DR. EDGARD O. ESPINOZA AND RANDY S. WILKINSON

Separating the Three Species of *Swietenia* spp. in Rhode Island Furniture Using Direct Analysis in Real Time–Time-of-Flight Mass Spectrometry

ABSTRACT—Separating the species of *Swietenia* spp. using traditional wood anatomy has been difficult because the cell structure of all three species is not diagnostic and the color and density overlap. Wood samples were taken from 16 pieces of 18th-century American furniture made in Rhode Island, all in the collection of the Yale University Art Gallery along with seven samples from the conservator's collection. This study compared heartwood chemotypes of 34 samples using direct analysis in real time–time-of-flight mass spectrometry to a known database. Results indicate that all three species of *Swietenia* can be reliably separated and were found in Rhode Island furniture made in the 18th century.

1. INTRODUCTION

Let's begin by looking at mahogany from a different perspective. Sometimes it is true that when you change the way you look at things, the things you look at change. We probably would all agree that the first impression of figure 1 is that we were looking at mahogany but just different pieces with slightly different colors. If given more time to study the wood, some of us would begin to question what we were looking at and maybe suggest that a couple of them are not mahogany.

Indeed, this is the case. The only mahogany piece is at the top left, as seen in figure 2. The others are (seen clockwise) muskwood, toon (sometimes called red cedar), crabwood, rose mahogany, and canjarana. All of these woods are members of the Meliaceae family or the mahogany family, but only one is a true mahogany—*Swietenia*. The other five are "mahogany look-a-likes." Therefore, a new approach is needed, a new way of seeing, and a new way to separate the mahogany species.

"Mahogany" has traditionally been described and identified differently by groups whose interests overlap but have had a different focus, namely botanists, wood anatomists, scientists, and members of the decorative arts community (curators, collectors, antique dealers, and craftsmen). Because the perspective of each group is different, the language used to identify and describe mahogany ranges from highly scientific to folklore at best. Understanding each group's perspective and the contribution each makes to identifying mahogany will ensure that the subject is not reviewed and evaluated from a single point of view.

2. BACKGROUND

To the botanist, mahogany is a member of the Meliaceae family, which contains some 52 genera and 621 species (Gasson and White 2008). The genus *Swietenia* is presently composed of three species: *Swietenia mahagoni* (Linnaeus) Jacquin, *Swietenia humilis* Zuccarini, *and Swietenia macrophylla* King. The botanist identifies its unknown by observing the flowers, fruit, leaf structure, and bark. The botanist also aids in defining the geographic area of growth. The limitation from the decorative arts point of view is that there are no flowers, fruits, and leaves of the tree; all that is left is processed wood with no information of its origins. Yet from a historical angle, proper placement of the wood into its genus and species has important implications.

The history of botanically separating the genus and species from others in the Meliaceae family is long and complicated. Before Carl Linnaeus's adoption of the binomial system of nomenclature in 1760, mahogany was classified as *Cedrela mahagoni*. Thus, for a botanist before 1760, mahogany was in the *Cedrela* genus, the same genus as Spanish cedar or cigarbox cedar. Nicolaus van Jacquin in 1760 separated *C. mahagoni* into a genus of its own, which he called *Swietenia*. It was named after Baron G. L. B. Swieten, a Dutch naturalist and physician (Keay 1996). For the next 76 years, botanically, mahogany was thought to be of this single genus and species, namely *S. mahagoni*. Between 1836 and 1837, *S. humilis*, a second species of mahogany, was described botanically by J. G. Zuccarini from specimens collected in southwestern Mexico. The final species was not added to the genus until 50 years later in 1886 by George King. *S. macrophylla* was named based on trees grown in the Botanic Garden at Calcutta from seeds apparently collected in Honduras.

In addition, it is believed that all three species grew in distinct geographic areas. The native range of *S. mahagoni* is confined to southern Florida and the West Indies. The native range of *S. humilis* grew on the Pacific coast of southwestern Mexico to Costa Rica, and the native range of *S. macrophylla* grew on the Yucatan Peninsula through Central America and into Columbia, Venezuela, Peru, and extreme western Brazil (Record and Hess 1943). It should be noted that the assignment to geographic areas of growth were largely developed in the late 19th and early 20th centuries. Keep in mind that *S. macrophylla* did not receive its own botanical name until 1886. If we were to look at a map drawn today, it would look much different owing to planting and hybridization.

Fig. 1. Mahogany—they all look similar.

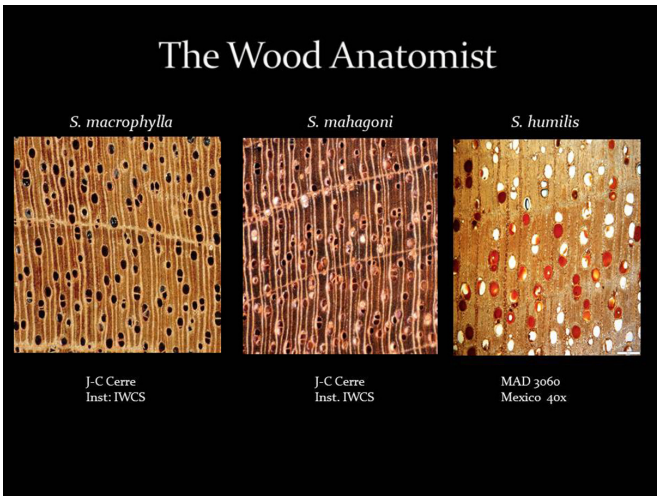

Fig. 3. Transverse section of all three species of *Swietenia*.

Moving to yet another perspective, the wood anatomists have been reluctant to separate the genus into specific species because of little variation in cell structure and the wide variation in grow rate, density, and color. Figure 3 shows transverse sections or end grain sections of all three species of mahogany. Notice the color difference; notice that some of the vessels have deposits in them, some red, some white, and some not at all. The wood anatomist assigns wood to a particular genus and sometimes species by observing and measuring individual wood cells and comparing them with a known standard, sometimes can be aided by determining the specific gravity of the wood in question. In the case of mahogany, getting to the genus level (i.e., *Swietenia* spp.) is not a problem, but getting to the exact species is not so straightforward. The limitations lie in not enough clear difference microscopically and overlapping ranges of specific gravity.

In figure 4, the two pieces of wood are the same size, but have a different color and weight. Yet both are mahogany. Note the huge difference in specific gravity: *S. mahagoni* has a specific gravity of .86, whereas *S. macrophylla* has a specific gravity of .46.

Many have attempted to overcome the limitation by drawing clearer separation between species using specific gravity and cell diameter (fig. 5). Kribs (1968), in his book *Commercial Foreign Woods on the American Market*, first published in 1959, groups all three species together and generally describes the color as pale brown, pink, light red, dark red, or reddish brown. Furthermore, the wood is light and soft to hard and heavy with a specific gravity of .40 to .85. Other attempts to make the distinction between the three species relied on specific gravity, suggesting that the upper range of *S. macrophylla* does not overlap with the lower specific gravity range of *S. mahagoni* and *S. humilis* (Lamb 1966; Lane 2016). As an attempt to be more accurate with the accepted specific gravity, *S. macrophylla* was reported to have a specific gravity of .57 to .68, with the average being .62, whereas *S. humilis* had a range of .67 to .89, with an average of .76

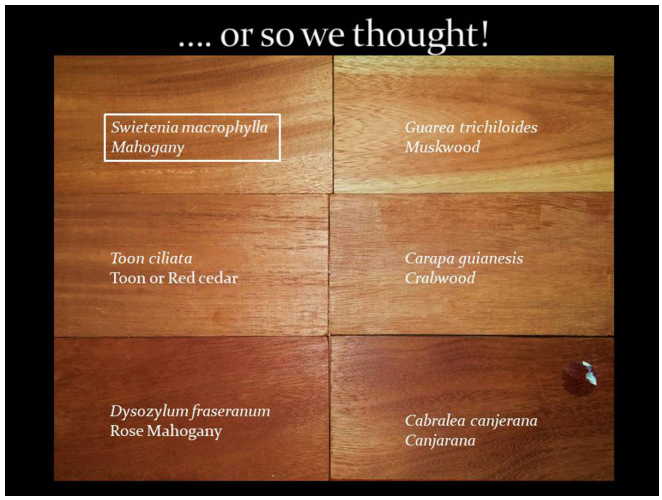

Fig. 2. *S. macrophylla* is seen at the top left.

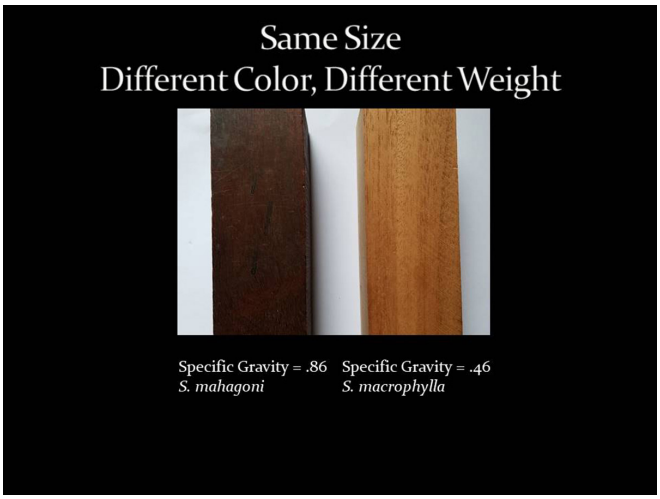

Fig. 4. Comparison of *S. mahagoni* and *S. macrophylla*.

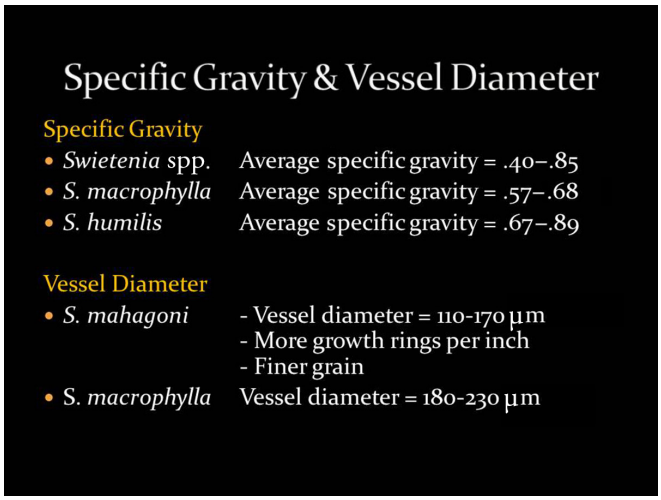

Fig. 5. Specific gravity and vessel diameter for *Swietenia* spp.

(Boone and Chudnoff 1970). A further attempt to draw some distinction between the three species relies on comparing diameters of the vessel elements and growth rings per inch, suggesting that *S. mahagoni* is slower growing, having more growth rings per inch and a finer grain (i.e., smaller vessel diameter) than that of *S. macrophylla*. It has also been suggested that the vessels are round or oval in *S. mahagoni*, having a diameter of 110 to 170 µm, whereas *S. macrophylla* has a vessel diameter of 180 to 230 µm. In the end, taking all of this information into account, the ability to reliably separate the three species can be a very well educated guess but is seldom definitive.

The members of the scientific community offer yet a different perspective. Due to the increased effort to combat illegal logging around the world, scientists have been working with wood anatomists to develop techniques to separate closely related species. Some of the promising approaches are near-infrared spectroscopy, direct analysis in real time–time-of-flight mass spectrometry (DART-TOFMS), DART Fourier transform ion cyclotron resonance mass spectrometry, DNA, pyrolysis–gas chromatography–mass spectrometry (Py-GCMS), and laser-induced breakdown spectroscopy (LIBS).

The use of near-infrared spectroscopy has been used successfully to separate *S. macrophylla* from a select group of look-a-like members of the Meliaceae family, such as crabwood, Spanish cedar, and gogo. Note that this technique cannot separate the three species of mahogany. The technique is fast and nondestructive, and this study was based on vouchered samples from 27 different countries.

DART-TOFMS has been used successfully to separate Brazilian rosewood (*Dalbergia nigra*) from other Brazilian rosewood look-a-likes. More recently, DART-TOFMS has been successful in separating the three species of mahogany to genus and species. It requires a small sample size, no sample preparation, can be minimally intrusive to the object, is very fast, and yields accurate mass measurements. It does, however, require a database of known vouchered samples by which an unknown sample is then compared. Note that this is unpublished research to date, except for the other species, such as *Dalbergia*.

Most recently, a more advanced method of DART-TOFMS was used to separate two species of *Pterocarpus*. This method required a 5-mg sample that was then made into powder and the solvent-extracted material was analyzed. Coupled with multivariate statistical analysis, it yielded a 100% accuracy rate.

The more promising science but most difficult to develop is the use of DNA. DNA extraction from plant leaf and bud tissue is fairly standard. DNA extraction for freshly harvested wood from the cambium tissue has also been found to yield DNA of high quality. But the DNA extraction from aged wood, particularly from the heartwood, is more challenging. DNA extraction technology is rapidly advancing and being used to help separate wood species and may ultimately be a key tool in wood identification.

The last perspective is that from the decorative arts. The ability to separate the three species of mahogany from the decorative arts perspective is limited at best and relies on color, density, figure, form, workability, and to some degree connoisseurship. The use of a common name and trade name compounds the problem. With at least 446 reported common names for "mahogany" used over the centuries, confusion is inherent (Alden 1998). If one factors in the language used to describe mahogany in account books, trade journals, shipping manifests, and advertisements from the 15th through 20th centuries, it becomes very clear very fast that the name is based exclusively on color, density, workability, and geographic region of growth, thus separation is based solely on connecting the geographic region of growth to density and color. For example, if an object were made of mahogany that was dark brown and dense with great figure, it was said to be "Cuban mahogany" or "Santo Domingo mahogany." What is really being said is that the wood looks like *S. mahagoni*, not the light soft mahogany *S. macrophylla*, and *S. humilis* is not even on the radar for the majority. This observation may not necessarily be incorrect, but it is not definitive. Furthermore, if one factors in the number of species that "look like mahogany" into the equation, the task to separate the three species of *Swietenia* becomes impossible given that one may he or she has an object made of mahogany, but in fact it is a look-a-like and not mahogany at all.

Reviewing books written about furniture, whether trade journals, auction house catalogs, or even books dedicated to furniture from a specific region or collection of a major museum, identification is usually done by eye. It is assumed that if the common name is used, the identification was done by eye. If the Latin name is used, it is assumed that the identification was conducted microscopically but only assigns identification to the genus level (i.e., *Swietenia* spp.).

Finally, it should be noted that not only is the focus of the aforementioned groups different, but the physical material that they are looking at is drastically different. The botanist sees the tree throughout an entire season of growth; the anatomist sees a processed piece of the tree that is cut into boards or veneer. The scientist obtains a minute sample of the wood, often needing only a few hundred micrograms of material. And finally, the members of the decorative arts community see an object that may be hundreds of years old that contains material derived from a tree that has been milled, molded, oxidized, and coated, often many times in its history.

3. SEPARATING THE SPECIES: DART-TOFMS

Now having a good understanding of past attempts to separate the species, let's turn our attention to the most current research (fig. 6).

In October 2017, 27 wood samples were taken from 16 different pieces of Rhode Island furniture in the collection of the Yale University Art Gallery. The objects to be sampled were selected by Patricia E. Kane and John Stuart Gordon. The 16 objects selected represent the pinnacle of style and craftsmanship in Rhode Island in the 18th century, and the selection was also made by observing the variation in color, grain, and quality of the woods used in these objects. Another 7 samples were taken from a private wood collection. These consisted of wood collected over the past 30 years and range from entire mahogany logs, crotch veneer, and pieces saved due to density and color.

The sample locations for all of the furniture in the collection at Yale were selected by finding the least obtrusive area to sample. This included behind locks, inside of case pieces, inside surfaces of drawer dividers, along existing damaged edges, and sites adjacent to hardware. The sample size varied from object to object based on sample location, but generally it was between 1 and 2 mm square and up to 25 mm in length.

In November 2017, the wood samples were taken to the U.S. Fish and Wildlife Forensics Laboratory in Ashland, Oregon. Working with Dr. Edgard Espinoza and his team, who developed the DART-TOFMS database for mahogany, the testing began. The advantages of DART-TOFMS are considerable. The method requires a very small sample size and no sample preparation. It can be very minimally intrusive to the object if done with care, is extremely fast, and yields accurate mass measurements (fig. 7). The first step in the process was to make tiny slivers from the collected samples and then hold them in the ion stream to obtain the data.

The database that Dr. Espinoza developed is seen in figure 8. On the top line, the average spectra for *S. mahagoni* is shown in blue. The next graph down is the average spectra for *S. macrophylla* in red, followed by average spectra for *S. humilis* in green. The finial graph in yellow is the atypical chemotype spectra for what is *S. mahagoni* or *S. humilis.* The key information to observe is that there are two chemotypes for *Swietenia*. One that has a mass/charge data above 760 represented in blue, red, and green, and one that does not is represented in yellow.

To add further clarity, kernel discriminant analysis was used to place the data in a more readable form in which all four groups clearly separate on a three-dimensional graph (fig. 9). The dark blue dots represent *S. mahagoni*, the red dots represent *S. macrophylla*, the green dots represent *S. humilis*, and the light blue dots represent the atypical chemotype suggesting either *S. mahagoni* or *S. humilis*. One last point to note here is that this model has a 92% accuracy rate. Figure 10 is a graph with the Yale samples added to it as black dots. The samples clearly separate into one of the four clusters. On this particular graph, six of the samples taken from the furniture are represented: one identified as *S. mahagoni*, two as *S. macrophylla*, two as *S. humilis*, and one as either *S. mahagoni* or *S. humilis*.

Fig. 6. The research project.

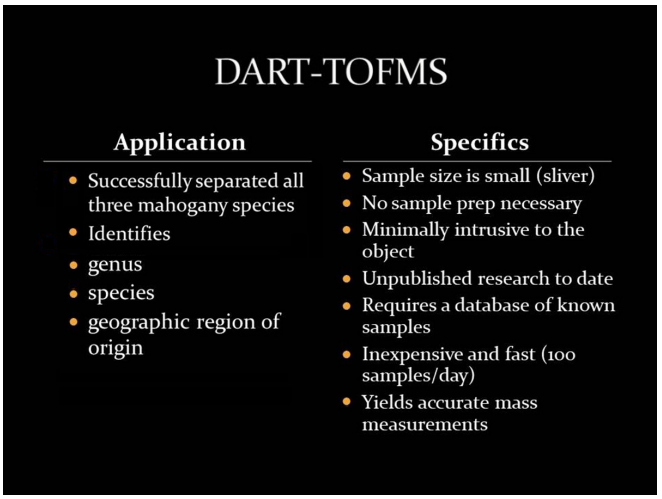

Fig. 7. DART-TOFMS.

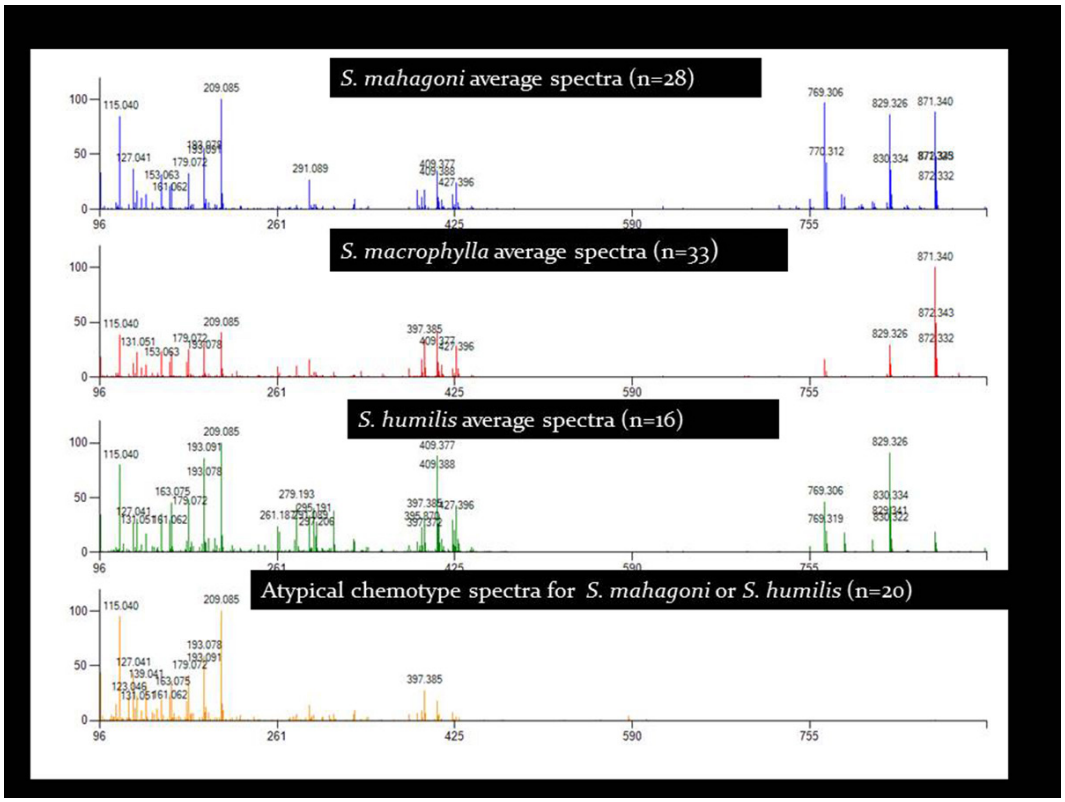

Fig. 8. Average spectra for all three species of *Swietenia*.

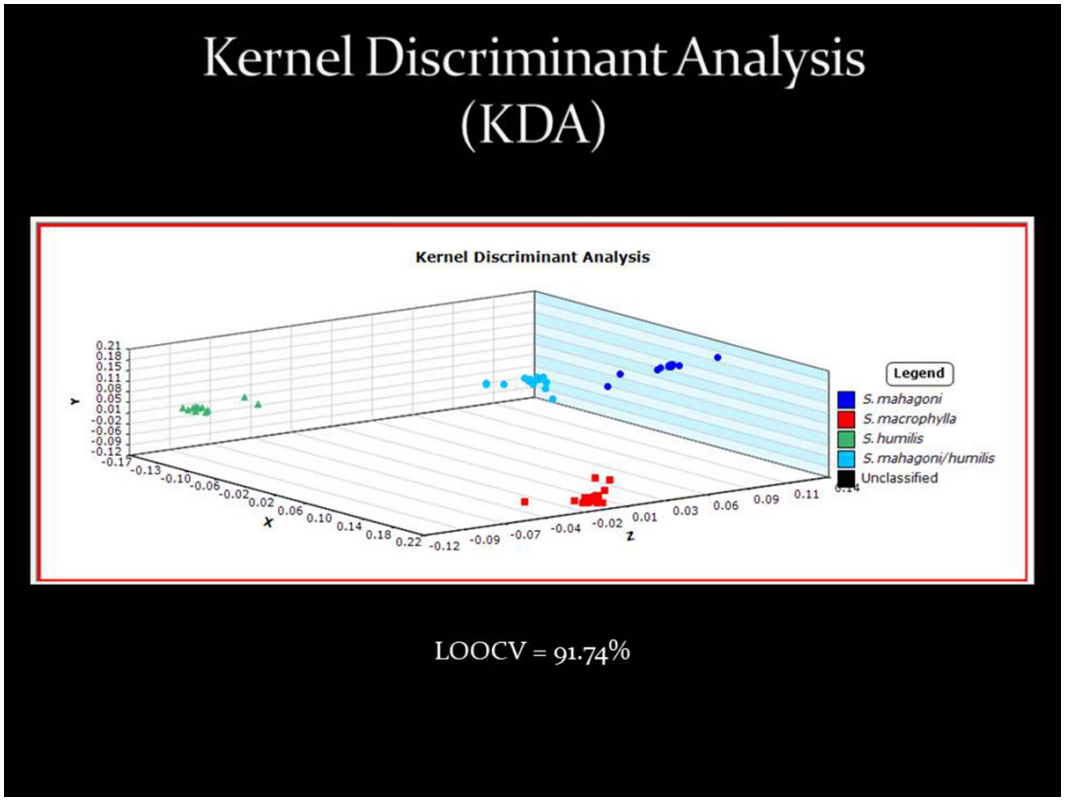

Fig. 9. Kernel discriminant analysis of the average spectra of *Swietenia*.

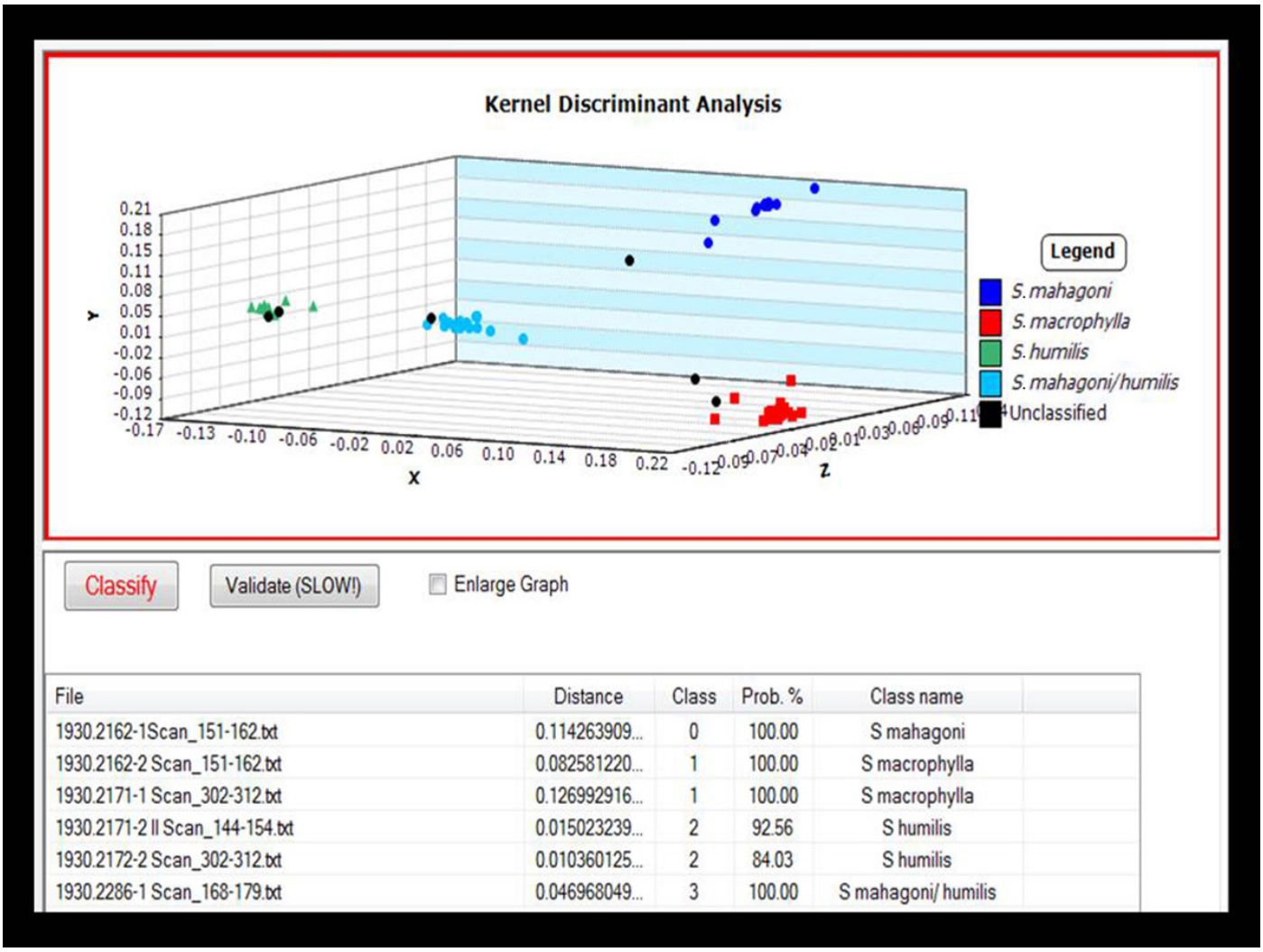

Fig. 10. Kernel discriminant analysis with six of the Yale samples represented as black dots.

4. RESULTS

The results of the analysis suggest that 10 samples were identified as *S. mahagoni*: 9 from the furniture at Yale and 1 from the private wood collection. Seven samples were identified as *S. humilis*: 4 from the furniture at Yale and 3 from the private wood collection. Four samples were identified as *S. macrophylla*: all from samples taken from Yale. Twelve samples were identified as either *S. mahagoni* or *S. humilis*: 9 taken from the furniture at Yale and 3 from the private wood collection. Finally, 1 sample from Yale was only identifiable to the genus level (fig. 11).

Now follow three brief case studies of the objects that were sampled to demonstrate in concrete terms what this research revealed. The first object was a wonderful Rhode Island chest-on-chest, as seen in figure 12. A sample was taken from the back of a drawer front, behind the lock, and from the proper right side along an existing defect. Notice that the drawer front was made from *S. mahagoni* and the case side from *S. macrophylla*.

The next example was that of a great Townsend high chest, as seen in figure 13. A sample was taken from the back of the drawer by removing the lock and then taking the sample, and the second sample was taken from the proper right side of the upper case side, near the back where a nail from the backboard caused a split. Notice that *S. humilis* was used on the front of the chest and *S. mahagoni* on the side.

The final example was from the fabulous chest of drawers seen in figure 14. Two samples were taken from the chest: the first from the underside of the drawer front and the second from the back edge of the proper right case side. Notice again that two different species were used to construct the chest; *S. mahagoni* was used to construct the drawer front and *S. macrophylla* was used for the case side.

Although one phase of the work was completed, the research did not end there. In September 2018, all 34 samples were taken to the U.S. Forest Products Lab in Madison, Wisconsin for

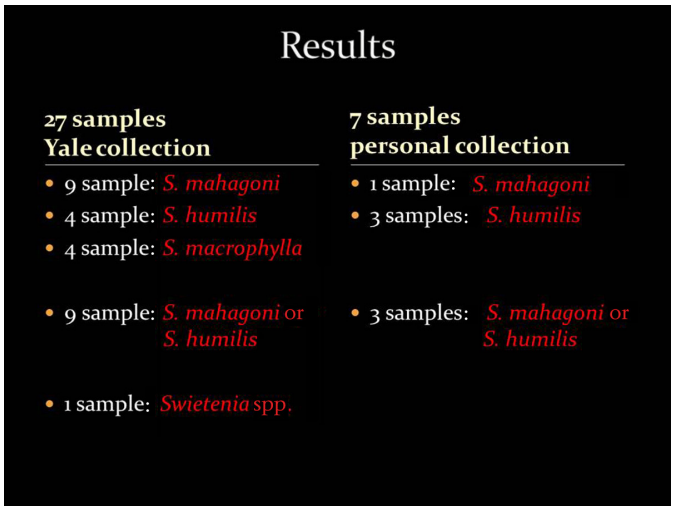

Fig. 11. DART-TOFMS results for all 34 samples tested.

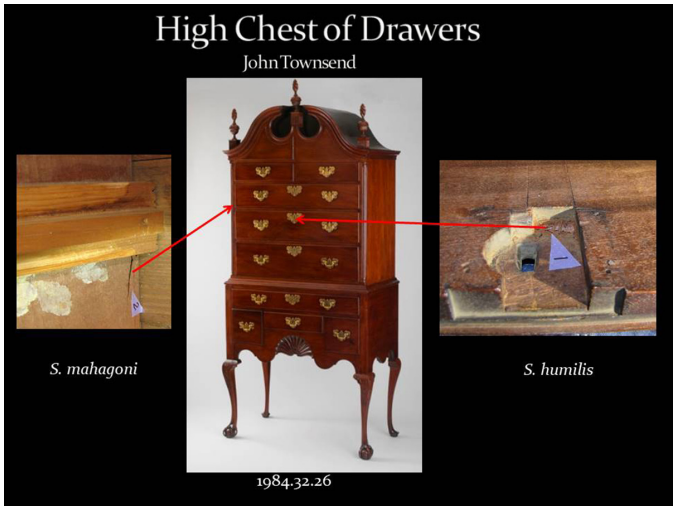

Fig. 13. High chest of drawers, John Townsend 1984.32.26. Courtesy of the Yale University Art Gallery.

further documentation. The goal of this research was to obtain photomicrographs of all 34 samples. Now there are photomicrographs of the three principal planes—transverse, radial, and tangential—for each sample, along with measurements for key cell types (fig. 15). In addition, 53 samples of mahogany were brought back to Yale for further testing via Py-GCMS.

5. CONCLUSION

The research suggests that DART-TOFMS was successful in identifying the presence of all three species of mahogany in the furniture of Rhode Island of the 18th century. The study also confirms that different species of mahogany were used on the same piece of furniture. *S. macrophylla* was found in only 4 of the 16 pieces of furniture from which samples were taken.

As with all cutting-edge research, there are unanswered questions. The first is this: What is the reason for the atypical chemotype? Is it purely biological? Is it a function of our sample site (i.e., where the sample was taken from, close to the pith of the tree, or closer to the bark? Can we further differentiate this second chemotype to suggest the positive presence of *S. mahagoni* or *S. humilis*? Keep in mind that 12 of the 34 samples shared this atypical chemotype. What if all 12 suggest *S. humilis*? Would that cause us to rethink the accepted geographic area where *S. humilis* grew?

Therefore, if *S. humilis* were not a commercially viable species, why is it found in the furniture of the 18th century, particularly Rhode Island furniture? After all, it was reported to only grow on the west coast of Central America. How did if find its way to Newport, and almost as important, why does *S. humilis* occur in large boards, planks, and veneers in a more modern collection?

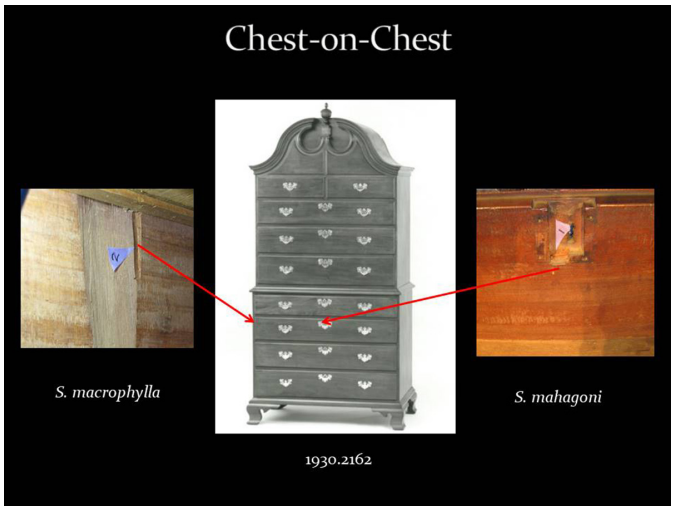

Fig. 12. Rhode Island chest-on-chest 1930.2162. Courtesy of the Yale University Art Gallery.

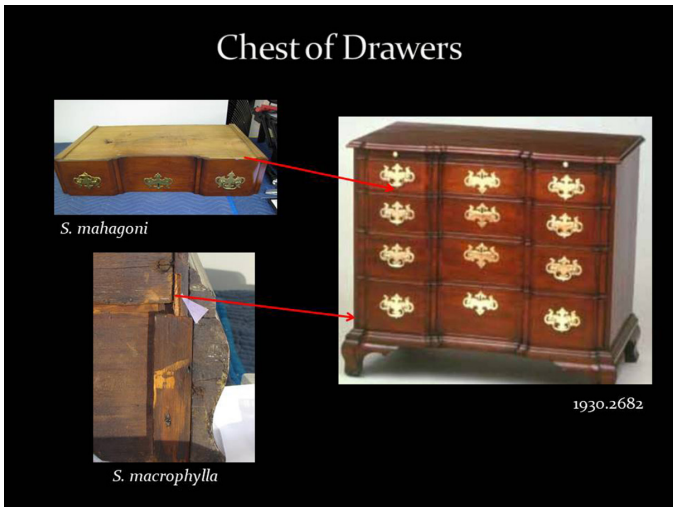

Fig. 14. Chest of drawers 1930.2682. Courtesy of the Yale University Art Gallery.

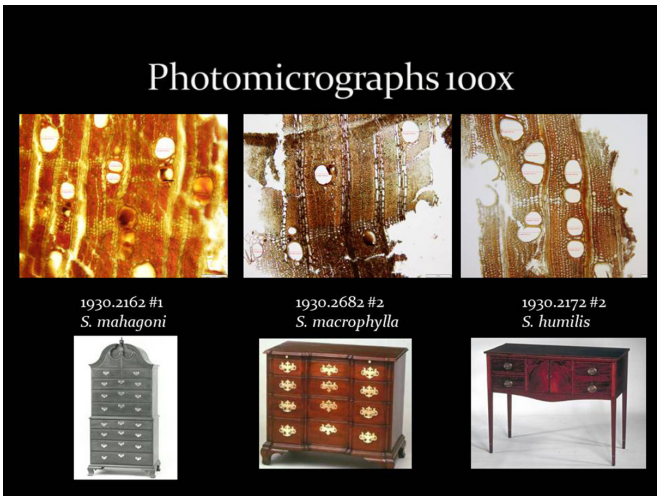

Fig. 15. Select photomicrographs, transverse section, 100x. Furniture photographs courtesy of the Yale University Art Gallery.

Considering that these important questions remain, the team is working to find answers to these questions using alternative methods, specifically the use of laser-induced breakdown spectroscopy (LIBS) and Py-GCMS. The team is actively collecting vouchered samples to build a database of both the three species of mahogany and the mahogany look-a-likes. Another grant from the Wunsch Americana Foundation was obtained to collect material from the mahogany look-a-likes and perform LIBS testing on these samples. Maybe even more exciting, actual core samples from *S. humilis* were obtained directly from Mexico. With the help of Dr. Marcelo Pace, it is now possible to sample these specimens by DART-TOFMS, Py-GCMS, and LIBS at known increments from the cambium to the pith. This is critical and may be key to understanding the two different chemotypes seen in mahogany. These scientific tools may hold the means to answering not only the remaining chemical questions but also building a database that can be shared by all institutions.

ACKNOWLEDGMENTS

The authors would like to thank those who supported this research: Patricia Kane and John Stuart Gordon from the Yale University Art Gallery; the Wunsch Americana Foundation for financial support; Dr. Anikó Bezur, Dr. Richard Hark, and Dr. Katherine Schilling from the Institute for the Preservation of Cultural Heritage; Michael Schilling from the Getty Conservation Institute; and Dr. Michael Wiemann from the Forest Products Lab.

REFERENCES

Alden, H. 1998. "Scientific Limits of Microscopic Wood Analysis of Objects d'Art." In *Proceedings of the American Institute for Conservation 26th Annual Meeting Poster Session, Arlington*. Washington, DC: AIC.

Boone, R. S., and M. Chudnoff. 1970. "Variations in Wood Density of the Mahoganies of Mexico and Central America." *Turrialba* 20 (3): 369–371.

Gasson, P., and L. White. 2008. *Mahogany*. Richmond, UK: Royal Botanic Gardens, Kew.

Keay, R. W. J. 1996. "The Future for the Genus *Swietenia* in Its Native Forests." *Botanical Journal of the Linnean Society* 122: 3–7.

Kribs, D. A. 1968. *Commercial Foreign Woods on the American Market*. New York, NY: Dover Publications.

Lamb, F. B. 1966. *Mahogany of Tropical America*. Ann Arbor, MI: University of Michigan Press.

Lane, J. W. 2016. *Identifying Tropical Hardwoods in Historic American Furniture*. Winterthur, DE: Henry Frances du Pont Winterthur Museum.

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

AUTHOR BIOGRAPHIES

DR. EDGARD ESPINOZA is the deputy director of the U.S. Fish and Wildlife Forensics Laboratory, located in Ashland, Oregon. For the past 30 years, Ed has been involved in the application of chemistry to wildlife forensic science questions, and this work has resulted in more than 60 peer-reviewed publications. Since 2010, Ed has been focusing on the analysis of timber products using direct analysis in real time–time-of-flight mass spectrometry. Ed has been instrumental in the founding of the Society for Wildlife Forensic Science (https://www.wildlifeforensicscience.org) and through this society developing proficiency tests and best practice guidelines for forensic scientists who work on flora and fauna evidence. Ed received his doctoral degree in forensic chemistry from the University of California, Berkeley. He is fluent in Castilian Spanish. Address: U.S. Fish and Wildlife Forensic Laboratory, 1490 East Main Street, Ashland, OR 97520-1310. E-mail: ed_espinoza@fws.org.

RANDY S. WILKINSON is a furniture conservator and principal in the firm of Fallon & Wilkinson LLC in Baltic, Connecticut. He received his training at the Smithsonian Institution's Furniture Conservation Training Program and earned his master's degree from Antioch University in 2000. He completed fellowships at the Preservation Society of Newport County, Rhode Island, and the Mystic Seaport Museum in Mystic, Connecticut. He has been teaching wood identification since 2009 and is currently conducting groundbreaking research on separating the three species of mahogany in conjunction with the Yale University Art Gallery in New Haven, Connecticut. Address: 32 Bushnell Hollow Road, Baltic, CT 06330. E-mail: randywilkinson@att.net.