pieces of Nicaraguan Pine, *Pinus caribaea*, were also included in the test. Of this relatively large number of pine samples, all but one were attacked by limnoria within 7 to 14 months. Limnoria damage did not progress beyond "moderate" on any of these samples, because the untreated pines were so heavily damaged by teredos that longer-term data were not obtainable.

Speculation on the reasons for the dearth of limnoria damage detected on the bulk of the tropical wood at Naos Island lead to several possibilities which may contribute, separately or in combination. One reason is that the most destructive species, *L. tripunctata*, is not active at the Naos Island site. Another reason is that at this location encrusting fouling organisms rapidly form a tight fouling mat around each panel. If the wood has sufficient resistance to ward off limnoria until the fouling cover is formed, it is questionable that the borers can subsequently make much headway. Finally, most of the tropical woods seem to be naturally more resistant to limnoria than the coniferous woods. Actually it would appear that pine (and probably fir) with the distinct bands of very soft earlywood and hard latewood provide the most ideal type of habitat for limnoria. They can easily work into the soft earlywood and are somewhat protected by the adjacent wall of hard latewood.

The followup exposures in the Caribbean at Coco Solo were especially oriented toward obtaining comparative limnoria data for some of the more desirable woods. Prior to the exposures, pine panels were immersed for several years at the test site and evaluated by Clapp Laboratories. Limnoria as well as the other two borer types, pholads and teredos, were found extremely active in this water. The limnoria were represented by the widespread species *L. lignorum* and the destructive warm-water species *L. tripunctata.*

Incidence of limnoria attack did prove to be much higher at the Coco Solo Caribbean site than in the Pacific. Many of the tropical woods that exhibited high resistance to limnoria at the Pacific site sustained considerable attack at Coco Solo; still, practically all the 44 tropical woods tested at Coco Solo were considerably more resistant to limnoria than the Southern Yellow Pine. Pine control panels were rapidly infested, and all were heavily damaged within 7 to 14 months. Figure 9 shows a pine panel after 7 months of immersion at Coco Solo. It shows the heavy early attack of limnoria and their selective boring in the soft earlywood. Pine samples inspected after only 3 months of exposure showed that limnoria during this short span were so active that marine fouling could not become well established, although fouling was already heavy on an adjacent tropical wood (Teak). By 14 months pine, fir and six low-density tropical woods were completely destroyed by the combined action of limnoria and the teredine borers.

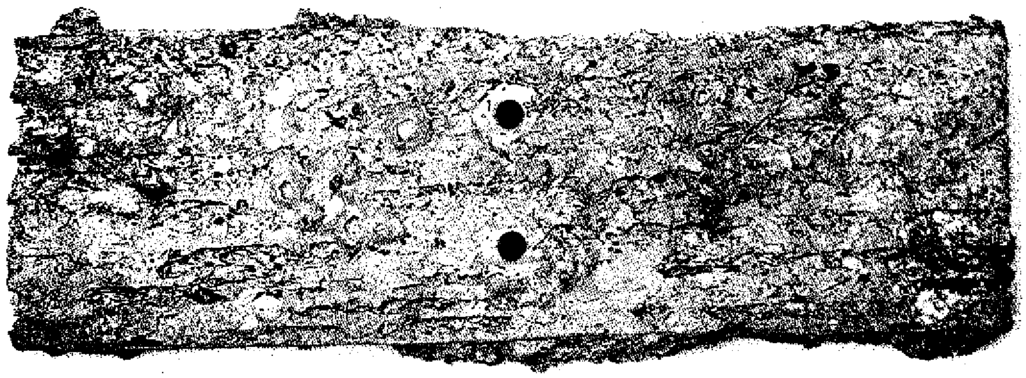


Fig. 9 - Limnoria-damaged Pine panel after 7 months of immersion in tropical seawater at Coco Solo, C.Z.

A list of the most limnoria-resistant woods in the Coco Solo exposure is shown in Table 5 in order of decreasing ability to resist attack. As with the pholads, this list can only include woods that are sufficiently resistant to teredo to last long enough to establish a limnoria rating. The first two woods, *Dalbergia retusa* and *Guajacum officinale*, showed no trace of limnoria damage throughout the 51 months of immersion in the Caribbean and 90 months in the Pacific. The others sustained a slight to moderate attack after 51 months in the Caribbean but none in the Pacific, except *Lophira procera*, which rated a trace attack in the Pacific after 90 months of immersion. As with the previous list of resistant woods, the specific gravities and silica contents are included for each of the limnoria-resistant species. There does not seem to be a significant correlation between density and limnoria attack. While the two most resistant woods, *Dalbergia retusa* and *Guajacum officinale*, are extremely dense and hard woods, three of the other highly resistant species, *Cordia alliodora* (0.42 sp gr), *Bombacopsis quinata* (0.47), and *Callitris glauca* (0.69), have a lower density. On the other hand, some very low-density woods, such as *Bombacopsis sessilis* and *Cedrela mexicana*, were rapidly attacked by limnoria.

Limnoria resistance also seems to be quite independent of silica content of the wood. All of the most resistant species had low silica contents, and a few of the high-silica woods, such as *Pouteria sp.*, were heavily attacked by limnoria. Also, the two teaks with high and low silica contents were not significantly different in resistance to limnoria.

WOODS OF SPECIAL INTEREST

After analysis of the long-term data collected in this study, a number of woods appear to be especially interesting and will be discussed individually. Some of these are included because of their high natural resistance to all classes of borers; others are

Table 5
Woods Showing High Natural Resistance to Limnoria in Tropical Seas

Botanical Name*	Source	Specific Gravity (air dry)	SiO_2 (%)
Dalbergia retusa	Panama	1.1	0.004
Guajacum officinale	Central America	1.23	0.003
Tabebuia guayacan	Panama	>1.0	0.007
Vouacapoua americana	Brazil	0.9-1.0	0.002
Callitris glauca	Australia	0.69	0.004
Conocarpus erectus	Panama	0.9-1.0	0.005
Cordia alliodora	Panama	0.42	0.01
Platymiscium pinnatum	Panama	0.9-1.0	0.003
Lophira procera	Africa	>1.0	0.002
Bombacopsis quinata	Panama	0.47	0.004

*Listed in order of decreasing resistance.

included because they have excellent structural potential and high resistance to one or two borer types. Some specific woods are discussed because of their reputation for borer resistance, although not necessarily in tropical environments. Figure 10 shows a comparative array of some of these special interest woods.

Bombacopsis quinata - Cedro Espino

Cedro Espino is a useful, medium-density wood which is a well-known commercial species in Panama. It is reported by Record and Hess (13) to be fairly plentiful throughout many parts of its range, which extends from Honduras to Venezuela. The wood has exceptionally high resistance to terrestrial wood-destroying organisms, i.e., termites and fungi. It was also found to have moderately high resistance to teredos and limnoria in the sea but as with many other generally durable wood species, it was unrelentingly attacked by pholads and brackish-water *Psiloteredo*. The combination of high durability to most biological attack, light-to-medium density, good structural properties, and trunks suitable for timber use make Cedro Espino a species with very high service potential.

Callitris glauca - Australian Cypress Pine

Two logs of Australian Cypress Pine were generously supplied by the Australian Dept. of Forest Products for these Canal Zone exposures. In tests by Edmondson (6) in Hawaiian waters, this low-silica wood was found to have very high resistance to all marine borers. In this study, *C. glauca* exposed at Naos Island was only moderately resistant to both teredos and pholads. A similar teredo rating was obtained in Miraflores Lake at 37 months—a relatively good rating for the brackish water.

The waters at Coco Solo are probably among the most borer-active in the world. The severity of attack at Coco Solo as compared to Hawaiian waters is indicated through the results of current exposures by the Cooperative Marine Piling Committee, which are revealing considerably faster attack on creosote pilings at Coco Solo (20). *C. glauca* was more severely damaged in these waters than in the Pacific exposures; the extent of damage to one sample can be seen in Fig. 10. At Coco Solo, inspections of all the *C. glauca*

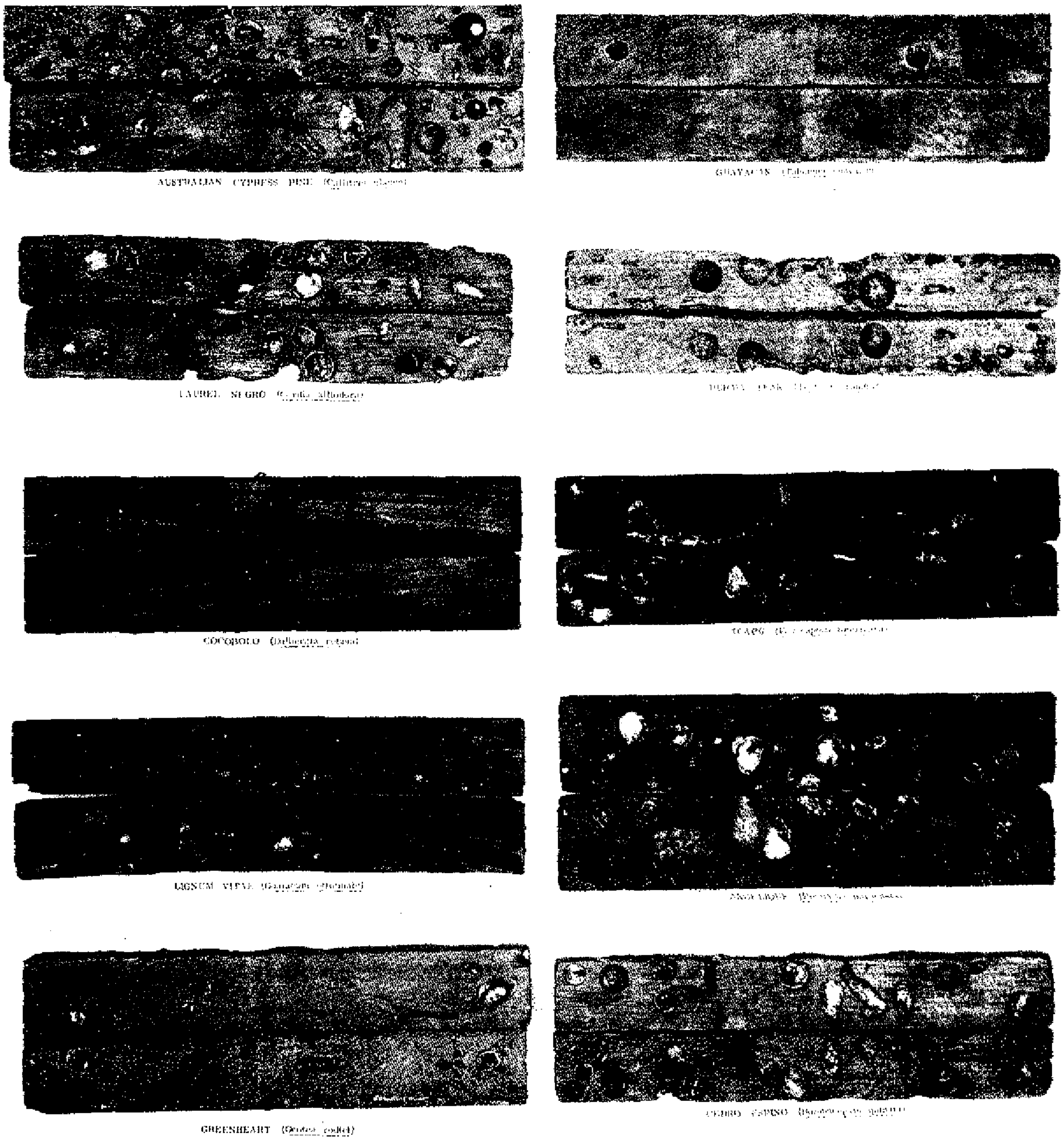


Fig. 10 - Comparison of various special interest natural woods after 51 months of immersion in the very borer-active Caribbean seawater at Coco Solo, C.Z.

samples revealed an average rating of moderate attack by teredos within 14 months, with damage progressing to heavy by 51 months. Pholad attack was even more rapid, with heavy damage occurring within 37 months. Limnoria, however, attacked the wood only lightly.

Cordia alliodora - Laurel Negro

Laurel was one of the most interesting woods in the investigation. It is relatively light, 0.4 to 0.5 air dry specific gravity, but strong for its weight. Wangaard (21) reports air-dry strength properties similar to those of Mahogany. According to Record and Hess (13), *C. alliodora* is a medium-to-large size tree of frequent occurrence throughout most of the American tropics, with useful and attractive wood worthy of greater consideration by consumers everywhere. Allen (14) suggests this as one of the finest native trees for reforestation. In this exposure study, *C. alliodora* was found to be highly resistant to teredo and limnoria in both the Pacific and Caribbean exposures; however, it was not resistant to pholads, Fig. 10. For pressure treating with creosote this was one of the best woods tried as will be set forth in the next report. This combination of fine structural properties, natural resistance to limnoria, and suitability for pressure treatment should provide marine construction timber of very long-lasting potential.

Dalbergia retusa - Cocobolo

The hard, heavy, oily wood of Cocobolo had the highest natural resistance to all borer classes of any of the 115 species tested. It is an important and well-known wood of commerce, generally used for knife handles, objects of turnery, etc. The small size and irregular shape of the tree, however, probably make it unsuitable for marine construction timbers. This exceptionally high resistance is not related to silica, since the silica content of the wood was very low. The oily constituent of the wood is known to be toxic to the skin of some workers, and the reason for the borer resistance may also be related to this substance. The wood is of special interest because of the possibility of identifying the protective component and using it to treat other more suitable and less costly timbers.

Dialium guineense - Tamarindo

Tamarindo is found from Mexico to Brazil and is very common in parts of this range (13). It is a large forest tree attaining heights of 115 ft. The wood is extremely hard, tough, strong, and heavy (air dry specific gravity 0.9 to 1.1). Only one timber sample was obtained for this study; this sample was found to have the highest silica content of any of the 115 woods tested (2.55%). In the Pacific seawater exposures, the wood showed very high resistance to both teredos and pholads through the full 7-1/2-year exposure period. Unfortunately, there was insufficient material to include this species in the followup exposures in the Caribbean, so relative limnoria resistance was not established.

Dicorynia paraensis - Angelique

Angelique is a hard, strong, medium-to-heavy wood that comes from a large forest tree in northern South America. It is one of the best known commercial timbers for use in marine borer infested waters. The wood is high in silica, and its borer resistance is reportedly due to this constituent. In the tropical seawater exposures Angelique was extremely resistant to teredine borers, and it also exhibited relatively high natural resistance to the brackish-water *Psiloteredo*; its resistance to limnoria was also high. Pholads, however, attacked the wood heavily during the longer periods of seawater immersion. The degree of this attack after 51 months in the Caribbean can be seen in Fig. 10. The pholad population, which developed more slowly than that of teredo, eventually became sufficiently dense to cause destruction of the wood. In the Pacific after 5 years of exposure a 4-by-4-in. tide staff of *D. paraensis* at the Naos Island pier was riddled and finally severed, solely by the activity of pholads.

Guajacum officinale - Lignum Vitae

Lignum vitae is one of the best-known woods of tropical America, having been an article of trade since 1508, when it was introduced into Europe for its reported medicinal value. Its major use now is as a self-lubricating bearing material. It is an extremely hard, strong, dense, oily wood. The exposure results with this wood illustrate most strongly the nonrelation between wood density and natural resistance to molluscan marine borers. Lignum vitae was the heaviest wood of the 115 species tested; its air dry specific gravity was 1.23. As can be seen in Fig. 10, after 51 months of exposure in the Caribbean, the samples of the wood were heavily attacked by teredos and moderately by pholads. In the earlier exposures in the Pacific similar results were obtained. On the other hand, it was extremely resistant to crustacean borers; there was no limnoria attack at all during any of the exposures.

Ocotea rodiei - Greenheart

Greenheart is one of the best-known marine construction timbers; it has been used very successfully in some northern temperate latitude installations. In our tropical tests, however, it was found only moderately resistant to teredo, pholads, and limnoria in the ocean, Fig. 10, and it was heavily attacked by *Psiloteredo healdi* in brackish water. Even though Greenheart is an excellent heavy construction timber, it is unsuitable when long-term durability in warm sea- and brackish water is required.

Pouteria Sp's. - Nispero de Monte, Mamecillo

There were two pouteria species in the study - *P. chiricana* and *P. campechiana;* both species have high in silica contents (1.9 and 2.1%). Resistance to teredo was very high for both. *P. campechiana* was one of the two best woods found for resisting the brackish-water teredo. Neither of the pouterias was resistant to limnoria attack, indicating that silica is not a significant factor in limnoria resistance. Edmonson (6) found another species, *P. demerarae,* to also have high teredo resistance. In most woods, borer resistance is specific; in *Pouteria,* however, molluscan borer resistance may be generic.

Tabebuia guayacan - Guayacán

In Panama, Guayacán is a medium-to-large forest tree of occasional-to-frequent occurrence. It has heavy, strong, tough wood of about 1.0 air dry specific gravity, and its physical properties are similar to those of Greenheart, except that its impact strength is considerably higher than that of Greenheart (22). With respect to terrestrial organisms it is one of the most durable woods found in Panama. Of the large forest of trees that was inundated by Lake Gatun more than 50 years ago, only a few sound trees still stand, and most of these are Guayacáns. In these marine studies, too, Guayacán was an excellent wood. It showed high resistance to teredos and limnoria and moderate resistance to pholads. Compared with Greenheart it was slightly better in resisting ocean teredos, appreciably better against limnoria, and slightly more resistant to pholads.

Tectona grandis - Teak

Two Teak logs were included in the study. One was imported by the Panama Canal Company from Burma and the other was from a 15-year-old tree grown in the Canal Zone experimental gardens. The tree grows well in Panama but has not been planted commercially. The wood from the two sources was very similar in appearance and about equal in terrestrial durability. Chemical analyses of the woods showed the Burma Teak to have a high (1.4%) silica content and the Teak from the Canal Zone to have a low (0.01%) silica content. This difference in silica content could be correlated with their resistance to teredine borers; the high-silica wood showed good resistance to ocean teredo, while the locally grown wood did not. The difference was much less apparent in the brackish water where samples from both logs were moderately attacked within 14 months. Neither was there much difference in the relation of silica to resistance to pholads and limnoria. Teak was not highly resistant to either, in most cases reaching "moderate" attack levels by 14 months of immersion. A view of pholad damage in Burma Teak is presented in Fig. 10.

Vouacapoua americana - Acapú

Acapú is a hard, heavy, low-silica wood from Brazil. It was one of the most borer-resistant woods found in a 41-wood exposure study at Kure Beach, N.C. (23). For our tropical exposure studies, the Yale School of Forestry supplied samples from the same log tested at Kure Beach. In the tropical seawater tests of 115 wood species, Acapú ranked about 11th in resistance to ocean teredos and pholads, but it was very high in resistance to limnoria, ranking fourth. It was heavily attacked by the brackish-water *Psiloteredo healdi.*

Southern Pine and Douglas Fir

Southern Pine from the U.S.A. was the major control wood in the investigation, and a large number of samples were exposed. Nicaraguan Pine, *P. caribaea*, a closely related wood, and Douglas Fir were also included. All of these were about equal in their natural resistance (or rather nonresistance) to marine borers; all were heavily attacked by the three different borer classes. Samples at Coco Solo were completely destroyed by the first scheduled removal at 14 months, and additional specimens had to be exposed to evaluate early damage. These coniferous woods seem to be much more susceptible to limnoria attack than any of the other 115 wood species tested. Since limnoria is the borer usually causing failure of pressure-creosoted marine pilings, treatment of timbers having natural limnoria resistance may provide much greater durability than that obtained with these woods.

SUMMARY

1. The Panama Canal Zone waters used for this investigation have proved to be among the most borer-active in the world. From the three exposure sites, two oceans and a brackish-water lake, over 30 species of wood borers have been identified. These waters have provided a very through screening test for the 115 wood species.

2. Damage caused by the three major classes of marine borers, i.e., teredo, pholad, and limnoria, has been evaluated separately. Of these, teredo is the most quickly destructive. Limnoria works rapidly in only a few woods, most notably U.S. coniferous, such as Southern Yellow Pine. Pholad populations developed slowly but eventually damaged almost all of the woods.

3. The brackish-water teredo species, *Psiloteredo healdi*, was generally more destructive than all the 28 ocean borer species combined. Many of the otherwise teredo-resistant woods, such as *O. rodiei* (Greenheart), *T. grandis* (Teak), and *V. americana* (Acapú), were heavily damaged in the lake exposures.

4. No difference in resistance was detectable between the two U.S. (control) woods—Douglas Fir and Southern Yellow Pine. In the natural untreated condition both were highly susceptible to all three classes of borers.

5. The 113 tropical wood species showed great variability in their resistance to the different marine borers. A large percentage (44% in the ocean and 61% in the lake) were destroyed in the first 14 months of exposure. Those surviving the early teredo attack generally succumbed eventually to the pholad, *Martesia*. Before 90 months 96% of the woods had been heavily damaged by one or more species of borer.

6. Wood density does not seem to be a controlling factor in borer resistance except possibly with pholads. Many very dense species were heavily attacked, while some light woods exhibited high resistance. However, hard, dense woods were generally more resistant to all borers than the lighter species.

7. Highly silicated woods were usually effective in resisting ocean teredos, but silica content seemed to have little influence on resistance to pholads and limnoria.

8. Only one wood showed high resistance to all classes of borers in all exposure environments—*Dalbergia retusa* (Cocobolo). Unfortunately the tree is unsuitable for use as timber. However, the high-density, low silica wood seems to be naturally impregnated with an oily substance; extraction and identification of this material may provide very useful information for wood preservation chemists.

9. Many of the woods were selectively resistant to certain species of borers and should be very good for specific installations. Two such woods were *C. alliodora* (Laurel) and *B. quinata* (Cedro Espino). Both are excellent structural woods of medium density that exhibited high resistance to all ocean borers except pholads. In northern temperate waters where pholads are not a problem these woods should be excellent marine materials.

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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 Dr. G. K. Brizicky from Yale; Mrs. Mary F. Southwell of the Index Nominum Genericorum Project at the Smithsonian reviewed all botanical and common names to assure correct listing.

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Table A1
Alphabetical Listing of Woods Studied
Botanical and Common Names

Acabú - see *Zanthoxylum belizense*	Berba - see *Brosimum sp.*
Acapú - see *Vouacapoua americana*	Bogamani - see *Virola koschnyi*
Aguacatillo - see *Phoebe johnstonii*	*Bombacopsis quinata* - Cedro Espino
Ajo - see *Caryocar sp.*	*Bombacopsis sessilis* - Ceibo
Alazano - see *Calycophyllum candidissimum*	Bongassi - see *Lophira procera*
Albarco - see *Cariniana pyriformis*	Bronze Shower - see *Cassia moschata*
Alcarreto - see *Aspidosperma megalocarpon*	*Brosimum sp.* - Berba, Guayabo Blanco
Alcornoque - see *Mora oleifera*	*Bursera simaruba* - Almácigo, Indio Desnudo
Alfaje - see *Trichilia tuberculata*	*Byrsonima crassifolia* - Nance
Algarrobo - see *Hymenaea courbaril*	Cabimo - see *Copaifera aromatica*
Almácigo - see *Bursera simaruba*	Caimito - see *Chrysophyllum cainito*
Almendro - see *Coumarouna oleifera*	*Callitris glauca* - Australian Cypress Pine
Almond - see *Terminalia catappa*	*Calophyllum brasiliense* - María
Amargo-amargo - see *Vatairea sp.*	*Calycophyllum candidissimum* - Alazano, Lemonwood, Lancewood
Amarillo - see *Terminalia amazonia*	Caoba - see *Swietenia macrophylla*
Amarillo de Guayaquil - see *Centrolobium orinocense*	Caraño - see *Trattinickia aspera*
Amarillo Negro - see *Lafoensia punicifolia*	*Carapa slateri* - Cedro Macho, Tangaré
Anacardium excelsum - Espavé	*Carapa sp.* - Cedro Vino
Andira inermis - Cocú	Carbonero de Amunición - see *Colubrina glandulosa*
Angelique - see *Dicorynia paraensis*	*Cariniana pyriformis* - Chibugá, Albarco
Anime - see *Tetragastris panamensis*	Carreto - see *Aspidosperma megalocarpon*
Aspidosperma megalocarpon (probably) - Carreto, Alcarreto	*Caryocar costaricense* - Henené
Astronium graveolens - Zorro, Zorillo, or Ron-ron	*Caryocar sp.* - Ajo
Australian Cypress Pine - see *Callitris glauca*	*Cassia moschata* - Bronze Shower
Avicennia marina - Mangle Salado	Cativo - see *Prioria copaifera*
Azobe - see *Lophira procera*	*Cedrela mexicana* - Cedro Amargo
Bala - see *Lophira procera*	*Cedrela sp.* - Cedro Granadino
Bálsamo - see *Myroxylon balsamum*	Cedro Amargo - see *Cedrela mexicana*
Bambito - see *Nectandra whitei*	Cedro Espino - see *Bombacopsis quinata*
Basra Locus - see *Dicorynia paraensis*	Cedro Granadino - see *Cedrela sp.*
	Cedro Macho - see *Carapa slateri*

(Table continues)

Table A1 (continued)

Cedro Vino - see *Carapa sp.*	*Enterolobium cyclocarpum* - Corotú
Ceibo - see *Bombacopsis sessilis*	*Erythrina glauca* - Gallito
Centrolobium orinocense - Amarillo de Guayaquil	*Eschweilera* (probably) - Guayabo Macho
Cerillo - see *Symphonia globulifera*	Espavé - see *Anacardium excelsum*
Chibugá - see *Cariniana pyriformis*	Gallito - see *Erythrina glauca*
Chlorophora tinctoria - Mora	Gavilán - see *Pentaclethra macroloba*
Chrysophyllum cainito - Caimito, Star Apple	*Genipa americana* - Jagua
Chuchupate - see *Guarea longipetiola*	*Gliricidia sepium* - Bala, Mata Ratón
Coco - see *Lecythis ampla*	Gorogán - see *Virola koschnyi*
Coco - see *Lecythis or Manilkara*	Greenheart - see *Ocotea rodiei*
Cocobolo - see *Dalbergia retusa*	Guácimo - see *Luehea seemannii*
Cocú - see *Andira inermis*	Guaragao - see *Guarea guara*
Colubrina glandulosa - Carbonero de Amunición	*Guajacum officinale* - Lignum Vitae
Conocarpus erectus - Zaragosa	*Guarea longipetiola* - Chuchupate
Copaifera aromatica - Cabimo	*Guarea guara* - Guaragao
Cordia alliodora - Laurel Negro	Guayabo Blanco - see *Brosimum sp.*
Cornus disciflora - Mata Hombro	Guayabo Macho - see *Eschweilera*
Corotú - see *Enterolobium cyclocarpum*	Guayacán - see *Tabebuia guayacan*
Coumarouna oleifera - Almendro	Guayacán Negro - see *Tabebuia chrysantha*
Crillo - see *Minquartia guianensis*	Henené - see *Caryocar costaricense*
Croton panamensis - Sangre	*Hippomane mancinella* - Manzanillo
Cuajado - see *Vitex floridula*	*Hura crepitans* - Nuno
Cutarro - see *Swartzia panamensis*	*Hyeronima alchorneoides* - Pantano
Dalbergia retusa - Cocobolo	*Hymenaea courbaril* - Algarrobo
Dalienze - see *Terminalia myriocarpa*	Iguanillo - see *Lonchocarpus sp.*
Dialium guineense - Tamarindo	Indio Desnudo - see *Bursera simaruba*
Dialyanthera otoba - Miguelario	Insibe - see *Ocotea dendrodaphne*
Dicorynia paraensis - Angelique, Basra Locus	Iron Wood - see *Lophira procera*
Diphysa robinioides - Macano	Jagua - see *Genipa americana*
Douglas Fir - see *Pseudotsuga taxifolia*	Jigua Negra - see *Licaria pittieri*
Ekki - see *Lophira procera*	*Lafoensia punicifolia* - Amarillo Negro
Ensiva - see *Ocotea dendrodaphne*	*Laguncularia racemosa* - Mangle Blanco
	Lancewood - see *Calycophyllum candidissium*
	Laurel Negro - see *Cordia alliodora*

(Table continues)

Table A1 (continued)

Lecythis ampla - Coco	Miguelario - see *Dialyanthera otoba*
Lecythis sp. - Coco	*Minquartia guianensis* - Crillo, Manwood
Lemonwood - see *Calycophyllum candidissimum*	Mora - see *Chlorophora tinctoria*
Licania arborea - Raspa	*Mora oleifera* - Alcornoque
Licaria pittieri - Jigua Negra	*Myroxylon balsamum* - Bálsamo
Lignum Vitae - see *Guajacum officinale*	Nance - see *Byrsonima crassifolia*
Lonchocarpus sp. - Iguanillo	Naranjillo - Unknown genus
Lophira procera - Bongassi, Ekki, Azobe	Naranjito - see *Swartzia simplex*
Luehea seemannii - Guácimo	Native Oak - see *Quercus sp.*
Macano - see *Diphysa robinioides*	Nazareño - see *Peltogyne purpurea*
Macano Blanco - Unknown genus	*Nectandra whitei* - Bambito
Macho - see *Tetrathylacium johansenii*	Nicaraguan Pine - see *Pinus caribaea*
Magnolia sororum - Vaco	Níspero Balata - see *Manilkara bidentata*
Mahogany - see *Swietenia macrophylla*	Níspero de Monte - see *Pouteria chiricana*
Malvecino - see *Sweetia panamensis*	Níspero Zapote - see *Manilkara chicle*
Mamecillo - see *Pouteria campechiana*	Nuno - see *Hura crepitans*
Mancha - see *Virola sebifera*	*Ocotea dendrodaphne* - Ensiva or Insibe
Mangle Blanco - see *Laguncularia racemosa*	*Ocotea rodiei* - Greenheart
Mangle Rojo (Atlantic) - see *Rhizophora mangle*	Palo de Sal - see *Pelliciera rhizophorae*
Mangle Rojo (Pacific) - see *Rhizophora brevistyla*	Panamá - see *Sterculia apetala*
Mangle Salado - see *Avicennia marina*	Pantano - see *Hyeronima alchorneoides*
Manglillo - see *Ternstroemia seemanii*	*Paramachaerium gruberi* - Sangrillo Negro
Manilkara sp. - Coco	*Pelliciera rhizophorae* - Palo de Sal
Manilkara bidentata - Níspero Balata	*Peltogyne purpurea* - Nazareño
Manilkara chicle - Níspero Zapote	*Pentaclethra macroloba* - Gavilán
Manilkara sp. - Rasca	*Phoebe johnstonii* - Aguacatillo
Manwood - see *Minquartia guianensis*	*Pinus caribaea* - Nicaraguan Pine
Manzanillo - see *Hippomane mancinella*	*Pinus sp.* - Southern Yellow Pine
María - see *Calophyllum brasiliense*	*Pithecellobium mangense* - Uña de Gato
Mata Hombro - see *Cornus disciflora*	*Pithecellobium saman* - Rain Tree
Mata Ratón - see *Gliricidia sepium*	*Platymiscium pinnatum* - Quirá
Mayo - see *Vochysia ferruginea*	*Pouteria campechiana* - Mamecillo
	Pouteria chiricana - Níspero de Monte
	Prioria copaifera - Cativo

(Table continues)

Table A1 (continued)

Pseudotsuga taxifolia - Douglas Fir	Teak (Burma) - see *Tectona grandis*
Quercus sp. - Roble de Monte, Native Oak	Teak (Canal Zone grown) - see *Tectona grandis*
Quirá - see *Platymiscium pinnatum*	*Tectona grandis* - Teak (Burma)
Rain Tree - see *Pithecellobium saman*	*Tectona grandis* - Teak (Canal Zone grown)
Rasca - see *Manilkara sp.*	*Terminalia amazonia* - Amarillo
Raspa - see *Licania arborea*	*Terminalia catappa* - Almond
Rhizophora brevistyla - Mangle Rojo (Pacific)	*Terminalia myriocarpa* - Dalienze (Panamanian grown)
Rhizophora mangle - Mangle Rojo (Atlantic)	*Ternstroemia seemannii* - Manglillo
Roble de Monte - see *Quercus sp.*	*Tetragastris panamensis* - Anime
Roble de Sabana - see *Tabebuia pentaphylla*	*Tetrathylacium johansenii* - Macho
Ron-ron - see *Astronium graveolens*	*Trattinickia aspera* - Caraño
Sambogum - see *Symphonia globulifera*	*Trichilia tuberculata* - Alfaje
Sangre - see *Croton panamensis*	Uña de Gato - see *Pithecellobium mangense*
Sangrillo Negro - see *Paramachaerium gruberi*	Vaco - see *Magnolia sororum*
Sigua - Unknown genus	Vasca - Unknown genus
Southern Yellow Pine - see *Pinus sp.*	*Vatairea sp.* (probably) - Amargo-amargo
Star Apple - see *Chrysophyllum cainito*	*Virola koschnyi* - Bogamani, Gorogán
Sterculia apetala - Panamá	*Virola sebifera* - Mancha
Swartzia panamensis - Cutarro	*Vitex floridula* - Cuajado
Swartzia simplex - Naranjito	*Vochysia ferruginea* - Mayo
Sweetia panamensis - Malvecino	*Vouacapoua americana* - Acapú
Swietenia macrophylla - Mahogany, Caoba	*Zanthoxylum belizense* - Acabú
Symphonia globulifera - Sambogum, Cerillo	Zaragosa - see *Conocarpus erectus*
Tabebuia chrysantha - Guayacán Negro	Zorillo - see *Astronium graveolens*
Tabebuia guayacan - Guayacán	Zorro - see *Astronium graveolens*
Tabebuia pentaphylla - Roble de Sabana	UNIDENTIFIED - Macano Blanco
Tamarindo - see *Dialium guianense*	UNIDENTIFIED - Naranjillo
Tangaré - see *Carapa slateri*	UNIDENTIFIED - Sigua
	UNIDENTIFIED - Vasca

Table A2
Marine Borers in Canal Zone Waters*

Miraflores Lake	Pacific Ocean	Caribbean Sea
(Brackish Water)	(Naos Island)	(Coco Solo)
Psiloteredo healdi Bartsch (1931)	*Teredo diegensis* Bartsch (1922)	*Teredo affinis* Deshayes (1863)
T. miraflora Bartsch (1922)	*T. panamensis* Bartsch (1922)	*T. bartschi* Clapp (1923)
Nausitora dryas	*T. trulliformis* Miller (1924)	*T. bensoni* Edmondson (1946)
Bankia gouldi Bartsch (1908)	*Nausitora sp.*	*T. clappi* Bartsch (1923)
	Bankia bipalmulata Lamarck (1801)	*T. dominicensis* Bartsch (1921)
	B. caribbea Clench and Turner (1946)	*T. furcillatus* Miller (1924)
	B. cieba Clench and Turner (1946)	*T. johnsoni* Clapp (1924)
	B. debenhami Iredale (1932)	*T. knoxi* Bartsch (1917)
	B. destructa Clench and Turner (1946)	*T. massa* Jousseaume (1923)
	B. fimbriatula Moll and Roch (1931)	*T. navalis* Linné (1758)
	B. gouldi Bartsch (1908)	*T. parksi* Bartsch (1921)
	B. katherinae Clench and Turner (1946)	*T. pedicellata* Quatrefages (1849)
	B. zeteki Bartsch (1921)	*T. portoricensis* Clapp (1924)
	Limnoria lignorum Rathke	*T. somersi* Clapp (1923)
	Martesia striata	*Nausitora sp.*
		Bankia caribbea Clench and Turner (1946)
		B. cieba Clench and Turner (1946)
		B. fimbriatula Moll and Roch (1931)
		B. fosteri Clench and Turner (1946)
		B. gouldi Bartsch (1908)
		B. katherinae Clench and Turner (1946)
		Limnoria lignorum Rathke
		L. tripunctata Menzies (1951)
		Martesia striata

*Ref. 12.

Table A3
Spectrographic Analyses of Experimental Woods

Generic Name of Wood	Amount of Each Element Present*																					
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Anacardium excelsum	0.26	M-S	VS	VS	M	VW	M	VW	W	VW	-	-	S	-	M-S	W	M-S	W	VW	W	-	-
Andira inermis	2.03	M	VS	VS	W	W	M	-	W	W	W	-	-	tr	M	tr	W	M	M	VW	-	VW
Aspidosperma megalocarpon (prob.)	0.50	M	VS	W-M	W	W	VW	tr	M	W	tr	-	-	-	M	W	W	M	VW	VW	VW	VW
Astronium graveolens	1.20	M	VS	S	W-M	VW	M	tr	W	W	W	-	S	-	S	M	M	M	-	VW	-	-
Avicennia marina	2.05	W	VS	VS	W	W	VS	tr	W	VW	-	-	M	-	M	-	M	W	-	-	-	-
Bombacopsis quinata	5.50	0.07	VS	S	VW	tr	W-M	Ftr	W	tr	W	-	S	-	VW	-	W	VW	-	-	-	-
Bombacopsis sessilis	2.62	S-VS	VS	VS	VW-M	W	W-M	tr	M	W	VW	-	VS	-	M	M	W-M	W	W	tr-VW	VW	W
Brosimum sp.	2.32	W	VS	S	tr-VW	W	M	-	VW	VW	-	-	M	-	M	W	M	W-M	-	-	-	-
Bursera simaruba	1.25	M	M-S	VS	W	W	M-S	VW-M	W-M	W	W	S	VS	VS	W-M	VW	M	M	VW	tr	VW	-
Byrsonima crassifolia	4.74	M	VS	S-VS	W-M	W	S	tr	W	W	-	-	S-VS	-	M	VW	M	M	-	tr	-	-
Callitris glauca	1.10	0.002	VS	VS	VS	M	M	VW	W	VW	tr	-	S	-	M	VW	VW	M	-	VW	-	-
Calophyllum brasiliense	0.59	M	VS	S	M	VW	S	tr-VW	W-M	VW-W	tr	-	M	VW	M	W-M	W	M	-	VW	VW	-
Calycophyllum candidissimum	1.14	0.004	VS	W-M	W	W	W-M	tr	W	VW	-	-	-	-	M	VW	W	W	VW	tr	-	-
Carapa slateri	1.02	M	VS	VS	M	VW	S	W	W-M	VW	-	VW	M	tr	M	M	W	M	tr	tr	-	VW
Carapa sp.	0.80	M-S	VS	S	VW	tr	M	Ftr	W	VW	tr	-	M	tr	W	W	W	W-M	W	tr	-	VW
Cariniana pyriformis	0.77	M-VS	S-VS	S-VS	VW-M	VW-W	M-S	VW	W	W	tr	-	S-VS	Ftr	W-M	VW-W	W-M	W	-	VW	-	W
Caryocar costaricense	1.02	M-S	VS	M-VS	W	VW-W	W-M	tr-VW	W	VW	-	-	W	W	M	W-M	W-M	W	VW	VW	-	-

*VS > 10%, S - 1 to 10%, M - 0.1 to 1%, W - 0.01 to 0.1%, VW - 0.001 to 0.01%, and tr - trace.

(Table continues)

Table A3 (continued)

Generic Name of Wood	Amount of Each Element Present																					
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Caryocar sp.	0.95	M	VS	VS	M	VW	M	tr	M	W	M	-	-	-	M	W	VW	W	VW	W	VW	-
Cassia moschata	1.14	W	VS	M	W	W	W-M	tr	W-M	W	-	-	-	W	M	-	VW	W	-	tr	-	-
Cedrela mexicana	0.50	M-S	VS	S	M	W	M-S	W	M	W	tr	tr	S	VW	M	W	M-S	M	W	W	W	VW
Cedrela sp.	0.68	M-S	VS	VS	M-S	VW-W	M	VW-W	M	W	W	tr	VS	tr	M-S	W-M	M	M	W	W	VW	-
Centrolobium orinocense	0.77	W-M	VS	S	W-M	M	W	VW	W-M	W	-	-	W	-	M	M	W	M	-	tr	VW	-
Chlorophora tinctoria	1.92	0.07	VS	M	W	VW	S	tr	VW	VW	-	-	S	-	M	VW	W	W	-	-	-	-
Chrysophyllum cainito	1.16	0.67	S	S	VW	VW	S	VW	W	W	-	-	S	Ftr	W	VW	M	W	-	-	-	W
Colubrina glandulosa	1.04	M	VS	VS	W	VW	M	tr	M	VW	W	-	W	-	W-M	tr	W	W	-	tr	-	-
Conocarpus erectus	2.22	M	VS	VS	VW	VW	S	tr	W	VW	tr	-	M-S	-	W-M	VW	W	M	-	-	-	-
Copaifera aromatica	1.27	M	VS	S-VS	VW-W	W-M	M-VS	tr	VW	VW-W	-	-	M-S	tr	W-M	VW-W	M	M	tr	-	VW	VW
Cordia alliodora	2.45	0.011	VS	VS	W	VW	W	VW	VW	VW	tr	-	-	-	M	W	-	M	-	tr	-	-
Cornus disciflora	1.95	M	VS	S	S	tr-VS	W-S	tr	W-M	VW	W-M	-	S	-	M	M	W	W	VW	VW	-	-
Coumarouna oleifera	0.71	W-M	VS	VS	W	M	M	tr	W	W	-	-	M	Ftr	W-M	M	-	W-M	-	tr	-	-
Croton panamensis	1.21	M	VS	S-VS	M	W	M-S	VW-W	M	M	tr	tr	VS	-	M	W	M	-	M	tr	-	-
Dalbergia retusa	0.56	0.004	VS	VS	W	W	W	VW	W	W	tr	-	-	tr	M	W	M	M	tr	tr	VW	VW
Dialium guineense	2.80	2.55	S	S	W-M	W	M	-	W-M	M	-	-	W	-	W	-	-	VW	-	tr	-	W
Dialyanthera otoba	1.18	M	VS	S	M	M	VS	VW	M	W	W-M	VS	S	VW	M	W	M	W	VW	W	VW	-
Dicorynia paraensis	0.80	0.72	S	S	M	W	M	W	W	W	VW	-	W	VW	W	-	-	M	W	W	VW	-
Diphysa robinioides	0.64	M	VS	VS	M-S	W	M	VW	M	VW	-	-	M	VW	M	W	M	W	-	W	VW	VW

(Table continues)

Table A3 (continued)

Generic Name of Wood	Amount of Each Element Present																				
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Enterolobium cyclocarpum	0.98	S	VS	M-S	S	W	VS	W	W-M	W	-	VW	VS	VW	M	VW	W	M	W	VW	VW	W
Erythrina glauca	0.26	M-S	S-VS	VS	M	W	VS	W	M	W	M	-	VS	VW	M	W	M	M	VW	W	VW	-
Eschweilera (prob.)	1.48	VS	S-VS	VS	W-S	VW-W	S-VS	tr-VW	W-M	VW	-	VW	S-VS	W	M	W-M	W-M	W-M	VW	M	VW	VW
Genipa americana	0.48	M-S	VS	VS	M-VS	W	W-M	VW	M	W	-	-	S-VS	VW	M	VW	M	W	VW	W-M	VW	-
Gliricidia sepium	1.02	M	VS	VS	W	W	W-M	tr	W	VW	-	-	-	tr	W	W	M	M	VW	tr	-	-
Guajacum officinale	0.74	0.003	VS	VS	M	VW	W	VW	M	W	tr	tr	M	VW	M	W	M	M	W	W	VW	-
Guarea longipetiola	1.32	S	VS	VS	W	VW	M	VW	W	VW	W	-	M	-	M	W	M	M	-	VW	VW	-
Guarea guara	2.94	S-VS	VS	S	W	tr	S	tr	W	W	tr	-	M	Ftr	M	W-M	W	W	-	-	-	-
Hippomane mancinella	2.88	W-M	VS	M-S	W	W	VS	tr	W	VW	W-M	-	M	-	M	-	M	W	-	tr	-	-
Hura crepitans	7.08	M	VS	S	M	W	M	VW	W	VW	VW	-	S	-	M	tr	W	M	VW	VW	-	-
Hyeronyma alchorneoides	1.72	M	VS	VS	M	W	S	VS	W	VW	VW	-	VS	-	M	W	W-M	M	VW	VW	VW	-
Hymenaea courbaril	2.04	W	VS	S	W	M	M	VW	W	W	tr	-	M	-	W	-	W	W	-	Ftr	-	-
Lafoensia punicifolia	0.51	W	VS	VS	W	W	M	tr	W	W	W	-	S	Ftr	M	M	M	M	-	tr	VW	-
Laguncularia racemosa	2.20	M	VS	M-S	M	W	VS	VW	M	VW-W	VW	-	S-VS	VW	M	VW	M	M	M	VW-W	VW	VW
Lecythis ampla	1.10	S	VS	S	M	W	S	VW	M	W	tr	-	VS	tr	W-M	M	M	W-M	tr	tr	-	-
Licania arborea	3.16	VS	VS	S	VW	VW	S	VW	W	W	VW	-	VS	-	W	-	-	W	-	tr	-	-
Licaria pittieri	0.13	M-S	VS	S-VS	M	M-S	M-VS	-	M-S	M	VW	VW	M-VS	W	M	tr-W	M	M	M	W	W	-
Lophira procera	0.32	0.002	VS	VS	M	M-S	M	W	W	W	VW	VW	S	VW	M	VW	W	M	VW	W	W	-

(Table continues)

Table A3 (continued)

Generic Name of Wood	Amount of Each Element Present																					
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Lonchocarpus sp.	0.77	M	VS	S	W	W	M	tr	W	VW	-	-	S	-	M	tr	M	W	-	tr	-	-
Luehea seemannii	2.05	W	VS	S	W	W	W-M	tr	W	VW-W	VW	-	VS	Ftr	M	tr	S	VW	-	-	-	-
Magnolia sororum	1.02	VW	VS	S	W-M	W	M	tr-VW	W	W	VW	-	S-VS	-	M	W-M	W	M	-	VW	VW	VW
Manilkara bidentata	0.51	M-S	VS	VS	M-S	W	S	VW-W	M	W	tr	VW	VS	tr	M	M	W	W	M	W-M	VW-W	W
Manilkara chicle	1.65	W-M	VS	S	W	VW	S	tr	W	VW	VW	-	S	-	M	tr	M	W	-	tr	-	-
Manilkara sp.	0.46	M	VS	VS	W	W-M	S	Ftr	W	VW	-	-	S	tr	W-M	W	VW	W	-	-	-	-
Minquartia guianensis	1.65	M	VS	S	VW-W	W	M-S	-	VW-W	VW	tr	-	M-S	-	M	W	M	M	VW	VW	-	-
Mora oleifera	1.25	M	VS	VS	W	M	S	-	M	W	-	-	S	Ftr	W-M	W	W-M	W	-	-	-	-
Myroxylon balsamum	0.52	M	VS	VS	W	VW	W-M	tr	W	VW	-	-	S	-	M	VW	W	M	tr	tr	-	-
Nectandra whitei	0.20	M-S	S	S-VS	M	M	M-S	VW-W	S	M	M	VW	S	VW	M	M	M	M	VW	tr-VW	tr-VW	M
Ocotea dendrodaphne	0.42	M	VS	S	VW-W	W	M-S	tr	W	W	-	tr	-	VW	M	tr	M	W	M	-	-	-
Ocotea rodiei	0.20	0.12	S-VS	VS	M	M-S	S-VS	W	W	W	VW	W	M	W	M	VW	-	M	-	W	W	-
Paramachaerium gruberi	1.85	M	VS	S	W-M	VW-W	M-S	VW	M	M	VW	-	S-VS	-	M	W	W	M	-	tr	-	-
Pelliciera rhizophorae	2.18	M	VS	VS	M	W	VS	tr	W	W	-	-	S	tr	M	-	M	M	W	VW	-	-
Peltogyne purpurea	0.66	M	VS	VS	M	VW	S	tr	W-M	W	tr	-	S	-	M	W	W	M	W	VW	W	-
Pentaclethra macroloba	0.20	S	VS	VS	M	W	VS	-	W	W	VW	VW	M	VW	M	VW	M	M	W	W	VW	-
Phoebe johnstonii	1.13	W	VS	S	S	M	S	VW	M	W	W	-	S	Ftr	W-M	W	M	W	tr	tr	VW	-
Pinus caribaea	0.25	M	VS	VS	M	M	M	W	W	VW	tr	VW	M	tr	W	VW	VW	M	VW	W	W	-
Pinus sp.	0.34	M	VS	VS	M	M-S	S	W	W	VW	VW	VW	S	VW	W	W	W	M	VW	W	W	-

(Table continues)

Table A3 (continued)

Generic Name of Wood	Amount of Each Element Present																					
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Pithecellobium mangense	1.68	M	VS	M-S	M	W	M	VW	M	VW	-	-	S	-	M	W	M	M	VW	VW	-	-
Pithecellobium saman	0.66	0.003	S	M	M	W	S	tr	W	W	-	-	S	-	M	VW	W	M	-	VW	-	-
Platymiscium pinnatum	0.90	0.003	VS	S	M	W	M	tr	W	W	-	-	S	-	M	W	M	M	VW	VW	VW	-
Pouteria campechiana	2.32	VS	VS	S	W	W	M	Ftr	M	VW	-	-	S	-	W	-	W	W	-	-	-	W
Pouteria chiricana	2.76	2.07	VS	S	W	W	S	-	W	W	VW	-	VS	tr	M-S	W	W	VW	-	tr	-	W
Prioria copaifera	1.67	W-M	S-VS	VS	tr-W	W	VS	VW	M	M	tr	-	S	-	M	VW-M	M	M	-	-	tr	-
Pseudotsuga taxifolia	0.20	M-S	VS	VS	M	M	M	W	M	W	tr	VS	-	tr	M	M	W	M	-	tr	VW	-
Quercus sp.	0.45	M	VS	S	W-M	W	M-S	VW	W-M	W	VW	-	S	tr	M	W	M	W	VW	VW	-	-
Rhizophora brevistyla	0.82	M	VS	S	M	M	VS	VW	M	VW	tr	-	W	VW	M	VW	W	W	-	W	VW	VW
Rhizophora mangle	1.88	M	VS	S	M	W	VS	tr	W	VW	tr	-	M	-	M	-	M	W	-	tr	-	-
Sterculia apetala	5.12	M	VS	VS	M-S	W	M	VW	M	W	VW	-	VS	VW	M	W	M	M	VW	W	-	-
Swartzia panamensis	0.65	M	VS	VS	M	VW-W	S-VS	tr	M	W-M	tr	-	S-VS	-	W	W	W-M	W-M	VW	VW	-	VW
Swartzia simplex	2.02	M	VS	S	VW	W	S	tr	M	VW	-	-	S	-	S	tr	M	W	-	-	-	-
Sweetia panamensis	0.24	S	VS	S	M-S	W	S	W	M-S	W	VW	VW	S	W	M	W	S	W	W	VW	W	VW
Swietenia macrophylla	1.40	M	VS	M	M	VW	W	VW	W	VW	-	-	W	VW	M	W	M	W	-	W	VW	-
Symphonia globulifera	0.64	M	VS	S-VS	M-S	W	S	W	M	M	W	tr	S	VW	M	VW	W-M	M	VW	VW	VW	-
Tabebuia chrysantha	0.52	M	VS	VS	M	W-M	W	tr	W	VW	-	VW	W	-	M	W	W	W	-	W	VW	-
Tabebuia guayacan	1.60	0.007	VS	VS	W	W-M	M	tr	W	W	-	VW	M	-	M	VW	W	W	-	VW	VW	-

(Table continues)

Table A3 (continued)

Generic Name of Wood	Amount of Each Element Present																			
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Tabebuia pentaphylla	0.82	M	VS	S	M	W	S	W	M	M	tr	tr	S-VS	tr	M	VS	M	VW	tr	tr	-	-
Tectona grandis (Panama)	0.46	0.01	VS	VS	M	VW	S	VW	M	VW	VW	-	-	-	W-M	W	M	W	-	VW	-	-
Tectona grandis (Burma)	2.00	1.44	S-VS	VS	V	VW	M	VW	W	VW	tr	-	W	tr	W	VW	M	M	-	VW	VW	-
Terminalia amazonia	0.90	M	VS	VS	W-M	W-M	S	VW	VW	VW	tr	-	M	-	M	W	W	M	tr	tr	VW	VW
Terminalia catappa	1.54	M	VS	S-VS	M	VW	VS	VW	W	W	VW	-	VS	-	M	-	M	M	-	W	VW	-
Terminalia myriocarpa	1.92	M	VS	VS	W	VW	S	VW	M	VW	VW	-	S	-	W-M	W	M	W	-	-	-	-
Ternstroemia seemannii	0.90	M	VS	VS	S	VW	VS	VW	M	W	-	-	VS	tr	M	W	M	M	VW	VW	tr	-
Tetragastris panamensis	0.52	M	VS	VS	M	M	M	VW	W	VW	-	-	S	VW	W	tr	M	M	-	VW	VW	-
Tetrathylacium johansenii	3.84	W	VS	S-VS	W	W	M	tr	VW	VW	-	-	S	-	M	M	M	M	-	-	-	-
Trattinickia aspera	0.95	S-VS	VS	VS	W-M	W	M-S	W	W-M	W	W-M	tr	VS	tr	M	VW-W	M	VW-W	VW	W	VW	VW
Trichilia tuberculata	2.08	VS	VS	S	W-M	W	S	-	M	W	W	-	VS	tr	M-S	M	W	W	-	VW	-	W
Vatairea sp.	0.62	W-S	VS	VS	W-M	W-M	M-S	VS-M	W-S	W	-	-	S	-	M	M	W	M	-	W	VW	W
Virola koschnyi	1.66	M	VS	VS	M	W	S	W	W-M	VW	W-M	VW	VS	VW	M	W	M	M	VW	VW	VW	-
Virola sebifera	0.36	M-S	VS	VS	M	M	S	W	M	W	VW	VW	VS	VW	M	VW	M	M	VW	W	W	-
Vitex floridula	1.55	M	VS	VS	tr-VW	W	S	-	M	W	W	-	VS	-	M	tr-W	M-S	W-M	VW	-	-	-
Vochysia ferruginea	0.92	M-S	W-M	M-S	S-VS	W-M	M	VW	W-M	W	VW	-	W-M	-	W	VW	VW-W	M	-	-	VW	-
Vouacapoua americana	0.32	0.002	VS	VS	M	M	S-VS	W	W	W	VW	-	VS	tr	M	W	M	M	VW	W	W	-
Zanthoxylum belizense	1.00	M	VS	VS	VW	W	M	VW	W	VW	tr	-	S	tr	W	W	M	M	W	-	-	-

(Table continues)

Table A3 (continued)

Generic Name of Wood	Amount of Each Element Present																					
	% Ash	Si	Ca	Mg	Al	Mn	Na	Pb	Fe	Cu	Mo	Sn	K	Ni	Sr	Ba	P	B	Cr	Ti	Zn	Li
Macano Blanco*	1.50	W	VS	M	W	VW	M	tr	W	VW	W-M	-	W	-	M	VW	-	M	-	VW	-	-
Vasca*	1.28	VS	VS	VS	M	W	S-VS	VW-W	W	VW	-	-	S-VS	VW	M	VW	M	M	-	VW	VW	VW
Sigua*	0.40	M	VS	S-VS	M	W	S	W	M	M	M	tr	S-VS	tr	M	W	M	M	tr	VW	tr	-
Naranjillo*	0.80	M	VS	VS	W	VW	S	VW	W	W	tr	-	S	-	M	M	M	M	-	VW	VW	-

*Common name; generic name in doubt.