United States Department of Agriculture

Research Opportunities in the Tropics

Summary of 2019 Evaluation of Test Sites in Panama and Suriname

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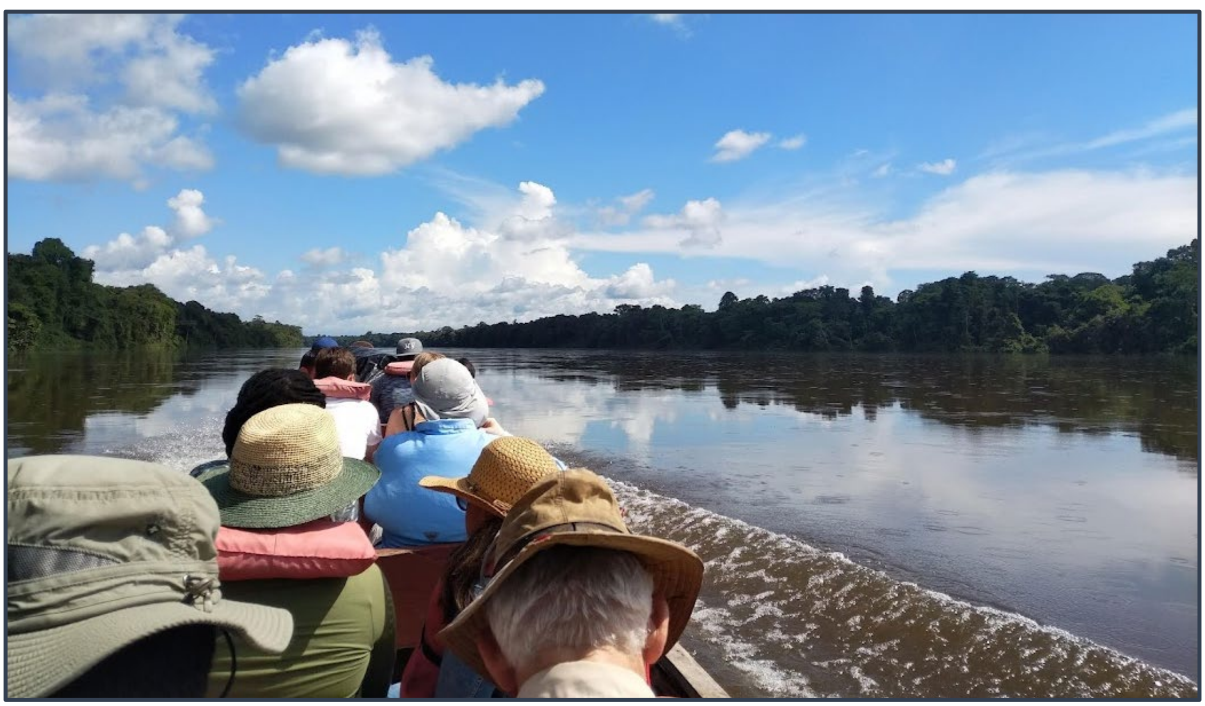

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Abstract

This report highlights the benefits of tropical research in wood durability, preservation, and related fields. The Forest Products Laboratory (FPL) has a long tradition of conducting tests in the tropics around the world and recognizes the benefits they present. Research needs are also discussed, and research partners are identified. The appendixes summarize activities during the 2019 research summit in Panama and Suriname in which FPL and Michigan Technological University (MTU) participated. In late 2017, Department of Defense (DOD) contacted FPL and MTU to assist in durability evaluations of military trailer decks operating in tropical environments around the world. As part of this collaborative partnership with TRAX International, the Tropic Regions Test Center, and DOD, FPL and MTU participated in a two-week visit to field test sites in Panama and Suriname. An overview and discussion of general findings are presented.

Keywords: Tropical testing, forest products, defense, tropical termites, wood preservation

Cover: FPL researchers and collaborators traveling via wooden longboats to Central Suriname Nature Reserve to make structural assessments of timber-framed pavilion located on the Coppename River as part of the two-week technical visit to Panama and Suriname. (Photo: Grant Kirker, FPL)

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Introduction

The tropics represent 40% of the earth's landmass and are home to roughly the same percentage of its human population (Hutchinson 1946). Tropical ecosystems are generally classified as those directly bordering the earth's equator and can be further delineated as those occurring between the Tropic of Cancer (23.43673° N) and the Tropic of Capricorn (23.43673° S).

In tropical climates, the average temperature is 18 °C (64.4 °F) or higher at all times during the year, and the monthly rainfall exceeds 60 mm (2.4 in.). These climates are divided into three types of region according to the Köppen climate classification: rainforest, monsoon, and wet and dry climate/savanna (Beck et al. 2018). These three climate classifications encompass the areas discussed in this report, but the temperature and rainfall at the sites described within this report exceed or, in the case of rainfall, greatly exceed the baseline values. Sherman (formerly U.S. Army Fort Sherman), near the Caribbean North entrance of the Panama Canal, is considered tropical rainforest and receives 3,300 mm (130 in.) of rainfall annually (Harding 2006). Paramaribo, the capital of Suriname, is also in a tropical rainforest classification region and receives approximately 2,200 (87 in.) of annual rainfall (Delvoye et al. 2018). The rain forests in these regions are composed of dense, old-growth forests with double or triple canopies that block sunlight and retain moisture from frequent, heavy rainfalls. Humidity varies between 95% and 100%, and a constant mean temperature of 23.9 °C (75 °F) persist at all hours continually throughout the year. Other regions, such as grasslands with grasses ranging from short to 6 m (20 ft) tall, coastlines, and mangrove swamps have year-round temperatures between 27 and 35 °C (80 and 95 °F) and relative humidity (RH) between 80% and 100%. As an environment for testing wood and wood-based materials, the tropics represent environments of high deterioration hazard with the most extremely challenging conditions for exterior exposure (that is, wood decays quickly and extensively). The greatest natural enemies of wood (water, fungi, and insects) are all hyper-prevalent, so wood exposed in this environment must be either extremely durable (owing to the presence of heartwood extractives) or pressure-treated with wood preservatives to slow the progression of rot and insect damage. Wood testing in the tropics has been conducted in the Panama Canal Zone since the mid-1920s, and several Forest Products Laboratory (FPL) researchers have contributed to that body of knowledge (Kirker et al. 2016). This current collaborative effort builds on FPL's historic efforts to properly understand wood performance in the tropics.

Current Project Strategic Goals

Wood Durability and Protection

The hardwood Apitong (*Dipterocarpus* spp.), also called Keruing, has been used nearly exclusively for decking on U.S. Army tactical trailers for some years. Apitong is an East Asian sourced tropical rainforest hardwood. The

International Union for Conservation of Nature (IUCN) Red List has declared 40 total Apitong species as “Critically Endangered” and “Endangered.” For the entire U.S Department of Defense (DoD), Apitong is the only known internationally recognized IUCN Red List “Endangered” and “Critically Endangered” species actively harvested for supply use. In response to this situation, the Tank Automotive and Armaments Command (TACOM) Commander directed a transition via attrition to sustainably sourced, nonlisted hardwood species. The intention is to address environmental and ethical compliance and to proactively manage Apitong’s obsolescence while mitigating potential supply and readiness issues. Leading authorities were consulted at FPL and Michigan Technological University (MTU) College of Forest Resources and Environmental Science, Wood Protection Group (CFRES-WPG) regarding a satisfactory cost-effective and sustainable replacement. FPL and MTU initiated a developmental study on biodeterioration enhancement treatments of cost-effective and widely available domestic hardwood species that have sufficient mechanical properties for trailer decking.

This effort includes testing the durability of enhanced domestic hardwoods compared with Apitong in real environments of high deterioration hazard. The specific objectives are to develop and validate sustainable tactical wood domestic hardwood lumber prototypes in order to provide a cost-effective, resilient, and high-readiness-level alternative to critically endangered Apitong. The performance of top candidate hardwood materials selected from a previous study will be evaluated at MTU-CFRES-WPG field sites in Hawaii and Louisiana and two of the Tropic Regions Test Center (TRTC) field sites in Panama and Suriname using standard American Wood Protection Association (AWPA) field tests. The joint research project, led by Dr. Xinfeng Xie of MTU, includes the following major tasks:

- Pressure treatment of test specimens of selected domestic hardwoods and commercial trailer decking boards with EPA registered environmentally friendly wood preservatives.
- Field installation and evaluation of combinations of the hardwoods and the preservatives for above ground performance (AWPA E16), ground proximity decay (AWPA E18), and ground proximity termite (AWPA E26) tests.
- Installation and evaluation of full-size decking on the trailer platforms that simulate high usage tactical trailers in tropical environments.
- Provide technical information that is critical to the implementation of enhanced domestic hardwoods in US Army trailer floorboard applications.

Nondestructive Testing and Evaluation of Wood

In conjunction with the trailer decking demonstration project, both laboratory and field studies have been initiated to develop other nondestructive testing and evaluation protocols:

- Assessing the physical and mechanical properties of hardwood boards for trailer decking applications
- Assessing deterioration levels of treated wood specimens installed at TRTC testing sites in Panama and Suriname during the standard AWPA field tests
- Inspecting the physical conditions (decay, insect damage) and mechanical performance of trailer deck platforms that are exposed to the tropical jungle environment in Suriname

Wear assessment of U.S. hardwoods for bridge decking and truck flooring

Wear resistance is considered to be an important property for wood and wood products in many applications. It is particularly important in trailer decking applications where heavy equipment is frequently loaded and unloaded. Hardwood boards used in such applications require good abrasion resistance and resilience—the ability to absorb and recover from impact or shock loading. FPL, Mississippi State University (MSU), and the U.S. Army Ground Vehicle Systems Center (GVSC) recently initiated a study to investigate wear resistance of some domestic hardwood species for potential use in bridge decking and truck and trailer flooring applications. In this research, six U.S. hardwood species will be evaluated—ash, hard maple, hickory, red oak, sweetgum, and white oak. Apitong will be included as a baseline reference for comparison. Contemporary wear (abrasion resistance) as well as Janka hardness characteristics for these species will be determined and compared with existing data, which may be 80 to 100 years old, and with tropical species. This information will help improve the use and application of U.S. hardwoods in severe-exposure exterior decking and trailer applications. Improving the use of U.S. hardwoods in these applications will create and enhance domestic markets for domestic hardwood species.

Abrasion Testing of Durability-Enhanced Domestic Hardwood Trailer Decking Products on Trailer Frame Platforms in an Extreme Tropical Environment

An ongoing MTU-CFRES-WPG test program at TRTC Afobaka Suriname is comparing durability of domestic hardwood decking options with an Apitong baseline. The test platforms are 6 by 11 ft with different decking types installed on each half (Table 1). Four types of decking fasteners (galvanized, casehardened galvanized, heat-treated and wax-coated, and stainless steel self-tapping screws) are also being tested for corrosion and holding performance. Initially, the platforms were subjected to 100 cycles of mechanical abrasion using a steel-tracked excavator (Fig. 1). Following the abrasion cycles, 4- by 2-ft water-saturated commodity-crate-grade untreated plywood panels were installed on platform centers with noncoated and nongalvanized alternating 3-in. #8 steel drywall screws and

Table 1—Types of decking boards abrasion tested

Type	Species	Description
1	Mixed oak	HAVCO, 11 ft, no coating, untreated
2	Mixed oak	HAVCO, 11 ft, no coating, treated
3	Mixed oak	HAVCO, 11 ft, top and bottom coating, treated
4	Mixed oak	HAVCO, 11 ft, reinforced bottom, treated
5	White oak	RAD, 12 ft, bottom coating, treated
6	White oak	RAD, 12 ft, no coating, treated
7	Red oak	RAD, 12 ft, no coating, treated
8	Sugar maple	Finger jointed, 11 ft, treated
9	Apitong	Solid lumber, untreated

[a] HAVCO—HAVCO, Scott City, Missouri; RAD—RAD Wood Products, Nescopeck, Pennsylvania.

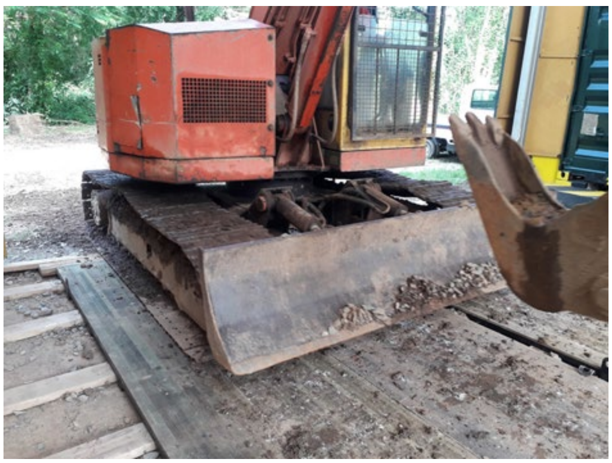

Figure 1—Cyclic abrasion testing with steel tracked excavator on test platforms (photo from TRTC).

3-in. 10d steel framing nails driven through the entire plywood plus deck thickness. The fasteners compromise the deck boards and the plywood creates high-moisture locations, both of which will facilitate more aggressive and accelerated fungal and insect attacks. The decking platforms are currently being subjected to accelerated biological degradation jungle exposure and monitored photographically at monthly intervals. At the one-year exposure interval, the platforms will be evaluated and subjected to three assessments: (1) biological degradation subjective visual inspection by MTU experts, (2) surface density measurements of decking boards with a Pilodyn spring penetrator meter, and (3) fatigue resistance of the platforms via 500 load cycles with an electric solid-tire forklift (for concentrated point loading). After the first-year evaluation, the platforms will undergo at least an additional year of extreme Amazonian environmental exposure. Throughout testing, fasteners will be inspected for corrosion, fracture, holding ability, bored hole elongation, and other damage. This testing will determine and validate the best future Army tactical trailer floorboard systems that are; sustainable, durable, and biodeterioration resistant.

Benefits of Tropical Testing Compared with Subtropical and Temperate Regions

FPL's decades of tropical testing was reviewed by Kirker et al. (2016). These tropical climates provide an ideal environment for accelerated and long-term field tests because of their abundance of biodeteriogens (such as termites and fungi), massive amounts of rainfall, and extensive weathering potential. Early stake tests in the 1930s and 1940s, performed in the Panama Canal Zone, were used to evaluate early preservative chemistries, some of which are still in use today. A drastic difference was noted in the performance of nondurable woods, but even preservative-treated woods failed more rapidly at the Panama test site, suggesting that these sites present a more severe environmental exposure than is commonly encountered in the United States for even some of the most efficacious wood preservatives ever developed. Aboveground exposure in this area is difficult to assess for decay because termite pressure is so severe—samples usually succumb to total destruction by termite attack before decay progression can be properly assessed. Methods to exclude arthropods can be employed to overcome this difficulty (Ulyshen and Wagner 2013). In addition to the accelerated field testing, full-size commodity testing of utility poles and agricultural posts conducted in Guam, Puerto Rico, and Hawaii have yielded valuable data on what improvements are required to current utility pole and post preservation methods in order to achieve suitable service life expectations in tropical biomes. An important point discussed in the review paper by Kirker et al. (2016) is the influence of local effects, which can vary considerably in both temperate and tropical climates. Overstory, soil characteristics, and predominant fauna are all factors that influence local biodeterioration rates. Having multiple sites located within tropical climates presents an ideal situation to study these effects.

Available Moisture

Panama is bordered by two oceans. The Pacific coast receives 1,140 to 2,290 mm (45 to 90 in.) of rainfall per year; the Caribbean coast (facing the Atlantic) receives1,500 to 3,550 mm (60 to 140 in.) per year. This difference is mainly due to the Tabasáro mountains, which face the rain-bearing trade winds. In addition to the oceans, Panama is also traversed by numerous short rivers and surface waters, which supply ample excess moisture. The climate of Panama is described as tropical, with lush forests and tropical savannahs. The calculated Scheffer index for Panama City, Panama, is approximately 200, approximately twice that of Gainesville, Florida. These are fairly crude measurements for the area, but much more detailed information collected and curated by the Smithsonian Tropical Research Institute (STRI) focuses heavily on the Barro Colorado Island (in Gatun Lake) and Gamboa areas (Kellogg 1929). The mean rainfall in Barro Colorado has fluctuated over the past 100 years, but most recent estimates range around 2,400 mm (95 in.) annually (STRI [no date]).

Suriname is also considered a tropical climate. Suriname is bordered by the Atlantic Ocean, and its central interior is composed mostly of pristine rainforests (Delvoye et al. 2018). Like Panama, Suriname has numerous interior rivers and lakes. The coastal area has both major and minor wet and dry seasons and also receives about 2,400 mm (95 in.) of rain annually. The canopied jungle maintains 95% to 100% RH and a near-constant 29.4 °C (85 °F) temperature. The 10-year calculated Scheffer index for this region is 274, which is comparable to San Juan, Puerto Rico.

Fungal Diversity

Fungal communities are immensely important in tropical ecosystems. They are key drivers of litter decomposition and nutrient cycling (Purahong et al. 2016, Braga-Neto et al. 2016). The fungal diversity of Panama has been surveyed and studied extensively by STRI and other prominent research institutions, but most recent assessments estimate a much higher biodiversity than is reported (Piepenbring et al. 2012). The most recent surveys of decay fungi on Barro Colorado Island (BCI) noted that fungal species outnumber tree species in the area and that fungal community composition was potentially a greater influence on diversity and abundance than host substrate (Nottingham et al. 2018). Proper characterization of fungal communities in tropical locales is often confounded by spatial and temporal patterns of fungal communities and staggered nutrient fluxes influenced by frequent wetting and drying events (Lodge 1993, 1997; Lodge et al. 1994). A 2006 survey of fungal records for Panama reported more than 1,800 fungal species in 646 genera. This dataset includes a total of 252 records for fungi belonging to the order Polyporales, which include many of the true wood decay fungi (Gilbert et al. 2002, Piepenbring 2007). This study also indicates that only about 3% of the true fungal diversity of this region has been documented, leaving much room for exciting new discoveries. Similarly, Suriname represents a potential wealth of undiscovered and undescribed fungal species. Recent fungal surveys of neighboring French Guiana's fungal population yielded 5,219 basidiomycete fungi, which included 989 members of the order Polyporales (Jaouen et al. 2019), and French Guiana and Suriname have many similarities in overall geography and land use. In addition to the interior rainforest, Suriname is also home to vast mangrove swamps, which are also a tremendous source of wood-degrading fungi that have not been fully explored (Sahoo and Dhal 2009). FPL researchers deployed untreated southern pine field stakes during the site visit to Central Suriname Nature Reserve located on the Coppename River (see App. B for details) that will be used to collect baseline data on the presence of fungi that can colonize and ultimately degrade southern pine, which constitutes a majority of building construction products in the United States. These stakes were placed at 1-km intervals along a wooded transect off the trail leading to the summit of Voltzberg Dome.

Insect Diversity (Particularly Termites)

Both regions have a rich history of entomological investigation. Panama's history of entomological investigation began during the construction of the Panama Canal (Freeman 2011, Henson 2016). Mosquito and fly control were key concerns because they presented a lethal threat to workers in the Canal Zone. In the 1920s, USDA scientist were stationed in Panama and did extensive work cataloging insect pests in this area, especially termites (Henson 2016; Snyder 1923; Snyder and Zetek 1924, 1934). The U.S. military and FPL both conducted extensive testing of wood products in tropical exposure to determine resistance of chemicals (Snyder and Zetek 1924, Snyder 1927, Hunt and Snyder 1930, Beal 1981) and naturally durable wood species (Bultman and Southwell 1976) to the aggressive tropical biota. Panama has numerous indigenous termite species, including *Coptotermes niger*, *Heterotermes convexinotarus*, *Heterotermes tenuis*, *Nasutitermes corniger*, and *Microcerotermes arboreus* (Beal 1981), as well as invasive *Coptotermes formosanus* termites.

Suriname was the subject of the pioneering work of Maria Sibylla Merian (Paravisini-Gebert 2012), who is credited as the world's first field ecologist. Suriname is home to termite species *Cryptotermes havilandi* and *Nasutitermes corniger* based on recent assessments (Evans et al. 2013), but the occurrence of more species, especially in the interior regions, seems almost inevitable.

Potential Partners

The exploratory trip to Panama and Suriname helped to identify several institutions that could be potential research partners.

Smithsonian Tropical Research Institute (STRI)

The Smithsonian Tropical Research Institute was founded with the purpose of increasing and sharing knowledge about the past, present, and future of tropical ecosystems and their relevance to human welfare. This work began in Panama in 1910, when the Smithsonian led one of the world's first major environmental impact studies, which surveyed and catalogued the flora and fauna of the lowland tropical forests that would be flooded with the creation of the Panama Canal. A century later, the Smithsonian in Panama is a standard-setting global platform for groundbreaking research on tropical forests and marine ecosystems and their astounding biodiversity. Today, STRI employs 40 staff scientists and hosts 1,400 scientific visitors every year, from undergraduates and interns to postdoctoral investigators and tenured research associates. Together, they collaborate on 350 ongoing research projects and publish more than 400 peer-reviewed articles in scientific journals every year. The research is shared widely around the global scientific community, reaches policymakers in Panama, the United

States, and beyond, receives media coverage around the globe, and is the foundation of an outreach and training program that reaches hundreds of teachers and tens of thousands of students every year.

University of Panama

The University of Panama (Universidad de Panamá) was founded on October 7, 1935, with a student body of 175 in the fields of education, commerce, natural sciences, pharmacy, pre-engineering, and law. As of 2008, it maintained a student body of 74,059 distributed in 228 buildings around the country. The University of Panama, founded under the administration of the President of the Republic, Dr. Harmodio Arias Madrid, by its first President, Dr. Octavio Méndez Pereira, is a state institution focused on quality, independent education. In meetings with the Director of Research, Dr. Janzel Villalaz, and Vice-Rector Guitierrez, it was clear that the interests of the University of Panama and CFRES overlap, given the breadth of research in CFRES and the University's work on biodiversity and conservation. The visiting group was able to see the extensive plant and wood collection and hear about the mycological collection that was established after a visit to MTU-CFRES-WPG in 2018.

CELOS, Anton de Kom University, Paramaribo, Suriname

CELOS is the Center for Agricultural Research in Suriname and is part of the Anton de Kom University of Suriname. It was established as part of the agricultural college of Wageningen, the Netherlands, in 1967 but has been a part of the University since 1975. CELOS includes a forest management department headed by Dr. Verginia Wortel and is interested in developing partnerships in education and research with other institutions. Opportunities for student exchanges between CELOS and CFRES were discussed, including the potential to develop a memorandum of understanding (MOU) and to determine how academic credit would be transferred. CELOS conducts research, including work with various nongovernmental organizations (NGOs), with interests in finding solutions to community issues relating to natural resources in Suriname, including restoration of degraded savannah, sustainable forest management, agroforestry, and REDD+ projects. It also offers an Master of Science degree in Sustainable Management of Natural Resources, managed by Riad Nurmohamed. The University and CELOS has land concessions available for research, including one that was visited by the group in the northern Amazon that included research plots dating back to 1965.

World Wildlife Fund

While in Panama, the visiting group was able to meet with Mr. Gomes, a representative of the World Wildlife Fund (WWF) in Suriname. He sees significant opportunities for collaboration with MTU-CFRES-WPG in forestry and wildlife and shared his perspectives on land management in Suriname. The forestry sector in Suriname has shifted away from being well-managed sustainable systems with a 40-year cycle. In the past six years, this has been challenged by a desire for more people to earn income from forestry. The situation has become serious as increasing land concessions are being granted in places where conflicts are developing. These changes have reduced sustainability, and infrastructure to access the hinterland has greatly increased. Monitoring, enforcement, and science related to land management, especially in forested areas, are lacking. One challenge is to ensure sustainability while meeting national economic contributions at a level that satisfies legislators. The state forestry institute is strong but needs more involvement in the decision-making process.

The WWF would like to invest in getting better estimates of amounts and locations of sustainable and nonsustainable forestry and sees itself having an observatory function. In particular, the forest/nonforest classification system that is used misses what happens below the canopy. Infrastructure also needs further development to assess changes over recent years in land use planning, policy, and sustainability.

The forests of Suriname, which occupy 93% to 94% of the land area, are falsely assumed to have undisturbed wildlife. For example, infrastructure relating to forestry operations is influencing wildlife conflicts as jaguars and pumas are pushed out of their habitat and closer to people. Baseline datasets for almost all wildlife species are lacking, and this is a significant concern. Collaboration with Universities and research institutes to develop baselines for key species, including jaguar and puma, is needed to develop understanding of these species from a policy and conservation viewpoint. The highest wildlife priority is jaguars and big cats in general. Illegal hunting pressure on jaguars is increasing because of the market for their parts (such as organs, glands, hide) in China. Programs to create baselines and assist in policy development are needed.

Tropic Regions Test Center

The Tropic Regions Test Center (TRTC) mission is to plan and conduct tropic environmental development tests on a wide variety of military electronic systems, materials, weapons, and equipment of all conceivable types, sizes, configurations, and uses. Past armed conflicts in tropical and desert regions have shown that the environmental conditions can wreak havoc on military tools and equipment. The TRTC provides invaluable estimates of real-world exposure of past, present, and future military equipment to understand the rigors of field exposure and how to ensure durability of material and combat readiness when they are needed. Located as part of the Yuma Proving Ground in Yuma, Arizona, the TRTC also has established field test sites in Hawaii, Panama, Suriname, and Australia that are used for routine and sometimes nonroutine testing of personal protective equipment (PPE), fabrics, metals, and other materials on up to full-size vehicular systems and weaponry.

U.S. Army Ground Vehicle Systems Center (GVSC)

The U.S. Army Combat Capabilities Development Command (DEVCOM) Ground Vehicle Systems Center (GVSC) (formerly Tank Automotive Research, Development and Engineering Center (TARDEC)), located in Warren, Michigan, is the premier U.S. Armed Forces research and development facility for advanced technology in ground systems. The CCDC is a major subordinate command of the U.S. Army Futures Command. GVSC shares its facilities at the Detroit Arsenal with the Tank-Automotive and Armaments Command Life Cycle Management Command (TACOM LCMC). Current technology focus areas include Tactical Vehicle and Trailer Sustainment, Ground Vehicle Power and Mobility (GVPM), Ground System Survivability, and Force Protection.

Discussion

This visit to tropical test sites in Panama and Suriname and the valuable exchanges that took place highlighted several potential research and educational opportunities in the tropics.

- *Exploratory research on tropical fungi and insects that attack wood in the tropics*—Although there are published records of insect and fungal biodiversity in this region, how these tropical species interact with treated wood is completely unknown and may result in discovery of fauna able to overcome and damage preservative-treated wood.
    - *Accelerated decay and termite testing to estimate service life of current and pending wood protectants in a severe climate*—The tropical conditions in these climates is ideal for accelerated and worst-case-scenario testing of naturally durable and preservative-treated wood. FPL has conducted tropical testing throughout its 110-year history and is well equipped to advise and conduct future testing. Building partnerships with TRTC and associated partners would facilitate much-needed technology transfer to help improve wood structural conditions in the area.
    - *Tropical decay succession on treated wood*—Fungal community structure in tropical climates is not fully understood but has been the subject of decades of research. The effects of these microbes on preservative-treated wood are relatively unstudied in this environment and represent an opportunity to screen present and future preservative chemistries against aggressive fungal pressure in a harsh climate.
    - *Surveying tropical fungi for copper and metal tolerance*—Suriname, in particular, is a metal-rich country, and mining has been a major industry in the region for decades. High levels of mining tailings are present in the soil and water in areas where mining was prevalent. These metal-rich environments are a perfect environment for the development of metal-tolerant fungi and bacteria, which have been shown to have utility in the study of wood preservatives and as potential bioremediation tools to detoxify metal contaminants in the environment. Further surveys of reclaimed mining sites present the opportunity to search for potentially new and undescribed metal-tolerant microbes.
- *Development of hazard tree assessment tools with tropical partners*—STRI has supported research on evaluating nondestructive testing tools to estimate the amount of internal decay and damage to living trees, with special attention to tropical rainforest trees with irregular trunk shapes (Gilbert et al. 2016). Internal decay is a major source of mortality for mature trees because trees structurally weakened by heart rot and butt rot are more susceptible to snapping and falling in heavy winds or precipitation. Typical nondestructive testing tools such as stress wave timing, sonic tomography, and resistance drilling were found to have significant limitations in dealing with tropical trees that have large root systems, buttresses, or are otherwise irregular in shape (Wang et al. 2004). The research experience at STRI suggest the need for more research activities to develop comprehensive protocols for a broad diversity of tree types, with special reference to irregularly shaped tropical forest trees. The FPL nondestructive testing and evaluation research team, along with university cooperators, has unique capabilities to develop advanced acoustic tools that can be targeted at tree inspection in tropical regions, offering potential for research collaboration with STRI.
- *Development and technology transfer of nondestructive testing (NDT) procedures for timber structure inspection*—During our technical visit in Suriname, we visited a historic timber structure, the St. Peter and Paul Cathedral in Paramaribo, claimed to be the largest wooden structure in South America. We also visited the Central Suriname Nature Reserve and its RaleighVallen Visitor Center Pavilion, a timber-frame eco-tourism facility. Both structures were constructed with local tropical hardwood species (Surinamese greenheart and basralocus) that are considered naturally durable and decay resistant. With the harsh tropical climate, both structures are subject to significant decay and insect damages. Routine inspection and repairs are the best way to maintain the integrity of the structures. Local engineers and university faculty and students can be trained to conduct basic structure inspections using advanced NDT tools and following proper inspection procedures. FPL scientists can provide training on inspection techniques, tool use, and data interpretation, either remotely (via the web) or in person (classroom setting). In areas with available Wi-Fi, FPL scientists can be present virtually alongside trained on-site personnel equipped with video cameras for visual inspection, recommendations for secondary and tertiary inspection processes, and real-time interpretation of inspection results. The goal is for local personnel to acquire the

knowledge, skills, and tools to confidently and competently perform structural inspections without needing FPL guidance.

- *Development of field protocols for monitoring and assessing wood biodeterioration in tropical settings*—Accelerated testing of new and existing technologies to protect wood from biodeterioration are primary to the mission of the wood durability and protection research work unit at FPL. Tropical exposures like these present an invaluable opportunity to validate new and existing test methodologies to better understand the biodeterioration process of wood and wood-based materials (De Groot 1992). The rich fungal and insect diversity offers an opportunity to assess worst-case scenarios for extreme ground contact decay hazard and also establish much needed preservative thresholds for tropical environments.

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Appendix A—Summary of Visit to Panama Test Sites

Tour and inspection of TRTC field sites—A major component of this scientific exchange was to observe conditions at tropical test sites in both Panama and Suriname. TRTC operates four test sites in Panama, Inland, Sherman (Coastal and Breakwater) (Fig. 2), and Horoko (Figs. 3, 4).

Barro Colorado Island (BCI)—FPL and MTU staff visited the Barro Colorado nature monument and the associated research laboratories located on BCI . It is a protected area for conservation research and has been used extensively by the STRI as a long-term ecological study site since its creation in 1923. Early termite studies by the USDA were conducted at BCI, and several prominent publications on termites of the tropics resulted from those studies.

STRI in Gamboa—FPL, MTU, and TRTC staff visited the Smithsonian Tropical Research Institute in Gamboa, Panama, to discuss current research priorities and potential partnership opportunities, such as insect and fungal diversity and wood biodeterioration research.

Appendix B—Summary of FPL and MTU Work in Suriname

Timber tourist structure at Fungu Island—The Visitor Center Pavilion is a three-story, 6,426-ft^2 (597 m^2) timber structure (Fig. 5) located at the shore of the Coppename River (Fig. 6), the entrance to the Central Suriname Nature Reserve, which was designated a UNESCO world heritage site in 2000. It was constructed in 1998 in collaboration with the North American Timber Framer's Guild (Phillips 2006) using locally sourced brown-heart (*Vouacapoua americana*) and purpleheart (*Peltogyne* spp.), both of which exhibit inherent durability to rot and insects (Comvalius 2001). FPL and MTU researchers made structural assessments of the pavilion. Initial assessment showed isolated patches of dry wood termite damage and localized patches of wood decay fungi, usually due to improper drainage or excessive moisture catches. A major source of decay hazard on the pavilion decking was the roof leaking as a result of severe deterioration of the plywood shingles (Fig. 7). The buildup of bat guano from bats sheltering in the upper levels during the day also contributed to surface deterioration found on some of the beams.

Saint Peter and Paul Cathedral—Known locally as the Petrus en Paulus Kathedral (Fig. 8), the cathedral was designed by Frans Harmes and constructed from 1883 to 1885 in Paramaribo's old town center. It is also designated as a UNESCO world heritage site. The cathedral measures 161 ft (49 m) long, 54 ft (16 m) tall, and 48 ft (14 m) wide and is claimed to be one of the largest wooden structures in

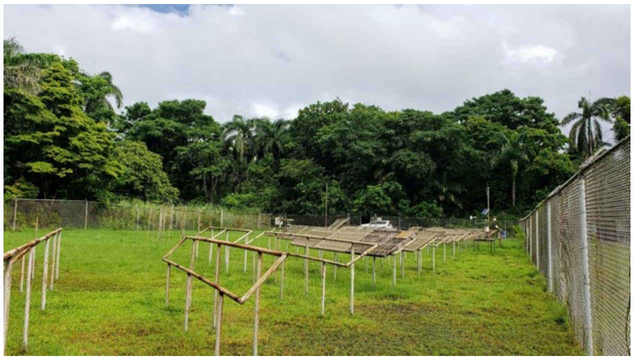

Figure 2—Sherman inland test site. Site has a very high water table and was wet at the time of inspection. It has very little canopy, so it is subject to high UV exposure and more rapid wetting and drying than canopied test sites. Severe decay attack was noted on untreated aspen samples after 6 months.

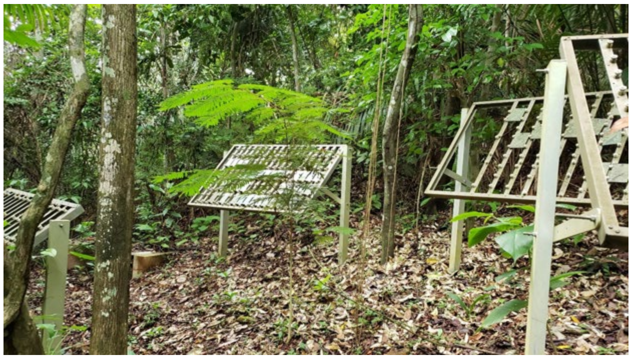

Figure 3—Experimental test racks at Horoko Test Site, originally used for fabric and metal coupon testing, could easily be retrofitted for wood specimens or engineered wood panels.

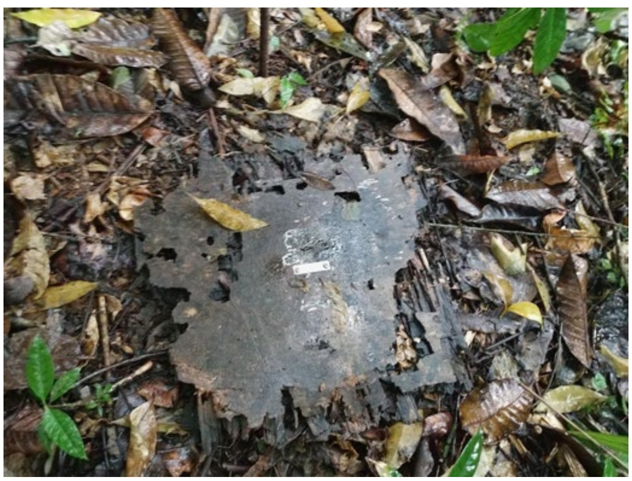

Figure 4—Plywood panel badly damaged by termite attack at Horoko Site, Panama. These untreated poplar plywood panels with MTU-CFRES-WPG tag have been in ground contact for approximately 8 months. Ground and arboreal termite nests were prevalent in this area and indicate very high termite pressure.

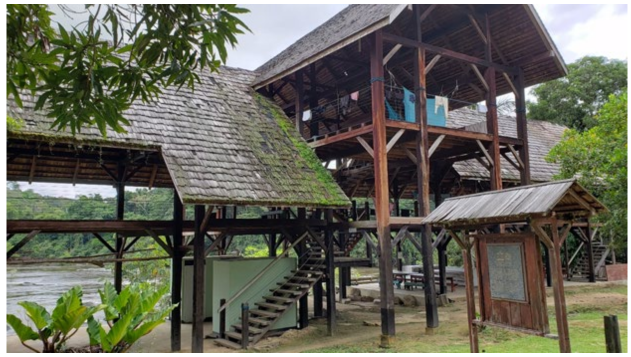

Figure 5—The three-story timber frame pavilion located in RaleighVallen, Central Surname Nature Reserve.

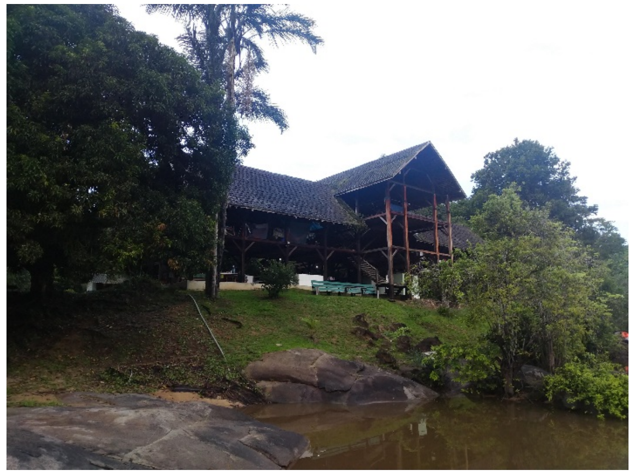

Figure 6—RaleighVallen, view from Coppename River.

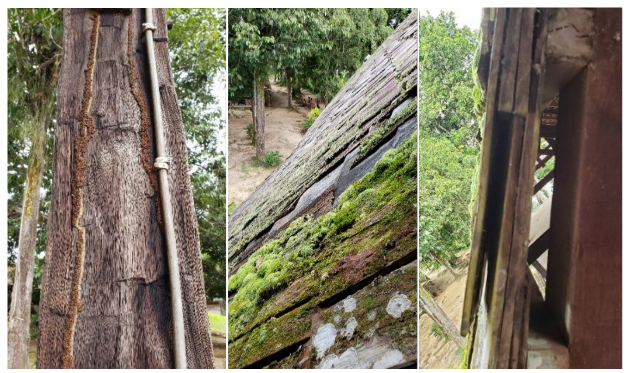

Figure 7—Termites and biodeterioration observed in the timber frame and roof of the Pavilion. Left, arboreal termite damage; center, deteriorated roof shingles, right, delaminated plywood shingles.

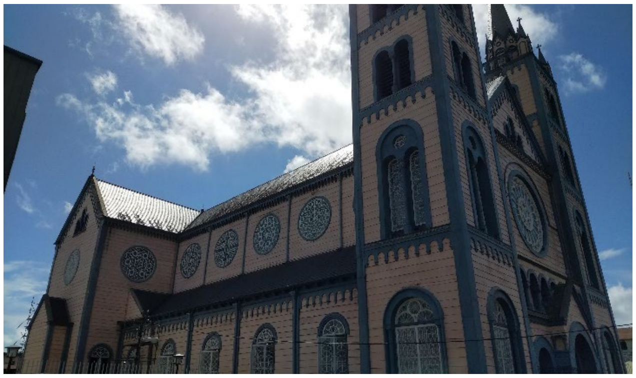

Figure 8—The St. Peter and Paul Cathedral, located in Paramaribo's old town center.

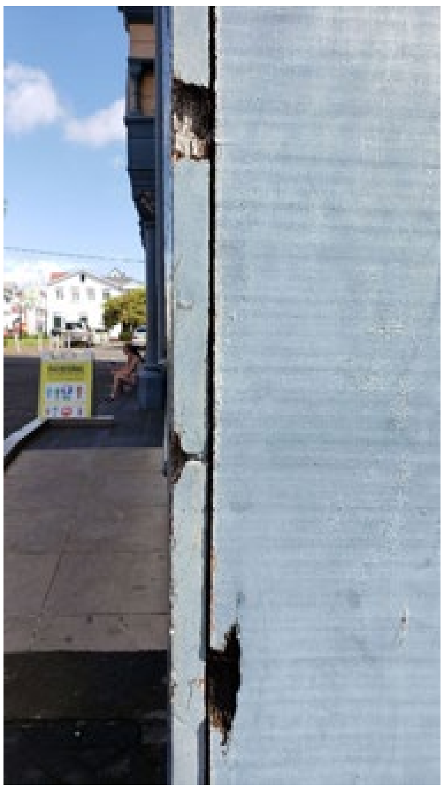

Figure 9—Localized decay (mostly brown rot) in exterior cladding.

South America. The structure was built using wood because of the unavailability of brick and stone in the capital city region. Like many of the former Dutch colonial buildings, records indicate that the façade and pillars of the cathedral are made of Surinamese greenheart and basralocus, both of which are considered naturally durable. The interior is clad with unfinished cedar. FPL researchers, who made only exterior observations because of an ongoing Catholic mass, noted excessive localized decay (mostly brown rot) in windowsills and exterior cladding (Fig. 9), and evidence of termite activity metal staining (Fig. 10). The cathedral was

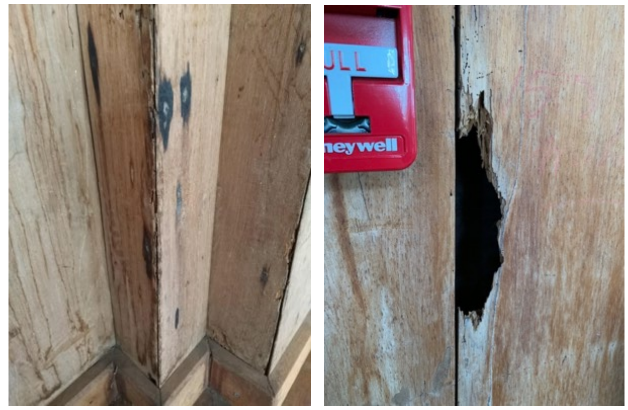

Figure 10—Termite channels, damage, and metal stain spots in the wall inside the cathedral.

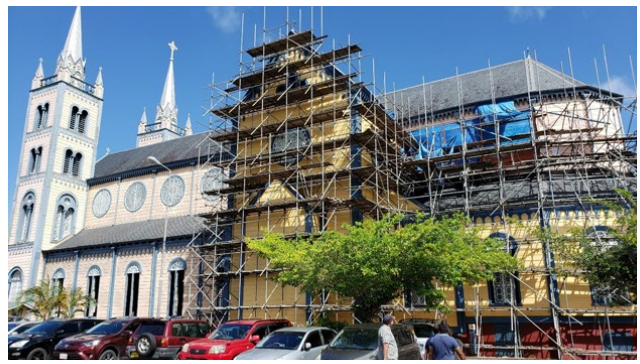

Figure 11—Exterior renovation of the Cathedral at the time of visit. Sidings and external window joinery were being replaced.

also under renovation during this time and siding and external window joinery were being replaced (Fig. 11). The Surinamese climate is very harsh on the colonial architecture, which is subject to rot because of the unavailability of preservative-treated wood.

Water Land Plywood manufacturer in Wanica Suriname—The plant makes hardwood plywood using local species of medium to low densities. Melamine formaldehyde adhesive, the primary glue used in the products, is imported from neighbor countries as bagged powder. The plant has almost the entire production line for plywood manufacturing, including veneer cutter, veneer dryer, roller adhesive applier, prepress/cold press, hot press (15 panels per batch), panel edge trimmer, and sanding machine. Two biomass boilers are used to supply steam for both the veneer dryer and the hot press. Veneer repairing, edge jointing, matching, and other procedures are done manually by the workers. The domestic market in Suriname is rather small; the major market locations for the products are Caribbean countries and primarily for furniture production. The company is interested in the North American market. Modern plywood production lines will not work well in Suriname because they are designed for small- to medium-diameter logs of a few species from secondary growth forests or plantations.

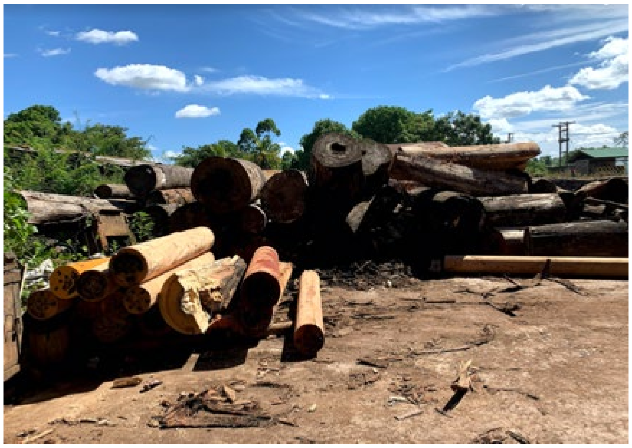

Figure 12—The corner of the log yard of the plywood manufacturer. Heart rot causes problems for veneer production.

The company utilizes local larger hardwood species from the virgin rain forest (Fig. 12). Most of the logs are unwanted species from local logging operations for tropical hardwoods of high densities. Therefore, multiple species are used in the plywood production. The company is facing a shortage of logs and has only enough log yard supply to last two days of veneer production. At the time of our visit, there was only one rotary veneer cutter in operation. The plant manager, Mr. Chen, was concerned about the supply of logs for their production. He mentioned low accessibility to the trees in the forest and little interest of the logging company for low-density trees due to their low values. However, he mentioned that his company is expanding. They have acquired the larger production line from an adjacent company, another plywood manufacturer that went out of business. Chen's company is the only plywood manufacturer in Suriname. The current production line started manufacturing plywood in 2018.