Arundo donax or Bust?

A Preliminary Investigation into Alternative Natural Materials for Oboe Reeds

by

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ABSTRACT

Since at least the Baroque era, all Western classical woodwind instruments have only used *Arundo donax* for reeds. This preliminary investigation is one of the first inquiries into alternative natural materials for oboe reeds. The first chapter of this document is an overview of what we currently know about the materials used for reeds from the start of historical documentation until today. The second part of this overview surveys double reed instruments outside of Western classical music for reed materials and candidates for oboe reeds. The second chapter is a survey of some plants in the Poaceae family—a group of woody grasses and the family *Arundo donax* is in—to determine if there are more candidates for oboe reeds. The third chapter consists of Martin Schuring and I making reeds from two experimental materials: *Phragmites* and *Bambusa textilis*. Additionally, Dr. Gardner and I conducted a study involving six participants. I processed *Phragmites*, *Arundo donax*, and *Bambusa textilis* into gouged cane and sent the participants three pieces of each material, which were labeled A, B, and C, respectively. The purpose of the study was to test if oboists with diverse backgrounds could scrape the provided cane into a reed that produces a sound on the oboe. The full study responses are in Appendix B. The last chapter of this document is a scope analysis, courtesy of Professor Jeffrey Kleim, of the plant samples I was able to obtain, which includes *Phragmites*, *Bambusa textilis*, and a few other plants. Furthermore, Dr. Lindsey Reymore and I tested the *Phragmites* and *Bambusa textilis* reeds Martin Schuring and I made by analyzing spectrograms, extracting audio descriptors from MATLAB, and running a few statistical tests to determine any statistically significant differences. Collective results indicate that eight oboists were able to make functional *Phragmites* and *Bambusa textilis*

reeds, there are many potential candidates, and there were some statistically significant differences in audio descriptors between the *Arundo donax*, *Phragmites*, and *Bambusa textilis* reeds. Since this is preliminary research and no candidates were deemed unsuitable, future and long-term research is required for more thorough and conclusive data collection and analysis.

DEDICATION

Dedicated to musicians who have lost their passion for music, may you once again find the joy and fulfillment music-making brings.

ACKNOWLEDGMENTS

I am filled with gratitude and have many people to thank. Thank you to my committee for helping me through the research and writing processes and for the endless support you give your students, including me. To Dr. Reymore, I am so thankful for the hours you have spent giving me such valuable feedback on this document and for the mentorship I have received from being a music theory teaching assistant. To Dr. Gardner, thank you for being a wonderful chamber music coach and for your guidance through the IRB process. Thank you Dr. Caslor for providing an invaluable learning environment in chamber winds for both conductors and instrumentalists and for tagging along on my committee. The biggest professional thank you goes to Martin, who has been beyond understanding, accommodating, and encourages me to pursue the worthwhile and crazy career ideas. Thank you to all of the donors that have contributed to my merit-based scholarships, without philanthropic people like you, students like me would not have the access to high quality education that we do. And lastly my personal gratitude extends to Kat, our dogs, my parents, and my family. Without my rescue dog I adopted when I first moved here, Duncan, I might have moved back to Illinois for the first year of my master's degree. Without my parents, I would not have been able to move to Arizona with such ease and I am incredibly thankful for their unconditional love and support. And thank you Kat for your love, support, and encouragement through the hardest years of my life, and for bringing your dogs, Lars and Mander, into Duncan and my lives. Our little family brings me so much joy and happiness.

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PREFACE

Many of my mentors have contributed the Experimental Materials section, IRB Study 00018503, Microscopic Imagery section, and Sound Analysis section.

Martin Schuring provided his opinions on making reeds with bamboo and *Phragmites* in the Experimental Materials section. Additionally, half of the recordings in the Sound Analysis section were of his playing and the reeds he made.

Dr. Joshua Gardner was the principal investigator of IRB Study 00018503 and guided me through the Internal Review Board process. He also facilitated contacting his previous collaborators to find an appropriate scope to get imagery of my plant materials.

Professor Jeffrey Kleim set up the Leica F12 scope and took photos of my plant materials through the scope in the Microscopic Imagery section.

Dr. Lindsey Reymore aided in creating the recordings of Martin and myself playing reeds. Furthermore, she uploaded select recordings in MATLAB to analyze the sound using chosen descriptors via statistical tests and helped me write and relate numerical data to semantic sound analysis. Moreover, she provided critical feedback to help shape and improve the effectiveness and clarity of this document.

I am incredibly thankful for the guidance I have received while working on this research paper.

INTRODUCTION

Before getting into the weeds, figuratively and literally in this case, there are a few questions to pose to understand the importance of this document. Why is only *Arundo donax* used to make reeds? What historical evidence is there that it has always been *Arundo donax*? Are there other plants like *Arundo donax* that can be used to make reeds? Oboists and bassoonists today are fanatical over reed making to the point that much of our literature is dedicated to the topic of reed making. Research on synthetic materials for reeds is still in its infancy and the studies that have been done are mostly preliminary. Regardless, none of these inquiries involve the actual plant woodwind players use to make reeds. With growing climate change concerns, it seems quite dangerous to only have one source of cane, especially considering that the bulk of the highest quality cane comes from specific regions in France. The record high temperatures and drought in Europe in 2022 were enough to cause issues in the harvesting phase of cane; some oboists could not find cane in stock and those who could reported issues with the cane quality. More research on looking into alternative natural materials instead of synthetic materials is a necessity. Oboists are very particular about making their reeds. We have a countless amount of different shapes, scraping styles, reed threads, staples, etc. that any synthetic and machine-made oboe reed could not fulfill. Many oboists enjoy the flexibility of making their own reeds and deciding what parameters to keep, what parameters to change, and always having the freedom to do so. This document will serve as a preliminary and comprehensive investigation into alternative natural materials for oboe reeds.

We begin with a compilation of what publications have said about the materials used for reeds and uncover some inconsistencies in historical documentation, and survey double reed instruments outside of Western classical music for the materials their reeds are made from. Then, we explore the family, Poaceae, *Arundo donax* is in to find and assess potential candidates for oboe reeds. Upon finishing the assessment of other plants for suitability, I document the reed making process involving *Phragmites* and bamboo. Martin Schuring also made reeds from *Phragmites* and bamboo and details his experience in making those reeds. Next, Dr. Joshua Gardner and I conducted an IRB approved study involving six participants and their experiences in making reeds with the two experimental materials, their responses are in Appendix B. Finally, we collect data involving Hardness Testers, scope imagery, and sound analysis using MATLAB Timbre Toolbox and spectrograms in Sonic Visualiser.

HISTORICAL OVERVIEW

From Antiquity to the Dark Ages

The Aulos and its Global Impact

One of the earliest double reed instruments we have historical records for is the aulos. The aulos is also known generally as a double pipe. It existed during the Classical period in ancient Greece and the Middle East known primarily by two names: Greek aulos (plural auloi) and Roman tibia (plural tibiae). Eventually, the migration of people brought the instrument to Europe and it remained there up to the Middle Ages.[1] The aulos still exists and there are remnants of the Roman tibia found where the Roman Empire reigned.[2] The aulos is the ancestor of many double reed instruments known today, including the oboe. Overall, plants are hardly mentioned in publications on the aulos other than the generic "cane" name and confident assumptions stated as fact that the plant used was *Arundo donax*. In Philip Bate's book, he notes that the double reed's lineage goes back to remote antiquity, however, the lineage is not continuous.[3] Bate implies that there are gaps in our historical records where the double reed's lineage is missing or inconsistent. Anthony Baines, author of *Woodwind Instruments and Their History*, suggests that before the "birth of civilization," the people who resided in the Near East had simple reed pipes.[4] It is a sound assumption to make that a flute instrument likely existed before a reed pipe considering the beginnings of historical documentation thousands of years ago to present day.

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[1] Encyclopedia Britannica, "aulos."
[2] Bate, *The Oboe: An Outline of its History, Development and Construction,* 12.
[3] Ibid, 11-12.
[4] Baines, *Woodwind Instruments and Their History*, 190.

At some point during its development, the reed became separate and detachable. Eventually, the reed was made from entirely different materials than the body of the pipes. Before the reed pipe, Robert E. Perdue Jr. insists that the use of *Arundo donax* is directly ascended from an early ancestor of the flute.[5] It is reasonable to infer that a simple flute existed prior to a one piece reed pipe, considering the evolution of human creation and invention. It is likely that the one piece reed pipe evolved to a reed pipe with a detachable reed, and then further evolved into a reed pipe with a detachable reed where the instrument body and reed were made from different materials. Perdue Jr. continues,

Figure 1: Woman Playing Aulos
South Theatre of Jerash Jordan



Figure 2: Aulos



> It would be difficult to estimate the earliest date at which canes of *Arundo donax* were first used for making flutes. Relics of the early Stone Age show that man knew how to form a single-toned pipe from bone. The earliest type, the nay, or vertical form, was closed at the base and sounded by blowing across the open end of the tube. Later pipes were sounded by blowing across an aperture placed just below the closed upper end of the tube and were held in a horizontal position…Early man soon discovered that a much more satisfactory instrument could be fashioned from a tube of vegetable material.[6]

It is uncertain what the vegetable material actually was. The centuries old premise that only *Arundo donax* has been used for musical instruments and their reeds could possibly be incorrect. Going back to ancient times, there are many variations of ancient pipes,

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[5] Perdue Jr., "Source of Musical Reeds and Industrial Cellulose," 375.
[6] Ibid, 375.

which include double pipes (Figure 1[7] and 2[8]), parallel pipes, hornpipes, bagpipes, divergent pipes, unequal pipes, and of course the aulos and monaulos.[9] Ancient Egyptians were one of the first peoples to play on a single pipe, also known by the name monaulos.[10] Baines continues, "The instrument is historically important since it represents perhaps the main direct link between the double pipes of the ancient era of reed-instrument history and the single pipes of the modern era."[11] The modern single pipes include many instruments, some of which have been around for thousands of years and are still very much part of living musical traditions and some that have played a huge role in the development of modern-day instruments.

Trading patterns throughout recorded history are known to carry goods and services, but they also carried musical traditions and instruments. The Old Silk Road, the main trade route dating back to the second century B.C.E., stretched from Greece and Europe across central Asia to the east coast of modern-day China and even further to modern-day Japan. The Chinese kuan-tzu, Japanese hichiriki, and many others are among the presumed descendants of the Greek and Egyptian doublepipes.[12] Previous research I have done led me to believe that the musical instruments were brought on the Silk Road east, settled into communities along the way, and then developed into various types of unique instruments to fit cultural practices. Philip Bate solidifies my theory, "In Oriental countries today the double-reed is used with instruments that have probably not changed

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[7] Regiment, "Aulos female southern theatre jerash."
[8] Xinstalker, "Aulos in osso di cervo."
[9] Baines, 194-205.
[10] Ibid, 202.
[11] Ibid, 202.
[12] Ibid, 191-202.

in form in 1,000 years—there is, for instance, evidence in Sanskrit musical writings—and it is almost certain that from the East it found its way into western Europe. The time and manner of that migration are, however, uncertain…Yet, when all our information is sifted, it becomes clear that the use of the double-reed was known in England, France, Spain, and Germany many centuries earlier."[13] Bates then references the evidence he used in making a similar hypothesis within F. W. Galpin's book, chapter 9 in *Old English Instruments of Music* and in Anthony Baines' book on the history of woodwind instruments.

In his book, Anthony Baines discusses the reed making process for ancient instruments in Asia. Both in ancient times and in Asian countries today, double reeds are made by cutting fresh cane, flattening one end of the cane, clamping it, and letting it dry out.[14] This process of making double reeds is almost counterintuitive to how we make them today. We let the plants dry completely before tubes are cut and sorted and we use complex tools and machines to whittle the cane into a playable reed. In pointing out the fresh-cut cane, Baines uses a thought-provoking phrase, "When the latter is fresh-cut cane or some other resilient plant stem…"[15] By saying "some other resilient plant stem," is he implying that no one knows for sure what type of plant was used for double reeds? Even the word "cane" in this sentence is a very vague description. As we will see later in this document, "cane" or "some other resilient plant stem" could refer to potentially hundreds of varieties of plants. Continuing with Robert E. Perdue Jr.'s article from 1958,

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[13] Bate, 12.
[14] Baines, 191.
[15] Ibid, 191.

he claims archeological evidence shows that the woodwind reed originated in Egypt or Mesopotamia as early as 3,000 B.C.E.[16] He solidifies and counters my theory at the same time that most double reed instruments descend from ancient Greece. He solidifies it by mentioning discoveries of "advanced instruments of this type" in various parts of the world dating back to ancient times. In most cases, these instruments' regional inception and common ancestor can be traced to the early civilizations in the middle east.[17] Perdue Jr. sort of counters my theory because up until this point, my theory was that the first reed instruments originated from ancient Greece. While Perdue Jr. does not explicitly debunk this theory, he looks for evidence in areas of the world outside ancient Greece for similar reed pipes. Thus, he lands on his theory that the woodwind reed originated in Egypt or Mesopotamia, which were older civilizations than the Greek Empire. In other words, his theory stretches further back in time than mine. Everything chronologically after the instruments traveled to ancient Greece until present day still aligns with my theory. Perdue Jr. continues, "The first Egyptian reed-woodwind on record was a single tube of cane with finger holes. Pipes of this type are known to have been in use before 3,000 B.C. and by this time, both single and double reeds had probably been developed."[18] Even though we do not have records of reed pipes before 3,000 B.C. when written history started to flourish, they probably existed and might have been widely used. Perdue Jr. describes one of these recorded instruments, "In Mesopotamia, the double-pipe instrument was modified to form a V-shaped double pipe, probably played with two

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[16] Perdue Jr., 377.
[17] Ibid, 377.
[18] Ibid, 377.

single reeds. This is the most familiar type in early paintings and sculpture…An idioglottal reed was cut into a detachable mouthpiece or in the case of some cane instruments cut into the end of the resonator."[19] In the context of ancient Mesopotamia, a idioglottal reed is more similar to a single reed, like a tongue, which is cut and shaped on a tube of cane. The reed was separate and attached to the body of the instrument (idioglottal), like if a modern day clarinet mouthpiece was carved from the same piece of wood but still distinct and detachable from the instrument's body. If it was not idioglottal, it was heteroglottal and the reed was carved from the body of the instrument making the reed undetachable.

Around 1600 B.C.E., the V-shaped double pipe was brought back to Egypt and is the instrument commonly represented on ancient hieroglyphs, paintings, and sculptures. It has not evolved much since and this instrument is still used today in Egypt and in the Islamic world.[20] Perdue Jr. details the travels of the double pipe, "The Moslems were largely responsible for the dispersal of the reed woodwind. They spread the pipe into China, the East Indies, Europe and North Africa, and indirectly through the early Spaniards, to the Americas."[21] Perdue Jr. goes on to say that the aulos used by Grecians and Romans was quite an advanced instrument for its time. It was not "a simple folk instrument like the early form developed by the Egyptians and Arabians."[22] To summarize multiple points, Perdue Jr. believes that some type of reed pipe existed prior to recorded history and the earliest writings that survived point to the woodwind reed

[19] Perdue Jr., 377.
[20] Ibid, 377.
[21] Ibid, 377-378.
[22] Ibid, 378.

originating in Egypt or Mesopotamia as early as 3,000 B.C.E. This Egyptian/Mesopotamian instrument made its way to ancient Greece. Around 1600 B.C.E., the instrument in ancient Greece traveled back to the middle east and has not evolved since, but is still widely used. The ancient Greece double pipes were developed into an innovative and intricate instrument for its time. It was known as the aulos, or monaulos for a single double reed pipe. The reed pipes made it to Rome when the Greco Empire was overthrown and then the Dark Ages hit in the fifth century A.D., ending the Roman Empire.[23] One more interesting statement Perdue Jr. makes in his article is,

> The factors primarily responsible for [middle eastern] origin are the unique characteristics of *Arundo donax* which make it the finest raw material for formation of the reed mechanism and the original geographic distribution of the plant around the Mediterranean Sea and along the Nile. Thus, of the early civilizations, only those of Egypt and Arabia had available the one material that could be most effectively developed. Throughout the entire period that reed instruments were under the influence of north African or southwestern Asiatic peoples, donax cane provided the preferred raw material for the reed and the most easily adapted and most favored material for the resonator as well.[24]

Perdue Jr. argues that one of the reasons why reed pipes originated in Mesopotamia and Egypt is because of the widespread growth of *Arundo donax* around the Mediterranean Sea and Nile River. He also assumes that only the Egyptian and Arabian civilizations had access to the *one viable material* from which to make these reed pipes' reeds: *Arundo donax*. We cannot prove that one of the primary reasons for these instruments originating in the Middle East was due to *the only viable material*, *Arundo donax*, being easily accessible in those regions. Similarly, modern instruments are made from a plethora of

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[23] Perdue Jr., 378.
[24] Ibid, 377.

different materials. Oboes can be made from various types of wood including grenadilla, violetwood, rosewood, and cocobolo. Orchestral string instruments have an even wider variety of woods to choose from including spruce, maple, rosewood, koa, mahogany, cedar, walnut, and ebony. To suggest that there is only one suitable wood for crafting oboes or string instruments would be a mistake, since each individual musician has their own unique preferences. Oboists especially are so keen on experimenting with shapes, brands of cane, staples, and threads. To my knowledge, no one has considered experimenting with the plant.

We have collectively accepted that *Arundo donax* was always used for double reed instruments dating back to antiquity and never stopped to question whether that is historically accurate or not. If we do not question the narrative, we will miss out on opportunities for valuable innovation. Humans are naturally curious about the world around us and our most impactful creations have occurred because we constantly ask questions. With that said, we should critically evaluate the works of authors such as Perdue Jr., and explore alternative natural materials based on historical documentation, including any overlooked or deliberately concealed information. The rationale behind Perdue Jr.'s lack of inquiry regarding the use of ancient reeds and the plants used to make them remains unclear.

Today, we know of over a thousand bamboo species and potentially up to one hundred species of grass-like plants, if not more, that grow in wetlands. It can be difficult to distinguish some of these plants from *Arundo donax*, since they are so similar. We cannot assume with our modern knowledge of plant sciences and advanced classification systems that the *only* plant all civilizations used to make reeds for all types of reed pipes

was specifically *Arundo donax*. In 3,000 B.C.E. humans were just beginning to document history in writing, so it is a bold assumption to make that they would have been able to tell one reed plant apart from another via written descriptions and names. It is important to note that while there is evidence that *Arundo donax* has been used to make oboe reeds since the baroque era, this does not necessarily mean that it is the only plant that has ever been used to make all types of reeds, including both single and double reeds, throughout history.

Anthony Baines writes in his book, "that a pair of aulos reeds was made from a single internode of cane (which varies from 6 inches to 9 inches long) and that where this was cut in two, to make the two reeds, the ends towards the cut formed the 'mouth' of the 'tongues' of each reed; or as we should say, the opening of the blades…The cane for aulos reeds was cut, incidentally, from the same plant that supplies our reed cane today; the best was said to come from around Lake Copais, forty miles north of Athens."[25] Baines' statement on the plant used for aulos reeds seems a bit uncertain. He only said "the same plant that supplies our reed cane today" without directly naming *Arundo donax*. Of the sources considered so far, there is only vague reference to the plant that oboists use for reeds, which is generically "cane plant" or *Arundo donax* without question or substantial evidence, or any potential for reference to the plant is glossed over. Baines' wording of "incidentally" infers it is simply coincidental that *Arundo donax* was used then and now, with no further inquiry. Baines also mentions Lake Copais, which was the largest lake in Greece until the late 1800s. It was drained to expand agricultural land.

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[25] Baines, 199.

When it was last drained, remnants of ancient ditches provided evidence for another time when Lake Copais was drained dating back to 1300 B.C.[26] With the discovery of a drainage project at Lake Copais almost 3,000 years ago due to cultivating the land, the best cane for aulos reeds, according to Baines, came from purposeful cultivation. Was it possible these plants were *Arundo donax*? Possibly, but could it also be possible these plants were something different? Also possible. Perdue Jr. says,

> Around the Mediterranean basin canes of *Arundo donax* were the classical raw material for this purpose, and their use originated independently of the use of bamboo for the same purpose in the Orient and islands of the south Pacific and the use of other materials in North and South America. Primitive flutes or flute-like instruments appear to have been developed by most primitive peoples.[27]

This statement contradicts his earlier statement that Egyptians and Arabians had access to the *only viable material* for reed pipe reeds when reed pipes were first conceived, and that material was *Arundo donax*. Plus, "around the Mediterranean basin" consists of coasts bordering the Mediterranean Sea including northern Africa, western regions in the Middle East, and southern Europe stretching from Greece to Portugal. If people brought reed pipes while they migrated and traveled around the ancient world and on the Silk Road, it would make more sense for live *Arundo donax* plants to have been brought along to make these instruments' reeds. Or the more likely theory might be that no one could tell the difference between *Arundo donax* and other related plants at that point in time, so maybe the *only viable material* consisted of several different plant species that looked the same and therefore, were all viewed as the same plant? With this more plausible theory,

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[26] Smith, "The Island of Gla: An Ancient Mycenaean Mystery."
[27] Perdue Jr., 375.

as time progressed and plant taxonomy gradually became universalized and Western art music tended to exclude other music globally, the *only viable material* by default became *Arundo donax*. Due to a lack of documentation and knowledge prior to our scientific classifications for the various giant reed and river canes based on reproduction, physical characteristic, and genealogy, it was likely easier to say *Arundo donax* was the only plant used for double reed instruments. Investigating the truth with little to no documentation at that point was probably too arduous. The use of the term "bamboo" for the East's double reed instruments' reeds might have sounded more "exotic," with most of the bamboo species being native to regions in Asia, and those instruments were viewed as inferior to the West's equivalent for centuries. The Western classical music field has progressed immensely in the last few decades to include music outside of our purview in conversations on what music is or is not. Similarly, we should look at other double reed instruments for inspiration in preliminary experimentation with different plants for our reeds. If there are other suitable plants for our reeds, why not pursue further research?

Many people today, including myself, have mistaken *Arundo donax* for a type of bamboo. While there are a plethora of bamboo species, *Arundo donax* is a woody grass. Bamboos and river canes are definitely related, but they are not interchangeable. Bamboos and river canes are also related to rice and corn, but we do not make reeds out of rice and corn plants. When Perdue Jr. mentioned the use of bamboo in Asia for double reeds, I suspect he might have been referring to *Phragmites*, since many living musical traditions today use *Phragmites* for their double reed instruments. *Phragmites* is more related to *Arundo donax* than bamboo is. Essentially, *Phragmites* and *Arundo donax* are siblings and both are cousins to bamboo, rice, and corn. Philip Bate says, "Of the changes

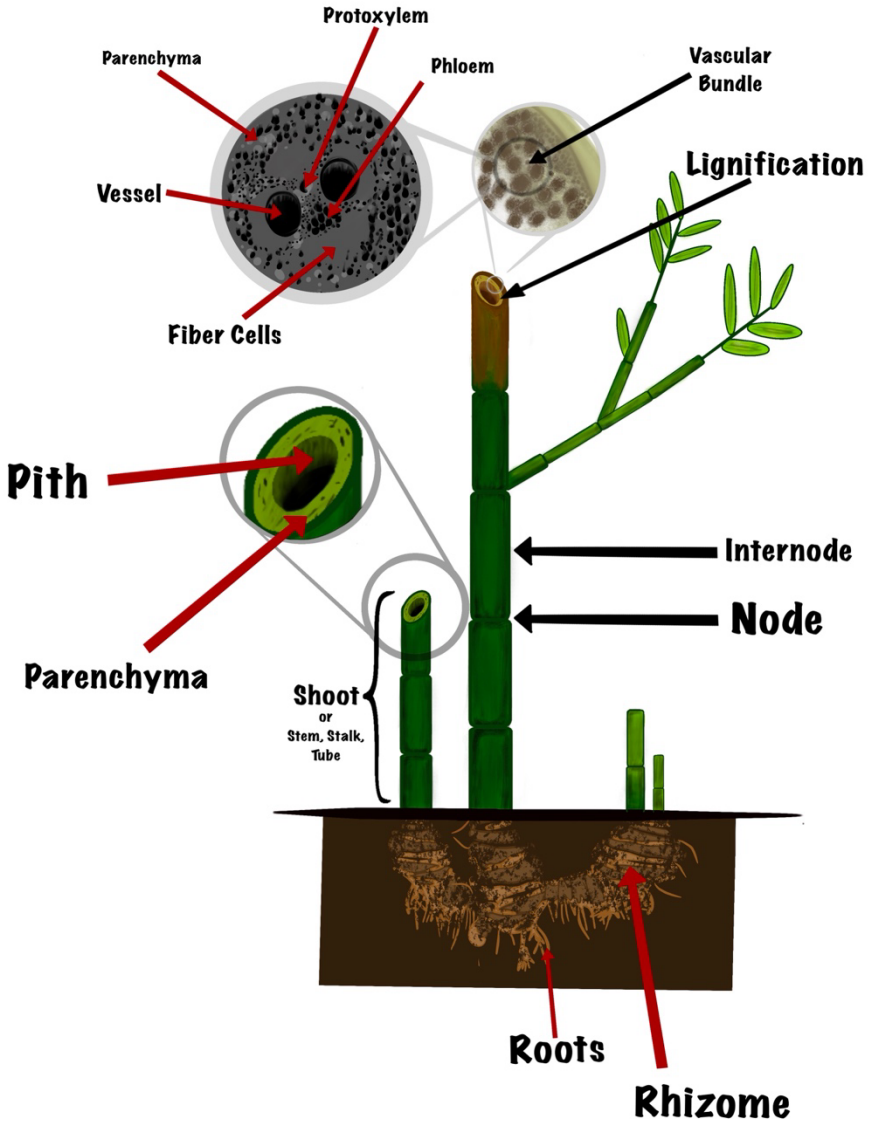
which affected the body of the instrument during that time we have ample evidence; regarding the associated reed we have very little. The oldest undoubted oboe reeds we possess today go back no further than the later years of the 18th century. This is not surprising when we remember how delicate the apparatus is and how perishable in use."[28] It is very unfortunate that the reeds from these ancient instruments and really any instrument older than the 1700s have not survived the test of time and ancient texts contain very little to no information on the reeds. This lack of historical documentation and preservation, as we will explore later, is not necessarily a direct fault of humanity, easily led to the notion today that any and all double reeds are only made from *Arundo donax*. With the natural biodiversity of plant species globally from the tops of the tallest mountains to the depths of the ocean floor, it is still a valid speculation that there is no way only *Arundo donax* was used to make double reeds for the entirety of human civilization.

[28] Bate, 12-13.

Theophrastus and the History of Plants

Continuing more on reeds and less on the evolutions of various reed pipes, we turn to an ancient Greek philosopher who was a successor to Aristotle, Theophrastus. Theophrastus' *History of Plants* is ten volumes of writings from around 370 B.C., the approximate year of his birth. In those ten volumes, he makes the first attempt in human

Figure 3: Bamboo Diagram



history to classify plants based on reproduction.[29] Even though there is little to no historical documentation and preservation, that does not mean there is nothing.

To relate Theophrastus' writings to what we know today in modern plant sciences, the basic structure of *Arundo donax* and all woody grasses is pictured in Figure 3. The diagram's main idea comes from Figure 1[30] in the Yang et al. article and I added more detail necessary for this document's discussions. Beginning underground are the roots. Roots contain rhizomes, which are areas of the roots that allow the plant to spread and multiply. The shoot, or stalk, is the support for the plant. On the shoot, are nodes, which are small solid areas that will grow roots and eventually new plants. Between the nodes are the internodes, which makes up most of the shoot and is the part of the plant used for musical instruments.

Barnaby Brown is the founder of a multi-author blog called "The Workshop of Dionysus." The blog focuses on the revival of ancient double pipes. Brown references Dr. Stelios Psaroudakēs' doctoral thesis[31] to provide evidence in the History of Plants. The thesis suggests that it may not have always been *Arundo donax* which was used for double reeds. He says,

> Like Robin Howell, Stelios Psaroudakēs suspected that *Phragmites australis* was the most likely candidate for 'aulos cane' (*auletikos kalamos*) over 25 years ago. He recently uploaded a PDF, 'Auletikos Kalamos', of the relevant pages from his doctoral thesis (1994)…These 15 pages are essential reading for every aulos player—solid scholarship to be re-read every few years, guiding our practical work and opening our minds to potentially better solutions.[32]

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[29] Loeb Classical Library, "Theophrastus, Enquiry into Plants, Volume I: Books 1-5."
[30] Yang et al., "The hydraulic architecture of an arborescent monocot: ontogeny-related adjustments in vessel size and leaf area compensate for increased resistance," 275.
[31] Psaroudakēs, "*Tragoidia*: Towards a Description of *Lexis* and *Melopoiia*."
[32] Brown, "*Phragmites* australis vs *Arundo donax*." The Workshop of Dionysus.

In Dr. Stelios Psaroudakēs' publication, he discusses the plants used for making reeds and instruments according to Theophrastus. Dr. Psaroudakēs uses some Greek words within the mostly English translations. An English translation of *History of Plants* is available online. The website, ToposText.org, compiles public domain translations of ancient Greek literature and it includes Theophrastus' ten volumes on plants.[33] Theophrastus discusses the various reed plants in thirteen passages, which is a sizable amount. Barnaby Brown cites the passage in §4.11.4, noting harvesting details, which is addressed in the next section on the modern aulos revival. Beginning with the first passage on reed plants, Theophrastus writes,

> **§4.11.1** Of the reed there are said to be two kinds, the one used for making pipes and the other kind. For that of the latter, there is only one kind, though individual plants differ in being strong and stout, or on the other hand slender and weak. The strong stout one they call the 'stake-reed,' the other the 'weaving reed.' The latter they say grows on the floating islands, the stout form in the 'reed-beds': this name they give to the places where there is a thick mass of reed with its roots entangled together. This occurs in any part of the lake where there is rich soil. It is said that the 'stake-reed' is also sometimes found in the same places as the reed used for pipes, in which places it is longer than the 'stake-reed' found elsewhere, but gets worm-eaten. These then are the differences in reeds of which they tell.[34]

Theophrastus makes the distinction between two different plants, one for making reed pipes and the "other kind." The "other kind" grows to be strong and tough or small and weak, which could refer to the age of the plant. Younger reed plants tend to be little and fragile and later on in their growth cycles, they are large and sturdy. The plant not used for making pipes has a wide variety of uses depending on if the reeds are fragile or

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[33] Theophrastus, "Enquiry into Plants."
[34] Ibid, §4.11.1.

sturdy and can grow in the same places as the plant used for pipes. The strong plants grow in reed beds, which aligns with what we know today about river canes. As the environment disrupts these plants whether from drought, fire, winds, inclement weather, etc., the plants grow back bigger and stronger. Theophrastus continues with discussing the growth of the plant used to make reed pipes,

> **§4.11.2** As to the reed used for pipes, it is not true, as some say, that it only grows once in nine years and that this is its regular rule of growth; it grows in general whenever the lake is full: but, because in former days this was supposed to happen generally once in nine years, they made the growth of the reed to correspond, taking what was really an accident to be a regular principle. As a matter of fact it grows whenever after a rainy season the water remains in the lake for at least two years,-and it is finer if the water remains longer; this is specially remembered to have happened in recent times at the time of the battle of Chaeronea. For before that period they told me that the lake was for several years deep; and, at a time later than that, when there was a severe visitation of the plague, it filled up; but, as the water did not remain but failed in winter, the reed did not grow; for they say, apparently with good reason, that, when the lake is deep, the reed increases in height, and, persisting for the next year, matures its growth; and that the reed which thus matures is suitable for making a reed mouthpiece, while that for which the water has not remained is suitable for making a 'cap.' Such then, it is said, is the reed's way of growth.[35]

Theophrastus makes a slight criticism here, where "some" have incorrectly stated that the plants used for pipes grow every nine years, which is the normal length of time between growth cycles. He corrects this by saying the amount of time between growth cycles is not nine years, but rather when Lake Copais fills with water after rainy seasons. Similar to the west coast of the United States, Lake Copais was an empty lake most of the

[35] Theophrastus, §4.11.2.

time and only appeared to be a lake after seasons with a lot of rainfall. The plants best suited for making reeds and "caps," which are the clamps used to hold the reed in its designated shape to dry, are the plants that have matured for two years.

In §4.11.3, Theophrastus continues with discussing plants used for pipes. He says, "it is said to differ from other reeds, to speak generally, in a certain luxuriance of growth, being of a fuller and more fleshy character…though the plume is smaller than that of other reeds, and some have no plume at all; these they call 'eunuch-reeds.' From these they say that the best mouthpieces are made, though many are spoiled in the making."[36] In other words, the plants used for pipes are fuller and more "fleshy" than other plants and can have small plumes or no plumes. A plume is part of a plant that looks like a feather, like a white dandelion that disperses its seeds in the wind. Since most river canes and bamboos have low seed viability, they largely reproduce through their roots. This is comparable to what Theophrastus said about plumes, that the plants used for pipes have very small plumes or no plumes at all. The mature and full plants are the best for mouthpieces. He even mentions "many are spoiled in the making" which resonates with oboists today because of how much cane is discarded due to low quality.

Theophrastus then goes into the processing method for making the reed plants into pipes,

> **§4.11.5** The manufacture is carried out in the following manner. Having collected the reed-stems they lay them in the open air during the winter, leaving on the rind; in the spring they strip this off, and, having rubbed the reeds thoroughly, put them in the sun. Later on, in the summer, they cut the sections from knot to knot into lengths and again put them for some

[36] Theophrastus, §4.11.3.

> time in the open air. They leave the upper knot on this internodal section-; and the lengths thus obtained are not less than two palmsbreadths long. Now they say that for making the mouthpieces the best lengths are those of the middle of the reed, whereas the lengths towards the upper growths make very soft mouthpieces and those next to the root very hard ones. They say too that the reed-tongues made out of the same length are of the same quality, while those made from different lengths are not; also that the one from the length next to the root forms a left-hand reed-tongue. Moreover, when the length is slit, the opening of the reed-tongues in either case is made towards the point at which the reed was cut; and, if the reed-tongues are made in any other manner, they are not quite of the same quality. Such then is the method of manufacture.[37]

The process for drying out the plants is remarkably similar to how *Arundo donax* is dried before tubes are available to purchase. The plants are left outside in the winter and the rind, which is a protective outer layer of the plant and presumably not what we refer to as bark, is stripped off in spring and left in the sun to age. What Theophrastus calls the knot is known as the node. The node is a small, thick, and solid part of the stem and between the nodes are the internodes. The internodes are often hollow and are the parts of *Arundo donax* used for reed making. So, the tube is cut from node to node and the middle of the plant is ideal for making mouthpieces. The upper part of the plant is too soft and the bottom part of the plant is too hard. The lengths of the internodes cut are "two palmsbreadths long," where one palmsbreath was the length from the tip of the middle finger to the bottom of the palm. The inaccuracy of these measurements with people having different size feet, arms, and hands might have contributed to why so much cane is "spoiled," like Theophrastus previously mentioned.

Theophrastus discusses where to find the plants used for pipes,

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[37] Theophrastus, §4.11.5.

§4.11.6 This reed grows in greatest abundance between the Kephisos and the Melas; this district is called Pelekania, and in it are certain 'pots,' as they are called, which are deep holes in the marsh,- and in these holes they say that it grows fairest; it is also said to be found where the river called the Probatia (Sheep) comes down, which is a stream that flows from Lebadeia. But it appears to grow fairest of all near 'Sharp Bend'; this place is the mouth of the Kephisos; near it is a rich plain called Hippias. There is another region north of the Sharp Bend called Boedrias; and here too they say that the reed grows fine, and in general that it is fairest wherever there is a piece of land with deep rich alluvial soil, where also Kephisos mingles his waters with the soil, and where there is further a deep hole in the marsh; for that about the Sharp Bend and Boedrias all these conditions are found. As proof that the Kephisos has a great effect in producing the reed of good quality they have the fact that, where the river called the 'Melas' flows into the marsh, though the marsh is there deep and the bottom of good alluvial soil, it either does not grow at all or at best but of poor quality. Let this suffice for an account of the growth and character of the reed used for pipes, of the manufacture, and of its distinctive features as compared with other reeds.[38]

Figure 4: Map of Ancient Boeotia



[38] Theophrastus, §4.116.

In Figure 4,[39] I highlighted locations Theophrastus describes on the 18th century map of ancient Boeotia where reed plants were found. Northwest of Lake Copais is the Kephisos, also known as Cephissus,[40] and the Melas are rivers, so between the rivers is the area of Pelekania. Presumably north of the Kephisos River, around the rainbow shaped arc, is where the "Sharp Bend" or Boedrias are located. South of the Kephisos is the Phalaris River, which goes through Lebadeia. This might be the Probatia River that Theophrastus mentions. Lastly, between the mouth of the Kephisos, Melas, and Lake Copais is presumably Hippias. A screenshot of modern Greece from Google Earth, (Figure 5)[41], is provided where I highlighted where these rivers, marshes, and Lake Copais were. It might prove to be worthwhile to have archeologists survey the areas where—according to Theophrastus—the reed plants for pipes grew in his time. If any organic material is found, an analysis of that organic material may determine if those plants were *Arundo*

Figure 5: 21st Century Greece 



[39] Barthélemy, "Map of Ancient Boeotia."
[40] Theoi Greek Mythology, "Kephisos."
[41] Google Earth. "Lake Copais, Orchomenos, Greece."

donax, or potentially something else. To my surprise and knowledge, this has not been done yet.

Strabo, a Greek philosopher who lived from about 64 BCE to 21 CE,[42] also wrote about where the plants for pipes were found. Unlike Theophrastus, Strabo wrote about geography extensively in what we know today as *The Geography of Strabo*. It consists of fourteen books that have been translated to English on ToposText.org. Strabo says,

> And it is said that a fissure in the earth opened up near Orchomenus, also, and that it admitted the Melas river, which flowed through the territory of Haliartus and formed there the marsh which produces the reed that is used for flutes. But this river has completely disappeared, either because it is dispersed by the fissure into invisible channels or because it is used up beforehand by the marshes and lakes in the neighborhood of Haliartus, from which the poet calls the place 'grassy,' when he says, 'and grassy Haliartus.[43]

In writing about the Melas River, the river had completely disappeared between the time Theophrastus wrote *Enquiry into Plants* and when Strabo wrote about geography, which is only a span of a few hundred years. Over the course of human history, we know of a few drainage projects at Lake Copais, the last of which led to Lake Copais being fertile farmland on Google Earth. Strabo mentions a poet calling the areas in Haliartus "grassy," of which the majority of plants considered for musical instruments are considered types of grass. Whether the "grassy" nature of the land after the Melas disappeared consisted of reed plants or not, is unknown.

The last mention found of these regions and the reeds come from Lieutenant-Colonel William Martin Leak, who was "a traveler and British military geographer who

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[42] Lasserre, "Strabo."
[43] Strabo, "The Geography of Strabo, Books 1-5 and 6-14," §9.2.18.

visited the southern Mani peninsula, Greece, in 1805."[44] The volumes he wrote on traveling in Greece are on ToposText.org, along with Strabo's and Theophrastus' writings. Leake says,

> The other large source or branch of the Melas, which is to the westward of the [Cephissian basin], follows for a considerable distance the foot of the cliffs of Orchomenus, and is then lost in the marshes. This illustrates Plutarch, who, after having remarked that 'the plain of Orchomenus is the largest and finest in Boeotia, but naked of trees and plants, except towards the Melas,' observes, that "this river rises below the city of Orchomenus, and is the only river in Greece which is navigable at its sources, though it has not a long course, the greater part being lost in impervious and muddy marshes, and the remainder uniting with the Cephissus near the place where the lake produces the auletic reed.'…Although I cannot obtain a confirmation of the periodical swelling of the Melas from the present inhabitants, such a negative testimony will hardly invalidate the observation of the more enlightened native of the neighbouring Chaeroneia…The marshes still produce in abundance the reeds for which Orchomenus was anciently noted. The auletic or flute-reed is described by Pliny as very long and without knots. Plutarch observes, that the best were produced near the junction of the Cephissus and Melas. But the latter river was not generally favourable to them, according to Theophrastus, who mentions as the best situations some deep pools called the Chytri, in a place named Pelicania between the Melas and Cephissus; the confluence of the Probatia and that of the Cephissus with the lake, a place to the northward of the latter junction named Boedrias, and generally wherever the water was deep and the bottom muddy. Hence the growth and quality depended upon the depth of water in the lake, which varied annually, and was said to be the greatest every ninth year.[45]

Leake, in the 1800s, does not say the Melas River was completely dry but rather that it flows into the Orchomenus region's marshes. Leake evidently read Theophrastus' writings and made an inference that the Melas River might ebb and flow depending on

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[44] Siefried et al., "Reconstructing historical journeys with least-cost analysis: Colonel William Leake in the Mani Peninsula, Greece," 392.
[45] Leake, "Travels in Northern Greece (v. 1-4)," §2.155-2.1556.

the season and climatic patterns, like Lake Copais had. As of 1805, the people who lived near the Melas River could not say for certain that it rises and falls. And as of 1805, the same areas Theophrastus wrote about nearly two thousand years prior still produce the same reed plants used to make pipes. Even though Theophrastus criticized the principle that the reed plants grew every nine years due to the water levels of the lake, Leake still holds that as truth. Further investigation of Lake Copais and these rivers today would lead to more solid data on the reed plants, if they still grow there. If they still exist, it would be relatively easy to identify what type of plants grow there, being *Arundo donax* or maybe a different plant. If this hypothetical investigation should take place, keeping in mind hybridization over the span of thousands of years is likely to have occurred so the reeds in those marshes, if any at all, are probably not the same plants that existed in 1805 or in Thephrastus' time. Leake mentions other types of reed plants:

> Distinct from the auletic reed were the Characeias, or reed serving to make fences and palisades, which was very thick and strong, and grew on the banks of the lake; and the Plotia, so called as growing on the [floating islands], which, like those of the Lake of Ioannina, are formed of decayed reeds, rushes, and roots of grass, furnishing a soil for fresh plants, and which, detaching themselves from the edge of large tracts of the same materials, are launched into the lake by the wind.[46]

This description of the other reed, Characeias, aligns almost identically to what Theophrastus wrote, which is addressed next. The only difference is that the reed plant had a name, Characeias, in 1805. Upon further investigation of the name, there is a species called Characeias in scientific classification terms, but it does not seem to be

[46] Leake, §2.157.

related at all to any reed plant. All other directions lead right back to Leake's geographical volumes. Theophrastus continues describing other reeds,

> **§ 4.11.7** But these are not the only kinds of reed; there are several others with distinctive characters which are easily recognised; there is one that is of compact growth in flesh and has its joints close together; another that is of open growth, with few joints; there is the hollow reed called by some the 'tubereed' inasmuch as it has hardly any wood or flesh; there is another which is solid and almost entirely filled with substance; there is another which is short, and another which is of strong growth tall and stout; there is one which is slender and has many leaves, another which has few leaves or only one. And in general there are many differences in natural character and in usefulness, each kind being useful for some particular purpose.[47]

Theophrastus emphasizes that there are more reed plants than just the type used for pipes and the "other kind" he initially discussed. Joints, in this passage, presumptively refer to the nodes. So there are plants with nodes that are close together, plants with little to no nodes, and plants that vary with hollowness, thickness, and leaf structures. He makes sure to say that all of these plants are useful for whatever purpose suits its properties. Two more distinctions he makes between the various types of reed plants are "bushy" and those that do not grow in a bush form. Theophrastus writes, "Some distinguish the various kinds by different names; commonest perhaps is the pole-reed, which is said to be of very bush habit…there is also a kind of reed (bush-grass) which grows on land and which is not erect, but sends outits stein over the ground…a number of reeds of this kind [bamboo] grow from one base and they do not form a bush…"[48] In distinguishing between bush reeds and non-bush reeds, he might be referring to clumping

[47] Theophrastus, §4.11.7.
[48] Ibid, §4.11.8, 4.11.10, 4.11.11.

versus running in terms of reproduction. Running reed plants stretch out further and "run" underground with their roots while clumping reed plants prefer to grow in small areas. Clumping plants still spread their roots underground, but not anywhere near the extent of running plants. So essentially, bushing may be analogous to clumping and non-bushing might be analogous to running. Theophrastus addresses bamboo,

> **§4.11.11** The Indian reed (bamboo) is very distinct, and as it were a totally different kind; the 'male' is solid and the 'female' hollow (for in this kind too they distinguish a 'male' and a 'female' form); a number of reeds of this kind grow from one base and they do not form a bush; the leaf is not long, but resembles the willow leaf; these reeds are of great size and of good substance, so that they are used for javelins. They grow by the river Akesines. All reeds are tenacious of life, and, if cut or burnt down, grow up again more vigorously; also their roots are stout and numerous, so that the plant is hard to destroy. The root is jointed, like that of the dogstooth grass, but this is not equally so in all kinds. However let this suffice for an account of reeds.[49]

Theophrastus is correct in stating that bamboo is distinct and different from any of the prior river canes discussed. He also affirms modern plant sciences here, where all reed-like plants grow back stronger when they are disrupted. Regarding bamboo and a few other reed plants, Theophrastus mentions male and female forms in the plants, which he might be attempting to connect the structure of the plants to its reproduction. This is the first instance where Theophrastus' writings do not align with modern plant science. Bamboos and reed-like plants grow by spreading their roots underground and popping up new shoots, and rarely do they reproduce by seed. He may be attempting to understand how reed plants reproduce, spread, and grow throughout their lifecycles by attributing

[49] Theophrastus, §4.11.11

male and female characteristics to the plant's interior structure rather than the plumes or flowers' reproductive systems.

After conversing with other oboists, it appears that the consensus is reeds of some aulos or aulos-like instruments were made of rush. Theophrastus actually mentions rush,

> **§4.12.1** It remains to speak of the rush,- as though it belonged to this class of plants, inasmuch as we must reckon this also among water plants. Of this there are three kinds, as some distinguish, the 'sharp' rush, which is barren and is called the male'; the 'fruiting' kind which we call the 'black head' because it has black fruit; this is stouter and fleshier: and third the 'entire rush' as it is called, which is distinguished by its size, stoutness and fleshiness…**§4.12.2**…The 'fruiting' — ones are in general scarcer, for the 'entire rush' is more useful for wicker-work because of its fleshiness and pliancy. The 'fruiting' rush in general produces a club-like head which swells straight from the wiry stem… Now it is a peculiar fact about the roots of this plant that they wither every year and that the fresh growth of roots comes from the part of the plant which is above ground. Such is the character of rushes.[50]

Theophrastus' brief discussion on rush questions this modern consensus that rush was used for pipes' reeds. §4.11.6 was the last mention of the plants used to make double pipes and rush was only mentioned much later in §4.12.1. His deliberate separation of the plants used to make pipes and rush along with rush withering every year debunks the consensus that rush was used for musical instruments. He even mentions the "fleshiness" and "pliancy," where pliancy is defined as being able to bend easily without being damaged or losing shape. These qualities are not conducive for appropriate material for musical instruments' reeds.

Barnaby Brown continues explaining Theophrastus' writings,

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[50] Theophrastus, §4.12.1, 4.12.2.

> Theophrastus describes several species of cane, none of which fits *Arundo donax*. The most likely explanation for this is that *Arundo* was not growing in Boeotia in the fourth century BCE, but is a later introduction: According to the World Checklist of Selected Plant Families (Board of Trustees of the Royal Botanic Gardens, Kew), this species is native only to a fairly narrow area bounded by Cyprus, Kazakhstan and Turkmenistan in the west, the Gulf States in the south and Japan south to Myanmar in the east. The same source describes it as occurring as an introduction from the Atlantic Ocean island groups and the Iberian Peninsula throughout the Mediterranean. Lotus wood and tibia bones were used for the bombyxes of more expensive, professional instruments—the ones buried as grave good that survive in museums. Ancient Egyptian doublepipes, however, (several of which survive from around 1100 BCE) are made of *Phragmites*. This is also the species used for aulos-like reeds in living musical traditions all the way from Egypt to Japan.[51]

Again, if there are both ancient writings from Greek philosophers all the way to living uses of *Phragmites* for musical instrument reeds, why are Western classical music musicians so stuck on *Arundo donax* or synthetic materials? Brown continues, "It is regrettable that we did not respect Theophrastus's writings earlier. By using reed cane ordered on the internet, swayed by convenience and modern Western cultural prejudice, I think we have lost a lot of time and energy travelling in the wrong direction. *Arundo* makes life as an aulos player unnecessarily difficult. The fact that *Phragmites* is disparaged or completely overlooked by Western reed makers is perhaps best explained as a cultural blind spot. This appears to be a perfect example of preconceptions hindering progress."[52] Barnaby Brown phrases the disregard for Theophrastus' writings as a "cultural blind spot." There still are a lot of "cultural blind spots" in Western classical music today despite conscious efforts to minimize them. As a result, there are blind spots within those cultural blind spots that most people do not know about or recognize. One of

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[51] Brown.
[52] Ibid.

those blind spots is unquestionably related to research related to single and double reeds, especially double reeds. Reed making is probably the area of classical music that has evolved and changed the most in the last few centuries, most notably in North America Marcel Tabuteau's conception of the American scrape oboe reed, for example. The progress in reed making has ceased to remotely explore other natural plants to use besides *Arundo donax*. Why can't we look toward cultures outside of the West throughout the history of human civilization for inspiration in the areas of reed making?

The Modern Day Aulos Revival

Over the last hundred years or so, there has been a surge of musicians who play on reconstructed period instruments, mostly from the medieval to baroque eras. However more recently, there has been a surge of amateur to professional musicians who play on reconstructed double pipes. One of these musicians is Barnaby Brown. Barnaby Brown posted in September of 2019 on "The Workshop of Dionysus" detailing his experiments with *Phragmites australis* cane. He says, "So far as I am aware, no aulos player today uses reeds made of Common Reed, *Phragmites australis*. We all use Giant Reed, *Arundo donax*. The reason is simple: the doublepipe revival began in a cultural environment that only esteemed *Arundo*. The expert reed players who influenced us had little or no experience using *Phragmites*. It cannot be ordered from reed cane suppliers because *Arundo* is the only species used to make reeds for oboe, bassoon, clarinet, Sardinian launeddas, and the bagpipes of Spain, France and Scotland—and this has been the case for at least 300 years. Had the aulos revival begun in Africa or Asia, it would have been a different story."[53] Brown makes a valid point here, that had the double pipe revival began in Africa or Asia, the reeds would presumably be made out of something else, with the most likely candidate being *Phragmites*. Today, hichiriki players in Japan still use *Phragmites*, and many double reed instruments in Asia have reeds made from *Phragmites*. It makes logical sense that if the double pipe revival began in Asia, the reeds would probably be made from *Phragmites*. Besides unknown potential prejudices that still persist in Western art music's culture, why have oboists not experimented with

[53] Brown, "*Phragmites* australis vs *Arundo donax*."

Phragmites? For how much oboists love to experiment with different shapes, gouges, threads, brands of cane, and staples, one would think they would also love to experiment with cane from different plants. Looking to other regions of the world at single and double reed instruments for vision on potential use of other materials for any woodwind instrument should be considered.

The double pipe revival beginning in the Western world, where *Arundo donax* is the primary and only plant used for musical instrument reeds, may or may not be historically accurate. The lack of research on using other materials for any musical instrument reed is very unfortunate. Brown's website led me to research various materials for making oboe reeds, only to find that this area of woodwind pedagogy is under-researched. Woodwind players seem to prefer using synthetic materials for making musical instrument reeds, even though the long-term health effects of these materials are not yet known. Instead of considering the history of natural materials used for reeds, they could experiment further with these materials to gain a better understanding of their potential. Many oboists struggle daily with making reeds and searching for the "perfect reed," which does not exist. We always complain about our reeds and often make subpar reeds to keep up with our playing needs. Maybe the perfect reed exists with a simple change of the plant we use?

Barnaby Brown continues with his *Phragmites* quest, "On 30 August, I made my first *Phragmites* reed…I picked up tips from many people but particularly from Callum Armstrong and Robin Howell. Thank you both for sharing your expertise! I am especially grateful to Robin for sharing his suspicion that *Phragmites* fitted the historical

evidence—literary and material—better than *Arundo*."[54] Brown says that his first attempt at making a reed with *Phragmites* was unprecedentedly successful. It took very little effort to make, functions better than *Arundo donax* reeds, and the tone, response, dynamic and timbral range are all "superior to anything I have experienced…I don't think this is due to my skill but to the material: *Phragmites australis*."[55] Brown used *Phragmites* cane which he harvested himself. Many people I know have attempted to make reeds for oboe or bassoon using *Arundo donax* they harvested along highways or grew themselves. The results, however, were disappointing. For Barnaby Brown to harvest *Phragmites* himself and have a huge success on the first reed he made speaks volumes to the potential quality of the plant for oboe reeds. This is likely why *Arundo donax* goes through such a rigorous sorting process, to weed out unsatisfactory tubes before reed manufacturers and vendors receive them to sell to musicians and reed makers.

For *Arundo donax*, the harvesting and curing process of cane in order for oboists to purchase the beautiful tube cane that various vendors sell is quite complicated. According to Capitol Cane, "*Arundo donax* stalks are harvested only after 2 years of growth. Harvest time is mid-December through March and is said to take place on the new moon. Some cane is cultivated on plantations and some cane is harvested in the wild."[56] Another website, the Arundo Research Company, says that cane is harvested at the new moon.[57] Mark Eubanks claims that cane is best at the new moon since "Pith is up because the moon is out during the day, and with that excess moisture in there the cane

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[54] Brown.
[55] Ibid.
[56] Capitol Cane, "From Field to Tube."
[57] Arundo Research Company, "Harvesting and curing *Arundo donax* for reed cane."

dries out more slowly and discourages shrinkage."[58] The pith Eubanks refers to is the soft interior of the plant that eventually breaks down and leaves it hollow.[59] In Brown's translation of Theophrastus' writings, Theophrastus says the time for harvesting the cane plants is late September at the start of the new moon,[60] so there could be some validity in harvesting at the new moon. The cane is then dried out for two to four months where the leaves are still attached. Once the leaves are removed or decomposed, it is gradually turned in the sun and this stage lasts at least three weeks, if not longer.

Overall, cane is dried outdoors anywhere between six to twelve months and the cane we end up with to make reeds is three to five years old. The three to five years number includes the growth of the plant from a freshly sprouted shoot to tube cane. Many oboists insist that the external cane color indicates the quality of the cane and will yield either good or bad reeds. The general yellowish color is due to the sun exposure stage. Sometimes, this color is uneven or a little lighter in some spots which indicates that certain sides of the tube simply received slightly more time in the sun than the other sides. The dark brown spots are from the leaves decaying during the initial drying stage. The yellow color or dark brown spots are external, not internal. If the internal colors of the cane were as variated as the external colors, then there should be caution moving forward in the reed making process, but since the yellow and dark brown colors are just due to how the cane was dried and nothing more, that should not be a deciding factor in whether the tube goes in the trash or not.

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[58] Arundo Research Company.
[59] Northwoods Oboe, "Where Oboe Cane Comes From."
[60] Brown.

Brown predicts that most double pipe players will switch over to *Phragmites* within three years. His reasons are, "1. The success rate making reeds is higher: a lower density and greater plasticity make *Phragmites* less prone to cracking when forming the blades. 2. For the same reason, reeds are less likely to crack after hours of playing; the frustration of your best concert reeds cracking will not be experienced so frequently." [61] The double pipe reed making process is quite different than the oboe reed making process, as we previously covered, and oboe reeds rarely crack during their lifespans. However the double pipe reed is still a double reed and it is a fair assumption to make that *Phragmites* oboe reeds would also have a higher success rate. It has also been four years since Brown made his prediction, and there have been no updates since on the *Phragmites* revolution for double pipe reed making.

Brown continues, "3. The chances of making a yoke of reeds from a single internodal section are higher, resulting in less time spent balancing singletons and more time spent playing beautifully-balanced reeds, matched by nature (because the vibrating tips grew 'kissing' each other on either side of a cut). 4. The time and effort involved in making reeds are lower: there is less substance to remove and much less force required to form the waist."[62] The third reason Brown listed for his prediction on switching entirely to *Phragmites* may partially apply to oboe or bassoon. Less time spent on reeds would be a wonderful benefit, since oboists spend at least a third if not more of their time making reeds and that extra time saved could go to practicing and improving their overall craft.

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[61] Brown.
[62] Ibid.

Phragmites oboe and bassoon reeds might also be much more balanced and vibrate better.

Brown goes on, "5. Only *Phragmites* fits the botanical description of aulos cane written in the decades after 338 BCE by Theophrastus. *Arundo* grows large and strong enough to make aulos reeds without any water in sight, whereas *Phragmites* is too small and weak to make reeds unless it grows in fertile soil in, or beside, a lake or river that hasn't run dry for at least two years."[63] *Arundo donax* is considered an invasive species in the United States[64], so it makes sense that it can grow even in the toughest conditions but that does not always mean *Arundo donax* grown in harsh conditions will yield high quality cane for reeds. A more careful and controlled approach to growing *Phragmites* might prove to be challenging with growing climate change concerns, however the climate has already threatened the supply of *Arundo donax* from France so it is worth a risk to attempt to cultivate *Phragmites* for reeds, if proven to be a successful candidate.

Continuing with his reasons why *Phragmites* is the reed plant of the future, Brown says,

> 6. Only by using historically-accurate plant species can we hope to penetrate the meaning of this passage by Theophrastus: 'Before the time of Antigenidas [fl. 387-53 BCE] when they played without plasticity [aplástōs, ? without pitch-bending], the time for the cutting, they say, had been under Arcturus in the month of Boedromion [i.e. late September: Arcturus was barely visible before 20 September in Boeotia, in the late 4th century BCE, and Boedromion ends at the new moon after 21 September]… When they embraced the plastic [plásis] style, the cutting changed too: now they cut it during the months of Skirrophorion and Hekatombaion, shortly before or just at [the summer] solstice. They say it becomes usable within three years, requires little preparation [kataulēsis,

[63] Brown.
[64] United States Department of Agriculture, "Field Guide for Managing Giant Reed in the Southwest."

> presumably either soaking the reeds before playing, or breaking in new reeds], and the reeds permit down-pulls [kataspásmata, ? greater downward inflections of pitch]. This is necessary for those playing with plasticity [lit. 'of plastic pipe-playing']. -Historia Plantarum IV.ii.4-5' This translation (and those below) is my own revision of Andrew Barker's, informed by conversations with Stefan Hagel and Sylvain Perrot, and by my own experience as an aulos player.[65]

Essentially, Theophrastus'—ancient Greek philosopher who was a successor to Aristotle—writings describe the pros and cons of harvesting cane under certain conditions. If harvested in late September, there can be no pitch bending when playing. If harvested around the summer solstice, it is easier for pitch bending when playing. The style of playing relies heavily on when cane can be harvested for reeds. The cane can be used within three years, which is not growth time but rather the period of time after a reed is constructed. For thousands of years, double reeds were made by cutting fresh cane, smushing the blades together, clamping it, and letting it dry. Brown continues, "Today, Arcturus rises some weeks later. The time for harvesting cane, however, has nothing to do with the influence of the stars: in ancient Greek culture, dates in the agricultural calendar were fixed to star-risings simply because the lunar months moved. A thirteenth month had to be inserted about every third year to keep the months in sync with the seasons."[66] In interpreting Theophrastus' explanation for the harvesting process of the cane, Brown relates the calendar the Greeks used to our modern day calendar to show similarities in harvesting *Phragmites* back then and how we harvest *Arundo donax* today.

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[65] Brown.
[66] Ibid.

From the Dark Ages to the 17th Century

The Downfall of the Aulos

Gregorian chant rose to popularity and musical instruments all but almost died out due to the Church's strict policies on musical instruments. In the Dark Ages, most were considered peasants and did not have easy access to most of the wind instruments that had survived up until that time. Since wind instruments were so inaccessible, the common folk of the early Dark Ages could not afford to learn about or how to play the Greek and Roman pipes. The professional aulos players and instrument makers were not able to carry on the information on how to play the aulos and how to construct it. As a result, the sophisticated Greek and Roman pipes died out and all traces of its existence vanished except for evidence of its existence in paintings. From the beginning of the Dark Ages until the late Medieval Period, we do not have any historical information on these reed pipes and "was thus an end line of evolution, completely submerged by the darkness of the Medieval Age, an extremity of a branch of the family tree whose main trunk was to culminate in the modern reed-woodwind."[67] This was not the end of all the reed pipes, but only the most complex and developed ones, which became inaccessible to the common person.

The simpler reed pipes survived in many other areas of the world and continued to spread globally. The simple reed pipe eventually made its way back to the Church as all instruments became more acceptable and restrictions loosened. The simple reed pipe

[67] Perdue Jr., 378-379.

eventually evolved into modern clarinets, oboes, bassoons, and saxophones.[68] Perdue Jr. poses an interesting question none of the other sources have,

> Today, one can only speculate as to what would be the nature or quality of our music, both classic and modern, had not *Arundo donax* been available to the early civilizations of Egypt and southwestern Asia and the later civilization of Europe. Undoubtedly, the initiative of the early artisan would have culminated in the successful application of another material to the making of reeds. Can we comprehend the effect of such a material upon the evolution of music?[69]

What would our music look like had instruments developed using a different plant for their reeds? How would other instruments have developed alongside woodwind instruments that use reeds? Double reed instruments have clearly been integral to the development of classical music as we know it today, so it is an interesting idea to ponder if brass, percussion, flutes, and strings would have also been different.

[68] Perdue Jr., 379.
[69] Ibid, 380.

Double Reed Instruments Not Considered by the West

Many Western classical musicians are unaware of a variety of double reed instruments due to their historical neglect and as a result, are unaware of the materials these instruments use for their reeds. Prior to my research, I thought most double reed instruments utilized *Arundo donax* for reeds, but that is not entirely correct. If we are looking at the history of double reeds to determine the reed materials mentioned, we should include double reeds outside of Western classical music. The instruments addressed in this section to survey reed materials are the chirisuya, hichiriki, the double reeds played by Native Americans on the northwestern coast of North America, suona, algaita, whit-horn, and the crumhorn.

Figure 6: Chirisuya



Perdue Jr. says, "Around the Mediterranean basin canes of *Arundo donax* were the classical raw material for this purpose, and their use originated independently of the use of bamboo for the same purpose in the Orient and islands of the south Pacific and the use of other materials in North and South America. Primitive flutes or flute-like instruments appear to have been developed by most primitive peoples."[70] The "other materials in North and South America" Perdue Jr. briefly mentions might give clues to other potential candidates. One of the instruments in Latin America is called the "chirisuya" (Figure 6)[71]and it is an Incan instrument.[72] Arturo Enrique Pinto Cárdenas

[70] Perdue Jr., 375.
[71] ArtProf, "Chirimia Guatemala."
[72] Cárdenas, "The 'Chirisuya' Instrument 'Inca' or Moorish?"

talks about this instrument in depth on the Museum of Musical Instruments and Cultural Center website, which is originally in Spanish, but I used Google Translate to translate it to English. Cárdenas says that the chirisuya is considered to be an instrument of the Incas,[73] of which the Incan Empire reigned in Peru from 1000 A.D. until 1537, when the Spanish took control of Peru.[74] The chirisuya comes from the chirimía, which is a type of oboe of Moorish origin. Indigenous people in some regions adopted the use of this instrument.[75] Interestingly enough, the reed was made of some type of plant material that was later modified to be made from the barrels of condor feathers.[76] Cárdenas reasoning for this change is, "Formally, condor feather reeds were used instead of reed, symbolic and religious, the cult of water = 'Inca' religion, instead of procession = Catholic religion and politically, from being a demonized instrument and prohibited in Catholic rites for being of Moorish origin to being adopted by cults of pre-Hispanic origin."[77] Switching chirisuya reed material from an unknown type of plant to condor feathers was purely for symbolic, religious, and cultural reasons.

Considering the history of the Church and how strict they once were with allowing any wind instruments in or near its doors, it makes sense that indigenous people of South America would want to make the chirisuya more acceptable to better fit their religious beliefs and culture rather than sticking with what Europeans deemed fit. Upon researching condor feathers to examine images, many sites say the feather has healing properties and are used in many rituals, not just in South America, but also in North

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[73] Cárdenas.
[74] "Incas." *Oxford Reference*.
[75] Cárdenas.
[76] Ibid.
[77] Ibid.

America. The author of a blog post on the Eagle Condor Farm website, simply going by the name Monica, says that feathers are linked to air, freedom, and pure potential in ancient symbolic meaning. She continues, "They are attributed to transformation that is strong, swift and potent. Feathers are used by a healer ('yachek' in the Andes or shaman) on the aura (energetic body) of an individual, in smooth, long strokes from the head to the feet, in order to clear energy. They are used from any one of the nine cardinal directions towards the body in order to invoke healing energy."[78] I wish Cárdenas would have known what type of reed material was used for the chirisuya before feathers were used, since *Arundo donax* probably did not grow widespread in South America at the time. Regardless, it is very interesting the indigenous people of Latin America used condor feathers for chirisuya reeds and I think oboists would find the physics of a double reed made from feathers fascinating. However, out of respect for the various cultures across the globe that use condor feathers in rituals and view them as sacred, the feathers are not part of my study and I did not pursue purchasing feathers for making oboe reeds.

The most well-known instruments Native Americans play are flute-like instruments, but some tribes have double reed instruments. F.W. Galpin details five tribes on the west coast of mainland Canada and a few islands off the coast in his article written in 1902. He says, "The [Native American] double-reed is not formed of natural reed or cane as among the peoples of other continents, but of wood, generally red cedar or spruce."[79] When coming up with the structure of this document, I figured the plants I might find were river canes or bamboos. I never would have thought a double reed

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[78] Monica, "Condor feather significance & healing."
[79] Galpin, "The Whistles and Reed Instruments of the American Indians of the North-West Coast," 124.

instrument from anywhere would have been made from trees with dense wood and trees mostly used as building materials, paper, and Christmas trees. Additionally, spruce wood is one of the standard materials used for guitars, mandolins, cellos, violins, and parts of pianos and harps.[80]

Galpin details the reed making process,

> The wood is split in half lengthwise, the lower part of each half is hollowed out, the hollow gradually diminishing in depth and size towards the upper end of the block. The two halves are then bound together with spruce roots and the upper part is thinned down on either side until a flat tongue-shaped end is left, split in half by the previous cleavage of wood. The two thin pieces, which stand slightly apart, vibrate and beat upon each other when the air is impelled through them.[81]

Galpin even went as far to make a reed like this for modern wind instruments, from 1902 when the article was written, and he was not able to produce a "musical note."[82] Whether Galpin was able to produce any sound using the spruce or red cedar reed on the modern wind instrument circa 1902 is unknown. Woodwind instruments have evolved arguably the most in history in the last 121 years, including Marcel Tabuteau's inception of the American scrape, so it would be a great experiment to see if spruce or cedar would actually work for oboe reeds. Of course, our machines and tools were designed and manufactured around *Arundo donax*, so the making of these reeds would be quite complicated. Assuming there is machinery that exists today that could theoretically cut tubes in the right diameter with the right thickness from spruce or cedar, we might be able to use our existing tools to process the cane all the way to a finished reed. After all,

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[80] Wikipedia, "Spruce."
[81] Galpin, 124.
[82] Ibid, 128.

American oboists scrape across the entire reed and the little bark on *Arundo donax* that is left does not necessarily have to be bark with the use of tree wood, those sections just have to be thicker in order to maintain the opening and skeleton of the reed. All of this is to assume that spruce and cedar are around the same hardness as *Arundo donax*. Since a lot of our reed making machines and tools are quite delicate and finicky, putting the spruce and cedar through the machines would break and damage them if it is significantly harder than *Arundo donax*. Also globally, the vast majority of double reed instruments' reed making processes involve working with fresh plant material and clamping it in the shape of a reed to dry.

Galpin continues later on in the article with a discussion about how the Northwest Coast Native Americans came up with the similar structure to nearly all double reed instruments across the world. He says, "The question therefore is not only what peoples are likely to have come in contact with these Indians, but also how far are the sound-producing principles common to both…At the close however of the eighteenth century there was a constant trade between this coast and China, and it has been suggested that the advanced skill and technical power of these Indians is due to some such—perhaps still earlier—communication with the Asiatic Continent…I do not think that the trade with China or the arrival of any Japanese voyagers can have given to these Indians such musical principles as they have."[83] Further inquiry into other sources on if any people from Asia were actively trading with the Northwest Coast Native Americans proves to be somewhat true. According to Robin Inglis, "In the era of prehistory and the historical

[83] Galpin, 134.

period there is also clear evidence that boats carrying people from Japan and China were swept across the North Pacific by the prevailing winds and currents to land upon the shores of America."[84] Inglis clarifies that the chronology following the arrival of people from Asia only highlights known events and achievements of specific people verified by the historical record.[85] John Meares, an English explorer, defied the laws of the East India Company and established a shore station and established a transoceanic link with China.[86] In Galpin's article, he says that while there is evidence that Japan, China, and other regions were trading with the Native Americans on the west coast of North America, the musical ways in which the Native Americans developed seems to have nothing to do with trade or voyagers.[87]

Galpin makes some other comments on how the Native Americans might have developed their reed instruments, but he never explicitly makes the assumption that maybe they developed their reed instruments on their own without any outside influence. He does say that Europeans might have visited the Northwest Coast Native Americans before Hernán Cortés, and those Europeans "taught them the arts and gave them the brighter and better side of their religion."[88] This article, written in 1902, has a lot of outdated language that is deemed to be offensive today. Galpin implies that Cortés and his "destroying horde" obliterated a "highly cultured nation," and he potentially meant the Native American nation only became cultured after Europeans visited the first time.[89]

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[84] Inglis, *Historical Dictionary of the Discovery and Exploration of the Northwest Coast of America*, xxix.
[85] Ibid, xxix.
[86] Ibid, 1xi.
[87] Galpin, 134.
[88] Ibid, 136.
[89] Ibid, 136.

On the other hand, he could have meant that Cortés destroyed a highly cultured Native American nation built prior to any Europeans arriving and prior to European influence.

It is unfortunate that we might never know where the Northwest Coast Native Americans learned about double reed instruments, if they themselves did not conceive of the instruments on their own. We still have the knowledge of how the reeds were made, what they were made from, and have some instruments that have survived in several museums. Galpin's article highlights an important point that is relevant to this document. The fact is that there were several double reed instruments that existed before modern times, including some that originate from the northwestern region of North America. This region is abundant in spruce and cedar trees, and river canes are not commonly found there. The Native Americans who lived in those regions adapted to their environment and created double reed from the resources they had access to, which is inspirational to the double reed (and even single reed) world today. If Native Americans could make double reeds out of trees, why can't we make modern woodwind reeds with them?

Like Barnaby Brown previously said, there are aulos-like reeds in living musical traditions globally. Even Anthony Baines in 1967 recognized reeds of various materials despite being adamant that the monaulos and its descendants, modern woodwind instruments, have always used *Arundo donax*. He states, "The bamboo Chinese reeds shown in Plate XIX are of the same kind, for a musical pipe called *kuan-tzu* (and the reed for the corresponding Japanese pipe *hichiriki*, fig. 44, b, is similar)."[90] In the description of Plate XIX, he lists the instruments' names and in parentheses is the material the reeds

[90] Baines, 192.

were made from. He mentions the whit-horn, which we discuss in this section, having a willow bark reed, the Chinese *kuan-tzu* having a bamboo reed, North African shawm having a maize reed, and Burmese shawm having a reed of palm leaf.[91] Currently, there is not enough literature on the North African shawm and Burmese shawm to cover them as extensively as the other instruments, but it is worth knowing the materials those musicians use for their reeds—maize and palm leaf, respectively. Maize, or corn, is analyzed in this document but the palm leaf is not due to the construction of the reed being a triple, quadruple, or sextuple reed, which would likely not be successful for the oboe.

One of the instruments Baines mentioned is the hichiriki (Figure 7)[92] which is a "Japanese double-reed wind instrument used in 7th century imperial court music."[93] Interestingly enough, hichiriki players do not use *Arundo donax* for their reeds. Instead, they use *Phragmites australis*, which is in the same family as *Arundo donax*. The hichiriki players insist that the best cane for reeds comes from a specific reed bed in Udono, which is along the Yodo river between Kyoto and Osaka.[94]



Figure 7: Japanese Hichiriki

[91] Baines, Plate XIX.
[92] Youtetsu, "Hichiriki."
[93] Kawasaki et al., "Why are *Phragmites* australis Canes Grown in an Udono Reed Bed the Best for Reeds of the Japanese Hichiriki?: A Structural Biomechanical Study," 46.
[94] Ibid, 46.

The authors continue,

> "This situation resembles that in which the best reeds for clarinet, oboe, or bassoon are manufactured from a cane of *Arundo donax* (*A. donax*, giant reed) that grows only in a few areas in the Var in southeastern France where the Mediterranean climate is very mild. Now, environmental disruption in Udono endangers the *P. australis* for hichiriki reeds and may bring a catastrophic crisis to gagaku. The International Double Reed Society, with members in more than 50 countries, expressed support for the call to protect and preserve the riverbanks of Udono, where the soul of hichiriki resides."[95]

Upon reading this passage in Kawasaki's article, a few thoughts come to mind. First, it is funny how both oboists and hichiriki players are so particular about where their cane is grown and harvested for reeds. I have experienced this bias myself and there are really no scientific explanations presented to me for why exactly *Arundo donax* that is grown in specific regions in France is the best choice for reed makers, it just is. This mentality is dangerous and leads to exclusivity and I hope to start a revolution in the double reed world by defeating mentalities like this. "It just is" is no longer acceptable in the 21st century in almost every facet of classical music including reed making. *Arundo donax* is native to Asia and only exists in Europe, the Middle East, North America, Australia, etc. because it has been cultivated in those regions for thousands of years.[96] *Arundo donax* is considered invasive in the United States and the United States Department of Agriculture published a "Field Guide for Managing Giant Reed in the Southwest" in September of 2014.[97] In the description, the USDA clearly says that *Arundo donax* is native to Asia and it is as widespread as many native species to Europe due to thousands of years of

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[95] Kawasaki et al., 46.
[96] Minogue, "Biology, Control and Invasive Potential of Giant Reed (*Arundo donax* L.) in Florida."
[97] United States Department of Agriculture.

purposeful cultivation.[98] If *Arundo donax* grows globally and is considered invasive in many parts of the world, why aren't we cultivating the invasive plants for oboe reeds in the United States? What is it about France that has us oboists so obsessive over where our cane comes from? And similarly, why do hichiriki players also obsess over their cane coming from the Udono reed bed? Maybe there is something further to investigate regarding both *Arundo donax* in France and *Phragmites* in the Udono reed bed. It could simply be a placebo effect or it could be the "it just is" mentality that is imbedded in certain cultures musically.

The second thought that arises from the Udono reed bed as a preference for reed cane is about the environmental disruption and IRDS giving its support to protect the riverbanks of Udono. Prior to reading Kawasaki's article, I was unaware of protections for the riverbanks in Udono supported by IDRS. The support from IDRS is incredibly inclusive since "International Double Reed Society" implies all double reeds globally, not just oboe and bassoon even though it is mostly an organization based on oboe and bassoon. The environmental support IDRS provides for hichiriki players and the riverbanks in Udono is a great first step toward including all double reed instruments in IDRS. The next step, at least what I propose as the next step, is to experiment with *Phragmites* for modern woodwind instruments. Of course, this *Phragmites* will not come from the Udono riverbanks, but the idea of using *Phragmites* for oboe reeds is enlightened by hichiriki players and their use of *Phragmites*.

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[98] United States Department of Agriculture.

Two similar instruments to the hichiriki are the algaita (Figure 8)[99] and the suona (Figure 9).[100] They are single-pipe double reeds that are "derived from the same origins, Persia and Arab (today the regions of Iran, Iraq, Syria, and Saudi Arabia)… In the end, the single-pipe double reed aerophone took almost 700 years to travel to Northwest Africa and in China, and in its first introduction to China grew familiar only in a small area; it was not fully accepted by the people of Central Plain until the Tang Dynasty."[101] The algaita reed is made from "wild reeds in various sizes" and makers use similar methods to compress and clamp reeds to dry out.[102] The suona reed, interestingly, is made from reeds or straws or insect shells.[103] In Shasha Zhu's master's thesis, there is no naming of what exactly the species of wild reeds is, however reeds are a species of grass. Upon further research, I came across the Max Planck Institute of Geoanthropology website. On it, there is an article called "Reeds from Great Wall Reveal Clim ate of Ancient Northwestern China." The unnamed author says that carbon isotope values analyzed from parts of the Great Wall indicate that the Tarim Basin region once flourished with common



Figure 8: Algaita



Figure 9: Suona

[99] Mplanetech, "Algaita."
[100] Daderot, "Suona."
[101] Zhu, "A Comparative Study of the Social Function of African Algaita and Chinese Suona," 37-38.
[102] Ibid, 45.
[103] Ibid, 47.

reeds (*Phragmites*).[104] The author summarizes the paper's findings and says when analyzing 13 different sites for organic material at the different sections of the Great Wall constructed during the Han, Jin, Tang, and Song dynasties, the organic material presented as *Phragmites*.[105] Since the suona was finally accepted during the Tang Dynasty, and the instrument makers used wild reeds to make its reed, plus the data from analyzing 13 different sites for organic material presenting as *Phragmites*, I think it is an incredibly safe notion to make that the reeds were made from *Phragmites*. In attempting to research what current suona and algaita players use for reeds, I tried reaching out to a few people via email and received no responses, and I could not find much scholarship in English.

In the article on collecting traditional English instruments, Alice Little says, "Among the musical instruments in the collection we find a Whit-horn, a 'primitive oboe', made of twisted willow bark."[106] Little continues by discussing the purpose of the Whit-horn, which was largely for waking up people in villages to call them to hunt.[107] The whit-horn in Figure 10 is my interpretation of the instrument based on Alice Little's photo[108] and from the photo of a whit-horn in the Musical Instruments Museum's collection.[109] The construction of the whit-horn is quite fascinating and considering it is referred to as a simple oboe by Henry Balfour, the whit-horn is not made of *Arundo donax* in the slightest. Little says, "Made from strips of willow bark wound into a funnel,

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[104] Max Planck Institute of Geoantrhopology, "Reeds from Great Wall Reveal Climate of Ancient Northwestern China."
[105] Ibid.
[106] Little, "Percy Manning, Henry Balfour, Thomas Carter, and the collecting of traditional English musical instruments," 27.
[107] Ibid, 33-34.
[108] Little, "The Whit-Horn."
[109] Colin, "Whithorn."

the horn was secured with hawthorn or blackthorn spines, the finished instrument measuring 18 inches (45 cm) in length and 4 inches (10 cm) across the bell. Bark was inserted into the narrow end to form a reed, with the mouthpiece pinched together around it, leading Balfour to label it as a type of oboe. In so doing, he simultaneously labels the instrument inferior due to its simplicity and links it to the modern oboe, an instrument that most readers would have considered to be a fully developed and cultured form. He suggests the idea that the latter might have evolved from the former."[110] The Grove Music Online entry details the double reed, "It has a double reed made of the 'inside willow' as described by William Kimber."[111]

With the experience I have making oboe reeds and experimenting with the various types of cane for this document, I do not believe Willow trees would be a good alternative for *Arundo donax*. The machinery needed in order to shape any tree, not just Willow trees, into the precise tubes needed for all of the current tools oboists use would be counterintuitive and too complicated. Additionally in the article by Larsen et al, the authors concluded that Willow trees can accumulate toxic chemicals posing a risk to consumers. They say that if chemicals are equally absorbed and disposed of in plants, there is no harm to animals or human consumers but willow

Figure 10: Whit-Horn



[110] Little, "Percy Manning, Henry Balfour, Thomas Carter, and the collecting of traditional English musical instruments," 34-35.
[111] La Rue, "Whithorn."

trees tend to not dispose of the chemicals as much as absorbing them. This leads to contamination and toxicity.[112] With how few reeds hundreds of years old actually survive, it is surprising that there is a surviving whit-horn reed, "A primitive form of this reed survives in the whit-horn (fig. 40, *ii*)—a one-note reed horn of coiled willow bark pinned together with blackthorn spines; it is still made in several parts of Europe and Asia."[113] Like river canes, there are probably many types of willow trees that exist; thus there could potentially be a safe species of willow trees to use for reeds. However, we tend to not know the disastrous effects of potentially toxic products until it is too late, so in this case, precautions should be taken.

Figure 11: Crumhorn



Taking a look at another instrument from the medieval period is the crumhorn (Figure 11).[114] According to Kenton Terry Meyer in his PhD thesis, "Krumhorn generally refers to the double-reed instrument with a curved shape and a reed cap, but it can also refer to any curved musical wind instrument, or to an animal horn, or even to an animal with curved horns."[115] Crumhorn is a generic term that can have a small variety of different meanings, either to musical instruments or an animal's curved horns. Meyer says that the design of the crumhorn is what you would expect from sixteenth century woodwind instruments. A reed cap covers the double reed and, "both of

[112] Larsen et al., "Uptake, Metabolism, Accumulation and Toxicity of Cyanide in Willow Trees."
[113] Baines, 191.
[114] Linden, "Moderne Krummhoerner."
[115] Meyer, "The Crumhorn," 5-6.

these fit onto a turned cap housing that is attached to the upper end of the cylindrically bored body…"[116] The only surviving crumhorn reed and staple is in the Kunsthistorisches Museum in Vienna.[117] Most of the crumhorns that exist today are reproductions, and those reproductions have not always been historically accurate.[118] In the 1970s, reproduction woodwind makers began trying to make historical instruments closer to what they probably were back then rather than make improvements and changes to fit modern players. Prior to the 1970s, reproduction woodwind makers seemed to only care about how to modify the designs of these older instruments to get more people, ranging from amateurs to professionals, to buy them. In the 1970s, some reproduction woodwind makers decided to return back to the historically accurate designs. This includes getting rid of the plastic reeds and making them from cane.[119] Meyer does not say what material the reproduced cane reeds are made from, how they are made, or what the dimensions are. He provides very little information about the plant used to make reeds or the process of making them. The crumhorn started its decline by the end of the sixteenth century and fell out of fashion.[120] Meyer discusses the revival of the crumhorn, "The crumhorn revival, if it can be separated from the early-music movement, grew considerably when crumhorns were adopted by amateur players who wanted an alternative to recorders. Anthony Baines offered an attractive endorsement of the instrument: The great virtue of the crumhorn is that it requires no special embouchure. It is as easy to blow as a recorder. It is, indeed, the equivalent among reed instruments to the recorder among

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[116] Meyer, 91.
[117] Ibid, 104.
[118] Ibid, 212.
[119] Ibid, 215.
[120] Ibid, 358.

flutes...Modern crumhorns also were fitted with plastic reeds to provide the long-term maintenance-free use that originally made the recorder attractive to amateurs."[121] Although historical instruments are now available for amateurs, the use of a plastic crumhorn reed is still disheartening.

[121] Meyer, 361-362.

The Shawm

The precursor to the oboe is the shawm (Figure 12).[122] According to Gretchen Peters, the shawm and trumpet were the most prominent instruments in subsidized music in French cities used in medieval institutions like courts, cities, and confraternities.[123] With how popular the shawm was, there is not much information on the materials the reeds are made from. Haynes does say, "The shawm reed did not vibrate freely in the mouth cavity, however, like those of oriental oboes that use a disk and whose reeds, made of rush or straw, are too delicate to vibrate when in direct contact with the lips."[124] As our earlier discussion noted, many Asian double reeds use *Phragmites* for their reeds, so the statement on using rush or straw seems to be incorrect. The shawm declined with the progress of music of the seventeenth century.[125] The design of the shawm could not be structurally developed further without creating an entirely new concept for a similar instrument. The music in the seventeenth century increased demands on the musicians and the instruments, so an instrument that was becoming functionally useless led to the development of the early oboe.

Figure 12: Shawm



[122] Klimeš, "Salmaj."
[123] Peters, *The Musical Sounds of Medieval French Cities: Players, Patrons, and* Politics, 255.
[124] Haynes, *The Eloquent Oboe: A History of the Hautboy 1640-1760*, 12-13.
[125] Ibid, 18.

From the Shawm's Decline to Modern Day

The Hautbois

Due to its inability to meet musical challenges, the shawm declined and players developed the hautbois with other double-reed instruments in mind.[126] According to Bruce Haynes in his notable book, *The Eloquent Oboe*, "The origins of [the hautboy's] evolution are traceable back to the 1580s, and the definitive hautboy (the instrument that was to retain its approximate form and proportions up to the present day) appeared in the late 1660s."[127] Haynes does mention that the reed is made from *Arundo donax*, but then leaves it at that with no question.[128]

The hautbois, or oboe, is well known to be a direct descendant of the shawm. It first appeared in the 1600s and since then has evolved into the modern day oboe. During the 19th century, woodwind instruments were constructed with more keys to accommodate "even-sounding semitones" with the progression of composers writing more complex music.[129] The construction of the reed had to change as well to accommodate the addition of more keys.[130] According to Rainer Weber,

> Reeds, and the remnants of reed, that survive from the eighteenth and early nineteenth century show an entirely different picture from that to which we are accustomed today…What has remained unaltered since then is the basic reed material—*Arundo donax*, although even here certain questions may be raised. There were, and always have been, regional differences; and today we might also ask to what extent matters have been affected by such environmental influences as climatic change, fertilizers and modern agricultural methods etc.[131]

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[126] Haynes, 12.
[127] Ibid, 12.
[128] Ibid, 64.
[129] Weber et al., "Early Double-Reeds," 233.
[130] Ibid, 233.
[131] Ibid, 233-234.

Even in the 1800s, musical instrument reeds were made from the same plant they are made from today. Weber continues with this assumption as if it is a fact. He even says that "*Arundo donax* belongs to the family of *arundinaria*, or *Phragmites*, marsh reeds—as does also bamboo."[132] Unfortunately, Weber does not ask the question of why none of the other reed-cane in the same family as *Arundo donax* are used for reeds today, or even in the 1800s. How could Weber acknowledge that *Arundo donax* is in the *Arundinaria* family along with *Phragmites* and bamboo, while sticking to the tried and true narrative? Nearly all single and double reed musicians reiterate the same narrative that we have only used *Arundo donax* dating back to the aulos without investigating that narrative further.

He goes on comparing reed making styles between time periods and between regions, but says nothing about the various plants in the same family. He does, however, make the statement, "Reed-makers for various instruments would thus appear to have existed by the sixteenth century. The chanter reed from a large *zampogna* (Sicilian bagpipe) is preserved which bears the inscription 'Ritter' written in pencil on the blade—which is presumably the signature of the maker."[133] Pursuing this lead further led right back to Weber's article, which had no citation. There was a photo of the reed, see Figure 8 in Weber et al.[134] In the article, "The Oldest English Oboe Reeds? An Examination of Nineteen Surviving Examples," there are photos of oboe reeds that appear to have

[132] Weber et al., 234.
[133] Ibid, 238.
[134] Ibid, 238.

survived from the late eighteenth-century at the earliest.[135] The authors attempted to explain the process for making these reeds and then drew diagrams of the reed measurements, see Plate II[136] and Figures 9[137] and 10[138] in Burgess and Hedrick.

With the lack of historical documentation and the implementation of the beginning of our modern taxonomic systems for hundreds of thousands of plants written in only 1735,[139] there could easily be confusion or duplication of identifying characteristics and previous names among similar species. Carl Linnaeus, the author of this first modern taxonomic system entitled *Systema Naturae*, says, "It is a settled question for men with a long experience in the art, that the greatest difficulty lies in the changing of generally accepted names, hence they should not be changed even if the number of those who err would seem to favour the error. And I cannot help if, according to my mind, older botanists interchanged names."[140] Between Theophrastus' *History of Plants* and Carl Linnaeus' *Systema Naturae* is about 2,105 years so logically, if the cane plants used were labeled "A," in 370 B.C.E., there is an extremely low likelihood that the same plant would still be labeled "A" in 1735 C.E. Linneaus even suggests this idea with saying that older botanists likely interchanged names.

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[135] Burgess and Hedrick, "The Oldest English Oboe Reeds? An Examination of Nineteen Surviving Examples," 45.
[136] Ibid, Plate II.
[137] Ibid, 49.
[138] Ibid, 49.
[139] Environment & Society Portal, "Linnaeus's *Systema Nature*."
[140] Linnaeus, "Systema Naturae," 24

Synthetic Reeds

The last few decades have given rise to synthetic and plastic reeds for musical instruments. Most professional musicians still remain skeptical of synthetic reeds despite some deliberately choosing them over cane. In the article "Longitudinal and Transversal Elasticity of Natural and Artificial Materials for Musical Instrument Reeds," the authors tested the elasticity of Carbon Fiberreeds, Légère reeds, and natural cane reeds using Young's Modulus Transversal, which measures the stiffness of an elastic material.[141] So the larger the number calculated, the more stiff the material is. They found,

> The highest moduli of elasticity were found for the Carbon Fiberreed with mean values of 18.9 GPa in the longitudinal direction and 5.3 GPa in the transversal direction. For plastic Légère reeds, mean values of 7.5 GPa and 1.9 GPa were obtained. These values were higher than those of natural dry reed, but the values measured on wet natural reeds, mimicking the playing condition, are still far lower, especially in the transversal direction…No visco-elasticity was observed in the synthetic reed materials and natural dry reed, but it was clearly present in the natural wet reed specimens.[142]

Essentially, soaked natural reeds are far more pliable than dry natural reeds and synthetic reeds. This introduces a plethora of questions, but what comes to mind first is how do synthetic reeds actually work? The study proved that synthetic and even dry natural reeds are much less elastic and pliable than wet natural reeds. A reed that has low elasticity and pliability might be harder to play and may correlate with less overtones in the sound due to less vibration. Yes, synthetic reeds last a long time and are little to no hassle, but at what cost? Maybe this is what accounts for the abnormal lifespan of synthetic reeds, the fibers in the material do not vibrate nearly as much, causing less frequencies in the sound

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[141] The Engineering ToolBox (2003). *Young's Modulus, Tensile Strength and Yield Strength Values for some Materials*.
[142] Ukshini et al., "Longitudinal and Transversal Elasticity of Natural and Artificial Materials for Musical Instrument Reeds," 11-12.

and that results in a long lifespan. Cane fibers are constantly soaked, dried, resoaked, and vibrating between the soaking and drying sessions, and with more vibrations in the reed and more movement of the fibers, it explains why cane reeds do not last as long. Another factor that decreases natural reeds' lifespans could be mineral deposits within the fibers from water and saliva. Natural cane reeds are made from plants and plants naturally absorb water and sometimes go through dry spells depending on the climate and weather. Regardless, there is still much research to be done within the music, physics, and engineering fields to design, manufacture, and eventually market "the perfect reed that never changes" to any musician of any level, if this is even possible.

In the brief overview of the history of cane materials in double reed instruments, we have come across the standard *Arundo donax*, *Phragmites*, bamboo, willow, red cedar, spruce, condor feathers, and synthetic materials. With the uncertainty and unavailability of willow, red cedar, spruce, and condor feathers, we will not pursue those materials further. What we are left with is *Arundo donax*, *Phragmites*, bamboo, and synthetic materials. This document does not examine synthetic materials, so that will not be pursued further. Upon further research into similar plants to *Arundo donax* and *Phragmites*, the following plants arose as potential candidates: another river cane with the same common name as *Arundo* (*Arundinaria gigantea*), graceful bamboo (*Bambusa textilis gracilis*), reed canarygrass (*Phalaris arundinacea*), reed grass (*Calamagrostis brachytricha*), and even corn (*Zea mays*) and sugarcane (*Saccharum officinarum*). The next portion of this document will be an analysis using various topics of study looking in depth at the above plants, including *Arundo donax* as a sort of "control" or "base" for the

analysis. The conclusions drawn will point us in a direction for physical experimentation with any materials that are accessible for this experiment.

SURVEY OF PLANTS

In order to establish a "control" for the survey of the various types of plants that we will investigate, we will start with *Arundo donax* and then move to *Phragmites*, *Arundinaria gigantea*, graceful bamboo, reed canarygrass, reed grass, giant mischantus, corn, and sugarcane. The sections following the survey will focus on the physical materials I processed into gouged oboe cane. Those materials are from *Phragmites* and bamboo.

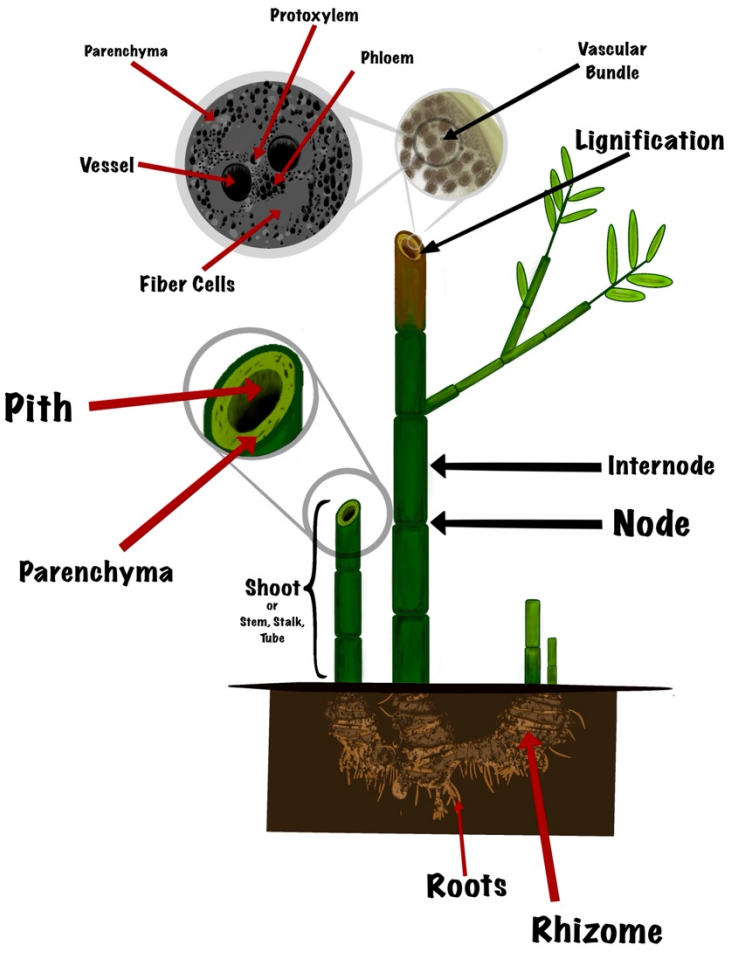
The analysis of these plants is straightforward and we use a wide range of resources available in plant sciences literature. This literature provides information on both individual plants and some comparisons between plants. The sources found are addressed and simplified as much as possible. Based on the articles, we make predictions about the suitability of these plants for oboe reeds. Before starting this analysis with the control, *Arundo donax*, some terms and parameters of this analysis will be defined for clarity. The International Code of Botanical Nomenclature is the system used for naming plants. Both parts of plants' names are commonly based in Latin.

The first part of the name, which is capitalized, is the genus and general classification. The second part of the name, which is not capitalized, is a more specific classification.[143] As we have already seen, all of the plants referenced thus far have two names. Rosie Lerner says, "Plants are grouped by their botanical similarities. A botanical family of plants shares certain characteristics such as foliage and flower form…Plants are then further grouped by even more similar characteristics…In nature, sometimes a

[143] Lerner, "How Plants Are Named."

particular species that is subjected to unique growing conditions might eventually produce a variant from the species that then reproduces itself."[144] The largest is the kingdom, which is essentially identifying if the living organism fits into the animal kingdom, plant kingdom, fungus kingdom, bacteria kingdom, etc. The next classification is the clade, which is "a grouping that includes a common ancestor and all the descendants (living and extinct) of that ancestor."[145] The order is the next classification, which consists of groups of families that are similar. Family is the classification before genus, which is the first name of the plant. The family, which groups plants together that share characteristics like foliage and flowers, of all of the plants addressed in this survey is the Poaceae family, a group of flowering grasses.

Figure 13: Bamboo Diagram



[144] Lerner.
[145] Understanding Evolution, "Clades (1 of 2) Definition."

The second name is the species, which is specific to the plant to identify exactly what the plant is. For example, *Arundo* and *donax* are terms derived from the old Latin and Greek names for reed.[146]

As far as plant terminology goes, Figure 13 shows the same diagram from Figure 3 in this document. This terminology applies to all woody grasses. Beginng below the soil level are roots and rhizomes. The roots are responsible for transporting water and nutrients from the soil to the plant. Rhizomes are essentially stems that grow underground and are responsible for producing new stems above ground.

Above the soil level are shoots, which is the entirety of the stem and is also referred to as a stalk or culm. Stem, stalk, and shoot are interchangeable but culms specifically refer to a hollow stem. Two parts of the shoot are nodes and internodes. Nodes are small solid parts of the shoot and the hollow parts of the shoot are internodes. All woodwind reeds are made from internodes of *Arundo donax*. The cross section on the shorter shoot in Figure 13 shows the pith and parenchyma. The pith is the soft tissue in the middle of the internodes and decays or becomes lignified after the plant dies, leaving the middle of the internodes hollow. Lignification, the top of the tallest shoot in Figure 13, is the process of gradually becoming woody. Parenchyma is permanent tissue that does not decay. The cross section of the tallest shoot zooms in on vascular bundles next to one another. The next magnification image in grayscale is one vascular bundle and its components. The most visible and identifiable parts of vascular bundles are vessels, fiber cells, and parenchyma tissues. New and young shoots are usually edible, but older shoots

[146]Wikipedia, "*Arundo donax*."

tend to be inedible. Still, young shoots are small and weak and old shoots are large and strong.

Before delving into the literature, it is important to understand the difference between running and clumping plants. Clumping plants' roots tend to spiral in somewhat fixed areas and take down obstacles in their path. Running plants' roots, on the other hand, spread laterally underground avoiding any obstacles in their path to "run" as quickly as they can. Many invasive species in the United States that are in the Poacaeae family are running plants.

As Matt Finstrom of the Bamboo Ranch in Tuscon, Arizona,[147] mentioned when I visited, it is quite challenging to pinpoint exactly where bamboos and river canes originate. Throughout human history, there has been a significant movement of goods, services, and plants, which has had a profound impact on the study of various plants. Cultivating a plant for thousands of years in specific areas does not mean it is native to that area, even though at first glance the plants might seem to grow as if they are native.

On the cellular level, it is important to understand the vascular system. Vascular systems are fundamentally the molecular transport system in plants. They are analogous to our circulatory systems as humans. The visible features all the way down to the cellular properties of *Arundo donax* for oboe reeds can affect the outcome of oboe reeds. Oboists are mostly concerned with the visible features, since that is what is seen with the naked eye. Rarely, if at all, do oboists concern themselves with the cellular qualities that lead to good or bad reeds. Throughout the growing process of *Arundo donax*, the plant

[147] Finstrom.

cell walls especially play a large part in "growth, development, response to environmental factors, and interactions with pathogens and symbionts."[148] As a result, microscopic imagery will be a key part in forming hypotheses of which plants might be potential candidates for making oboe reeds.

[148] Chen et al., "Anatomical and chemical characteristics of foliar vascular bundles in four reed ecotypes adapted to different habitats," 556.

Arundo donax

Arundo donax (Figure 14)[149] is a type of woody grass in the Poaceae family that can grow over 20 feet tall. The common name for *Arundo donax* is giant reed, but it can also be referred to as *Phragmites*, carrizo, Arundo grass, elephant grass, Spanish cane, wild cane, or oboe cane. *Arundo donax* is native to regions in Asia and has been purposefully grown in Europe, northern Africa, and the Middle East for thousands of years.[150] The United States Department of Agriculture says, "From a distance, giant reed looks like a corn plant and is similar in appearance to common reed (*Phragmites australis* L.), a native grass found widely across the United States."[151] *Arundo donax* is the reed cane that clarinetists, saxophonists, oboists, and bassoonists use for their reeds. As was noted in the prior overview of history, many publications, articles, journals, books, websites, etc. barely mention *Arundo donax* when it comes to writing about reed making. If mentioned at all, it is brief and without question the plant that has always been used for making musical instrument reeds is *Arundo donax*. This is why *Arundo donax* will be the "control" for the scientific analysis portion and the experimental portion.

Figure 14: *Arundo donax*



Continuing with its description, *Arundo donax*'s root system contains rhizomes, which is the part of the plant that is mostly responsible for reproduction, as it does not

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[149] Fonseca Mata, "Carrizo (*Arundo donax*) en Guanajuato."
[150] United States Department of Agriculture.
[151] Ibid.

germinate easily from seeds. *Arundo donax* is a clumping plant. The shoots are sturdy and hollow and can be up to two inches in diameter. Its leaves are pale to blue green and have alternating lengths.[152] Nearly half of the musical sources in the historical overview say that *Arundo donax* is native to the Mediterranean. Matt Finstrom[153] and the USDA[154] solidify my assumption that *Arundo donax* is probably native to parts of Asia and was cultivated for thousands of years in the Mediterranean and Middle East. The USDA considers *Arundo donax* to be invasive in the United States and has listed various control strategies or elimination strategies for America.[155] *Arundo donax* tends to grow in sand dunes, riparian areas, and wetlands.[156]

In the book, *Perennial grasses for bioenergy and bioproducts*, the authors mention something quite peculiar about *Arundo donax*. They suggest that *Arundo donax* L. might be the result of natural cross-breeding between *Arundo plinni* and a diploid of the same species, or *Arundo plinni* and *Phragmites australis*.[157] The family tree from this chapter is in Figure 4.1 in Christou et al.[158] *Phragmites* is the first alternative plant in this analysis and the potential that *Arundo donax* could be a hybrid of another *Arundo* species and *Phragmites* is surprising. When this cross-breeding happened is unknown, but the genetic analysis presented in the *Perennial grasses* book chapter on *Arundo donax* might indicate that a different plant than the familiar *Arundo donax* could have been used to make musical instruments.

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[152] USDA.
[153] Finstrom.
[154] USDA.
[155] Ibid.
[156] California Invasive Plant Council, "*Arundo donax*."
[157] Christou et al., "Giant Reed: From Production to End Use," 109.
[158] Ibid, 110.

Arundo donax does not normally reproduce with seeds since seed viability is often too low.[159] Instead, it reproduces from rhizomes—part of the root system—3 to 10 feet underground where it spreads and sprouts new growth.[160] Small roots or shoots containing nodes, which are the bumps on the shoots, can grow which makes *Arundo donax* a threat to the U.S. since it is not native.[161] Vascular systems, which is defined as the transport system of the plant that carries water, minerals, nutrients, organic compounds, and signaling molecules within the plant,[162] are important to consider. According to Robert E. Perdue Jr., "*Arundo donax* stems exhibit typical monocotyledonous structures."[163] Monocotyledonous is a term for a group of grass or grass-like flowering plants, so *Arundo donax* is a typical example of a plant that fits into this group. On vascular bundles, Perdue Jr. says, "Although the vascular bundles are distributed freely throughout the cross-sectional area of fundamental parenchyma, those toward the periphery of the shoots are smaller and more numerous than are those toward the interior."[164] The vascular system is divided into bundles. The parenchyma is the permanent tissues of the plant, so the vascular bundles are freely distributed throughout the cross-sections of the permanent tissues. Toward the bark of the shoot, which is the main part we make oboe reeds with, the vascular bundles are smaller and more dense. This makes sense, since the center of the shoot, called the pith, decomposes and disappears throughout the drying process after harvesting for oboe reeds. The less dense

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[159] USDA.
[160] Ibid.
[161] Ibid.
[162] Jung et al., "Molecular Mechanisms Underlying Vascular Development."
[163] Perdue Jr., "Source of Musical Reeds and Industrial Cellulose," 371.
[164] Ibid, 371-372.

the vascular tissue is, the softer it is and the quicker it decomposes and dries out. Perdue Jr. continues, "The vascular bundles are collateral and are surrounded by one or more rows of thick-walled, strongly lignified fibers. These fibers are long and narrow and taper to a fine point. The larger bundles of the interior are commonly enclosed by a single row of fibers. Toward the periphery of the stem, as the size of the bundles decreases, the number of rows of fibers associated with the bundles increases. Near the exterior of the stem, where the bundles are small and comparatively close together, the fibers are sufficiently abundant to form a continuous ring of structural tissue within which are scattered the vascular elements. This structural ring is separated from the epidermal layer by a narrow band of parenchyma cells that in mature stems are comparatively small, thick-walled, and lignified."[165] So the part of *Arundo donax* we use for our reeds contains the largest amount of fibers compared to the interior, which contributes to how we determine cane quality and how the reed vibrates. In Glave et al., there is a micrograph of good quality cane in Figure 4[166] and bad quality cane in Figure 5.[167] The vessels (circles) are very uniform and consistent in the good quality cane. In the poor quality cane, the vessels are irregular shapes and inconsistently sized.

The structures of *Arundo donax* not visible to the naked eye could be key in unlocking the "perfect reed" since the lowest quality cane we receive tends to be soft and very grainy. In Markus Rüggeberg's article, he says, "The structure of these plant stems can therefore be regarded as fibre reinforced composite with a highly inhomogeneous

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[165] Perdue Jr., 371-372.
[166] Glave et al., "Quality indicators for woodwind reed material," 675.
[167] Ibid, 675.

distribution of stresses when loaded. Stress discontinuities arise at the interfaces of fibres and parenchymatous tissue and shear stresses will develop at the ends of the reinforcing fibres and at free edges in the composites. Therefore, failure might be initiated at these points."[168] Essentially, when woody grasses are stressed from inconsistent weather patterns, the solid structure of the plant shoots "develop at the ends of the reinforcing fibres" causing structural irregularities. So, the low quality cane we discard probably comes from plants that were stressed during the two year growth period. Again, *Arundo donax* is a type of grass, not bamboo. From a distance, it resembles corn and can be hard to distinguish from *Phragmites*, as previously stated by the USDA.[169] It has tall and hollow shoots that can reach up to two inches in diameter and long pointy leaves that alternate sides as it grows. On rare occasions, the flowers appear only at the top of the stalks, similar to how corn flowers.

To compare each plant with *Arundo donax*, the sources cited here mostly analyze data on vascular systems, wall architecture, cellular structures, moisture, and salt content, as we have already seen. The physical and visible structures of the plants, like rhizomes, culms, leaves, and branching are also compared to *Arundo donax*. Not every plant has been studied in depth, so published and useful information will be used to the extent necessary for this document.

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[168] Rüggeberg et al., "Structural and mechanical design of tissue interfaces in the giant reed *Arundo donax*."
[169] United States Department of Agriculture.

Phragmites

The first plant that arose in my research is *Phragmites* (Figure 15)[170] commonly known as common reed. *Phragmites* consists of four species, but they are all perennial reed grasses in the Poaceae family, like *Arundo donax*. The most widespread *Phragmites* specie is *Phragmites australis*, where *australis* is translated to southern. *Arundo donax* grows quickly but has an intolerance to freezing temperatures. On the other hand, *Phragmites* adapts more easily to various climates due to how the different subspecies of *Phragmites* have evolved. It is resistant to drought, salinity, and low temperatures.[171] So, *Phragmites* seems to adapt to different environments more efficiently than *Arundo donax*. The genetic variation within any plant species, but especially *Phragmites* in this case, is subject to how each variant evolves in various environments.[172] *Phragmites* grows up to 20 feet tall and is nearly identical to *Arundo donax* in appearance.

Figure 15: *Phragmites*



Native and non-native species to the United States have almost indistinguishable differences and it is often hard to identify native from non-native. The European *Phragmites* species are more rigorous and unrelenting, causing similar disturbances as

[170] Ryu, "*Phragmites* karka (Retz.) Trin."
[171] Chen et al., 556.
[172] Ibid, 556.

Arundo donax in the United States. Non-native *Phragmites* tends to be running plants and the native *Phragmites* tends to be clumping plants, so the non-native plants spread much faster than the native plants. As a result, the native species to North America struggle to survive more. Like *Arundo donax*, *Phragmites* is most often found in ditches, "disturbed sites," and areas with a high salinity content.[173] The four species of *Phragmites* include *australis*, *japonicus*, *karka*, and *mauritianus*.[174]

In a hypothetical experiment, farmers could purposefully grow common reed in a wide variety of environments and climates, with temperatures ranging from freezing to scorching, and humidity ranging from desert dry to tropical and humid. Those plants could be harvested from each region and tested to see which region produces the highest quality cane for musical instrument reeds. Of course genetic variation does not happen overnight, but common reed already grows in a plethora of climates so this hypothetical experiment could still be successful. This hypothetical experiment is similar to the authors' experiment in the Kawasaki et al. article on a case study of why one specific reed bed is the best for making hichiriki reeds. In this study, *Phragmites australis* was taken from five reed beds in Japan along the following rivers: Kitakami River, Watarase River, Turumi River, Uji River, and Yodo River. The reed bed near the Yodo River is known as Udono.[175] With regard to the vascular bundles of common reed, the authors say,

> Vascular bundles (*Vb*) are distributed in [central cylinder] *Cc*. Each *Vb* is enclosed by cells with thick walls, which form a vascular bundle sheath

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[173] Sturtevant et al., "*Phragmites australis australis* (Cav.) Trin. Ex Steud."
[174] Wikipedia, "*Phragmites*."
[175] Kawasaki et al., "Why are *Phragmites* australis Canes Grown in an Udono Reed Bed the Best for Reeds of the Japanese Hichiriki?: A Structural and Biomechanical Study," 48.

> (*Bs*). The *Bs* is called a fiber ring from the shape of its transverse cross section. The plant *P. australis* almost resembles *A. donax* in plant anatomical characteristics as previously reported, but is different not only in scale of outer shape but also size of cells, as their English names of 'common reed' for *P australis* and 'giant reed' for *A. donax* imply. This is a reason why *A. donax* cannot be used for *rozetsu* [hichriki reeds].[176]

So *Arundo donax* cannot be used for hichiriki reeds because its cells are too big. Since common reed has smaller cells, it might work more in oboists' favor than *Arundo donax* for oboe reeds. Fibers and grains within *Arundo donax* cane help musicians determine if the cane will make for good reeds or bad reeds. Ideal cane fibers and grains are close together/small and even, at least in my experience. With smaller cells in *Phragmites*, it might make for more consistent and better results since the vibrations of a hypothetical oboe reed might make for an equivalent reed made from *Arundo donax* or even a better reed. On *Phragmites australis* and hichiriki reeds, the authors mention that there are only a few sources on *Phragmites*, its anatomy, and how it functions for hichiriki reeds.[177]

The authors of Kawasaki et al. continue, "The reed plant *Phragmites australis* (*P. australis*, common reed) commonly grows in wetlands in wide regions of the world. Although it can be found in reed beds along many rivers and lakesides in Japan, for more than 1,200 years the best reeds for the hichiriki have been made only out of canes of *P. australis* harvested from Udono, which is a limited reed bed of riverbanks located south of the border between Kyoto and Osaka along the Yodo River (Figure 2). This situation resembles that in which the best reeds for clarinet, oboe, or bassoon are manufactured from a cane of *Arundo donax* (*A. donax*, giant reed) that grows only in a few areas in the

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[176] Kawasaki et al., 48.
[177] Ibid, 46.

Var in southeastern France where the Mediterranean climate is very mild."[178] The authors in this study also analyzed clarinet reeds and found that the shape and spread of the vascular bundles and the permanent tissues are what mostly affect the sound of a clarinet reed. An ideal reed's vascular bundles are even and consistent in size and spread and contributes to balance, which is necessary for good vibrations throughout the reed, but especially in the tip.[179] These parameters for a successful reed are also applicable to oboe reeds. The homogenous nature of the grains in the cane probably correlate to the homogenous vascular bundles to ensure balance and stability in the reed. The authors continue to talk about hichiriki reeds, "With the good acoustic double-reed *rozetsu*, each blade might vibrate smoothly and resonate as one body along their surfaces. So a homogenous structure is required for resonance of the *rozetsu* blades. The quality is very different among canes even grown in the same place among parts of the same cane…Hichiriki players say that it has become harder and harder to get good canes for reed material, similar to the situation of clarinet and oboe players using *Arundo donax* reeds."[180] Hichiriki players seem to be in the same situation as woodwind players, where it is becoming increasingly more difficult to find high quality cane for reeds, despite both using different plants.

[178] Kawasaki et al., 46.
[179] Ibid, 49.
[180] Ibid, 49.

Arundinaria gigantea

The next plant is *Arundinaria gigantea* (Figure 16)[181]. It has a similar common name as *Arundo donax*, which is "giant cane" and is also in the Poaceae family. *Arundinaria* is Latin for reeds and *gigantea* is Latin for gigantic. The other two subspecies are *Arundinaria tecta* and *Arundinaria appalaciana*, with *tecta* meaning covered and *appalaciana* meaning Appalachian, the mountain range in the southeastern United States.

Figure 16: *Arundinaria gigantea*



According to Daniel Lee Marsh, taxonomy of the *Arundinaria* genus is complicated due to a lack of documentation and description.[182] This is sort of reminiscent of the challenges in pinpointing *Arundo donax* as being the primary and only source of double reed material since before recorded history due to similar gaps in documentation and a lack of preserved reeds and instruments. Marsh did mention that *Arundinaria* was initially misplaced within the genus of *Arundo*.[183] *Arundinaria* and its three species are the only native species of bamboo to North America.[184] *Arundinaria* was very widespread in North America, but due to modern agriculture and land development

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[181] Stang, "*Arundinaria gigantea* 3zz."
[182] Marsh, "The Taxonomy and Ecology of Cane, *Arundinaria gigantea* (Walter) Muhlenberg," 14.
[183] Ibid, 15.
[184] Pankau, "Illinois' Only Native Bamboo Species."

practices, the population has been decimated. In the state of Illinois, it is less than 2% of its native range .[185] This is akin to the whole North American continent as well. Paul R. Gagnon further explains the decline of *Arundinaria*, "Following European settlement, canebrakes declined by an estimated 98%, becoming a critically endangered component of southeastern bottomland forest ecosystems. Alteration of disturbance regimes (e.g., fire and flooding), overgrazing and systematic plowing of cane lands all contributed to canebrake decline."[186] Unfortunately, we do not know how many invasive species might have contributed to its decline.

Arundinaria reproduces in the same way that *Arundo donax* and *Phragmites* do, it runs underground and produces shoots via rhizomes.[187] On reproduction in disturbed areas, "Cane's [*Arundinaria gigantea*] rhizome network spreads outward from the site of germination, so genets tend to increase as they grow. Individual rhizomes can grow more than 6 m in a single season. In the forest understory between wind disturbances, cane genets could survive windstorms, just as they often do fires. Where a disturbance generates high light levels, accelerated rhizome and culm production from this underground network could produce a dense canebrake."[188] Essentially, natural phenomena in weather and climate patterns in the form of "disturbances" can produce a more dense area of *Arundinaria gigantea*. *Arundinaria*, similar to *Arundo donax* and *Phragmites*, grow in wetlands nearby rivers and streams mostly in the central and

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[185] Pankau.
[186] Gagnon, "Population Biology and Disturbance Ecology of a Native North American Bamboo (*Arundinaria gigantea*)," 6.
[187] North Carolina Extension Gardener Plant Toolbox, "*Arundinaria gigantea*."
[188] Gagnon, 7.

southeastern regions of the United States.[189] It can grow up to 25 feet tall, but is typically between 8 and 20 feet.[190] *Arundinaria gigantea* is a running species, however it still suffers tremendously from invasive plant species and agricultural practices.

Because of the rapid decline of wild *Arundinaria gigantea*, caution should be taken for using what is left for musical instrument reeds. However, growing *Arundinaria* in a purposefully cultivated and controlled environment with great care would be beneficial in two ways. The first is an effort to repopulate the natural areas in which *Arundinaria* thrives and the second is to grow it for musical instrument reeds. Both of these efforts could exist at the same time. In Arizona, it is commonplace to see farmers grow a variety of cacti for landscaping purposes and for purchase. Cacti are even sold in Sky Harbor International Airport and since a majority of cacti are only native to the southwestern parts of the United States and Mexico, people still grow cacti to sell them throughout the country in big box stores like Lowes, Home Depot, and Menards. Of course, if you go to a Menards in Illinois, they only sell the smaller varieties of cacti with the intent of remaining indoors year round. In Arizona, big box stores sell large cacti that are outside in the garden centers with the intention of planting the cacti outside in the ground. Additionally, I grew 21 giant saguaro cacti from seed, and I purchased the seeds from a "Grow Your Own Giant Saguaro" kit when first visiting Arizona. Giant saguaros are the most protected cacti species in the state of Arizona and if you have a giant saguaro cactus on your property that you wish to be removed and replanted elsewhere, you must contact a special state department to have it moved. It is illegal for anyone to

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[189] North Carolina Extension Gardener Plant Toolbox.
[190] Ibid.

cut down a giant saguaro. I also own a cactus that is rapidly declining in population called *Matucana paucicostata*. If it is legal and encouraged to grow and sell rare and endangered cactus varieties that only exist in smaller regions than the regions where Arundinaria grows, then I do not see any issue with doing the same with Arundinaria. Especially considering that modern agricultural practices have decimated the cane's natural population and climate change might prove to be beneficial for the repopulation efforts proposed here.

Unfortunately, there are no known publications that contain microscopic images of the culms of *Arundinaria gigantea*. However, during data collection for this project, I collaborated with Professor Jeffrey Kleim at Arizona State University to take microscopic imagery of my own *Arundinaria gigantea* samples. This imagery is located in the Microscopic Imagery section later on in this document.

Interestingly, the Cherokee Nation has historically used *Arundinaria gigantea* to make arrows, baskets, blowguns, flutes, and fishing poles.[191] As a result of Cherokee Native Americans using *Arundinaria* for flutes, it might be possible that *Arundinaria* might be a great candidate for making oboe reeds.

[191] Cherokee Ethnobiology, "River Cane."

Bambusa textilis

The plant many people confuse *Arundo donax* with is *Bambusa textilis*, also known as graceful bamboo or weaver's bamboo (Figure 17).[192] *Bambusa*, referring to bamboo, and *textilis* coming from Latin meaning woven, so the common name weaver's bamboo makes sense. While *Arundo donax* and bamboo are similar, *Arundo donax* is actually more related to corn and sugarcane than bamboo. Bamboo is again, also in the Poaceae family with around 1400 species worldwide.[193] Bamboo is usually hollow and there are is a plethora of varieties, so one of them must be a good candidate for oboe reeds. This type of bamboo, *Bambusa textilis*, is native to China and grows between 25 and 40 feet tall and the shoots can be up to two inches in diameter,[194] which is a bit larger than *Arundo donax* typically grows, but still in the realm of acceptable diameters for oboe reeds.

Figure 17: *Bambusa textilis*



Unlike most bamboos, it is one of the more cold tolerant bamboos. Its leaf shape is very similar to *Arundo donax*, however the shoots are much more pronounced than the previous plants analyzed, and the previous plants seem to have a lot more leaves. It reproduces, again in the same way, with rhizomes. Bamboos consist of both running and clumping species, however, *Bambusa textilis* is a clumping bamboo.

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[192] Starr, "Starr 070906-8505 *Bambusa textilis*."
[193] van Dam et al., "Bamboo Production for Industrial Utilization," 178.
[194] San Marcos Growers, "*Bambusa textilis* – Weaver's Bamboo."

According to the Loh et al., identification and differentiation of the various bamboo species have been based on the flower structures, but it is quite challenging to pinpoint the exact species since bamboos rarely flower.[195] The biology and genetics of bamboo, like the previous plants, are quite complicated. Since there are so many varieties of bamboo and so many disparities between the varieties, such as growth phases ranging from 1 to 120 years and inconsistencies in flowering.[196] As a result, most of the research on bamboo consists of DNA analyses, taxonomy, and investigations into medicinal properties of the shoots and leaves. According to van Dam et al., "Sustainable bamboo production and utilization are considered to be directly relevant to many of the UN sustainable development goals (SDGs) that are targeting important aspects of poverty reduction, housing and urban development, as well as use of renewable energy, combating climate change, and land degradation."[197] Since there is already plenty of sustainable production of bamboo globally, it would not be too difficult to add production for oboe reeds to the list of uses for bamboo. Some species of bamboo also grow faster than one meter per day and overall, bamboo can survive throughout the harshest conditions of the planet.[198]

Bamboo is one of the most versatile plants with an incredibly extensive range of uses such as edible shoots, toothpicks, chopsticks, crafted baskets and mats, tools, musical instruments, artwork, and even in construction material for houses.[199] Since

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[195] Loh et al., "A Study of Genetic Variation and Relationships within the Bamboo Subtribe Bambusinae using Amplified Fragment Length Polymorphism," 607.
[196] Ibid, 607.
[197] van Dam et al., 175.
[198] Ibid, 178.
[199] Ibid, 175.

bamboo is commonly used for musical instruments, it could be a fantastic candidate for oboe reeds. Like *Arundo donax*, "The bamboo stems contain thick-walled fiber strands associated with the vascular bundles embedded in the parenchyma tissues that provide the mechanical strength of the culms...In microscopic view these regular-shaped groups of fiber cells are distributed evenly with regular distances in between. At the edges the bundles are closer together than in the interior parts of the culm, near the soft pith and hollow center (lacuna)."[200] The fiber cells are distributed evenly and the vascular bundles are much closer together toward the bark of the shoots.

In addition to already being used for musical instruments, bamboo having a comparable structure as *Arundo donax* points to even more potential for being an alternative to *Arundo donax*. Furthermore, bamboo can be easily manufactured into a composite material with synthetics like polypropylene, polyethylene, and polyesters.[201] "Up to 60% bamboo fibers or particles" are able to be combined with molten plastic to create any shape with a mold.[202] Some of these substances are used in making synthetic reeds. A composite reed made with polypropylene and bamboo might be better than only using synthetic materials for reeds. In the Kaur et al. article, the authors detail extracting bamboo fibers. They say, "The bamboo fibre is naturally found in bamboo trees, it can be extracted by using various methods and processes… In original bamboo fibre the fibres are extracted directly from the natural bamboo using mechanical and physical method, without treating the bamboo chemically."[203] The fiber structure of bamboo can be

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[200] van Dam et al., 181.
[201] Ibid, 198.
[202] Ibid, 198.
[203] Kaur et al., 845.

extracted safely and without chemicals to keep the original fiber structure in composites, which would be safe for musical instrument reeds. We have already implemented composite materials in the musical world with various composite and synthetic professional model oboes, so I do not see why we cannot extend this sort of experimentation to our reeds. Perhaps this is the element that was lacking and why Légère seems to have abandoned the American scrape reed.

***Phyllostachys pubescens* (Moso Bamboo)**

Another type of bamboo that might be a good candidate for oboe reeds is moso bamboo (Figure 18)[204], with a scientific name of *Phyllostachys pubescens*. Moso bamboo is native to China and Taiwan and largely used in place of timber.[205] It is a running bamboo and mature plants will have shoots with a diameter of four to five inches,[206] which still contains appropriate diameters for oboe reeds. Unfortunately, it seems to only thrive in its native regions in China and Taiwan and has difficulty growing in the United States.[207] Moso bamboo is also in the Poaceae family. According to Boichita Bucur, "The substitutive species of cane (*Arundo donax*) are: common reed (*Phragmites*) *and* moso bamboo (*Phyllostachys pubescens*)."[208] Musical properties will be investigated in one of the last portions of this section, but interestingly saxophone reeds were successfully made out of moso bamboo in the Cheng et al. article.[209] After glancing thorough many types of bamboo, it seems that there could be tens if not hundreds of potential candidates for oboe

Figure 18: Moso Bamboo



[204] Krzysztof Ziarnek, "*Phyllostachys pubescens*."
[205] Bambu Batu, "Moso Bamboo: The King of Grasses."
[206] Ibid.
[207] Ibid.
[208] Bucur, 1179.
[209] Cheng et al., "Bamboos as the material for saxophone reeds."

reeds. Bamboo generally is easy to grow and it grows rather quickly. One of the only aspects of bamboo that we have to be cautious about is how it is processed. According to Matt Finstrom, most commercially available bamboo stakes are treated with toxic chemicals that should not be ingested.[210] This is most common with bamboo stakes that are imported into the United States to subdue the bamboo's reproduction since it is not native to North America. Bamboo is either coated with chemicals or the chemicals are added to the soil so the bamboo absorbs the chemicals to prevent growth. Removal of these chemicals is impossible, so great care should be taken if any reader decides to attempt to experiment with bamboo to prevent ingestion of toxic chemicals from treated bamboo.

Moso bamboo, and nearly all bamboo species, "have a wide environmental adaptation profile, ranging from tropical to temperate and montane ecology to plains, their mechanisms to cope with environmental stress are contrastive. Owing to their perennial nature, bamboos encounter stress factors such as cold, drought, salinity, and high temperature more commonly than any other grass species."[211] Bamboo is extremely adaptable and hardy to many climates around the globe, which would work in the favor of reed players. Bamboo's strength in encountering challenges related to climate change, along with seemingly an infinite number of species, leads to the hypothesis that bamboo would be the most ideal candidate so far since at least one of these bamboo species would be suitable for oboe reeds.

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[210] Finstrom.
[211] Ramakrishnan et al., "Genetics and genomics of moso bamboo (*Phyllostachys edulis*): Current status, future challenges, and biotechnological opportunities toward a sustainable bamboo industry," 23.

General Bamboo Conclusions

Bamboo as a whole is unbelievably versatile in its uses and with today's fight against climate change, is a very sustainable option. The market for bamboo is skyrocketing and micropropagation in a short period of time is achievable.[212] Considering potential climate concerns, bamboo appears to be the future for many facets. With over 1400 species, bamboo comes in a wide range of sizes. The two species investigated were due to a mention of a bamboo species in an article and the other I was able to physically obtain, but there are more potential varieties that might be even more suitable for oboe reeds.

[212] Sandhu et al., "In vitro propagation of bamboo species through axillary shoot proliferation: a review," 48.

Phalaris arundinacea

Another potential candidate is reed canary grass, known formally as *Phalaris arundinacea* (Figure 19).[213] It grows between three to nine feet tall, has a similar appearance to *Arundo donax*, *Phragmites*, and *Arundinaria gigantea*. Reed canary grass is native to parts of Europe and Asia, with a possible variety native to North America. Like the other plants investigated so far, it is difficult to distinguish between what varieties are native to which continent, but it was not as common as it was in North America before Europeans brought it here.[214] DNA and genetic analysis for much of the species of perennial grasses is lacking. In the book chapter on reed canary grass from the book *Perennial grasses for bioenergy and biproduct*, the authors say, "RCG [reed canary grass] is a widely adapted temperate grass and broadly tolerant of many stresses including flooding, drought, freezing, and grazing. As such, it can be found in a wide array of habitats, including wetlands, riparian zones, steam banks, irrigation channels, roadsides, forest margins, pastures, and disturbed areas."[215] Reed canary grass and its hardiness would be a great addition to the materials musicians use to make reeds since it can grow in a wide variety of environments, has some resistance to stresses, and can potentially help mitigate effects of climate change on the supply of musical instrument cane.

Figure 19: *Phalaris arundinacea*



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[213]Herring, "*Phalaris arundinacea* 1-eheep (5097348751)."
[214] Oxbow Farm and Conservation Center, "Reed Canarygrass."
[215] Jensen et al., "Reed Canary Grass: From Production to End Use," 154.

Unlike the previous candidates, reed canary grass seeds are quite viable and it tends to be more of a running plant than clumping. Upon glancing at images of reed canary grass, it is hard to tell if it has hollow shoots that are the exact diameters we would need for reeds. Reed canary grass, harvested in spring, does have hollow stems which tend to be around two meters tall and taper to five millimeters in diameter.[216] Since the diameter tapers to about 5 mm in diameter, there is a larger diameter than 5 mm on most of the stem which might be in the appropriate range for oboe reeds.

Xia Zhang's article "Structural features of *Phalaris arundinacea* in the Jianghan Floodplain of the Yangtze River, China" contains microscopic images of the culms of reed canary grass, see Figure 3[217] in Zhang's article. Zhang and the other authors say, "In *P. arundinacea* rhizomes, the narrow, suberized, lignified PMR in culms and the lignified PMR in rhizomes are somewhat similar to *C. dactylon*, *P. distichum*, *H. altissima*…It is well known that air space systems transport oxygen for organs under hypoxia and anoxic stress and that many wetland species constitutively form aerenchyma even under aerobic conditions. Air space tissues in grasses, like *P. arundinacea* and other Floodplain grasses, are typical features with two general forms: lysigenous cavities in stem pith and cortex and schizo-lysigenous aerenchyma in roots."[218] Zhang defines PMR as peripheral mechanical ring. Lignified being defined as becoming woody, the peripheral mechanical ring in culms and in rhizomes are lignified or woody. So the stem, which is where oboe reeds would potentially be made from, and some of the roots are woody. Additionally,

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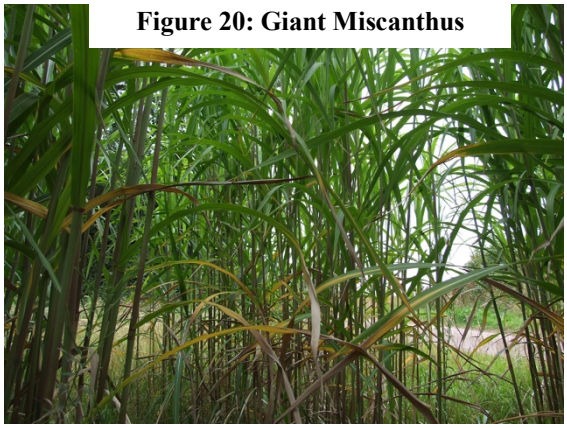
[216] Jensen et al., 160.
[217] Zhang et al., "Structural features of *Phalaris arundinacea* in the Jianghan Floodplain of the Yangtze River, China,"103.
[218] Ibid, 105.

“lysigenous cavities in stem pith” cues into the hollow center of a dried out reed canary grass tube. The authors list three other floodplain grasses which could be potential candidates for future research. The “air space tissues” the authors refer to is most likely vascular bundles, which is similar, if not the same as the vascular bundles in *Arundo donax*. If you take a tube of *Arundo donax* and put one end in water and blow into the other end, bubbles will form in the water. This is also possible with pre-gouged cane. The “air space tissues” dried out and left microscopic canals which is the part of the cane that we determine to be grainy. The same water test could be done with reed canary grass and the other plants investigated. It is unknown whether these microscopic canals are the same size as *Arundo donax*, but the aspects of reed canary grass this article details indicate a potential candidate for oboe reeds.

Miscanthus x giganteus

The next plant in this analysis is Giant miscanthus (Figure 20),[219] with a scientific name of *Miscanthus* x *giganteus*. Giant miscanthus "is a perennial rhizomatous grass native to East Asia…It was first introduced into Europe from Japan in the 1930s by the Danish plant collector Axel Olsen…Miscanthus belongs to the same grass tribe as maize, sorghum, and sugarcane; the Andropogoneae."[220]

Figure 20: Giant Miscanthus



Miscanthus is also, again, in the Poaceae family and is closely related to corn, sorghum, and sugarcane. There have also been hybrids recently identified that can grow in extreme conditions that include drought, low temperatures, and salinity.[221]

Today, miscanthus is mostly used for making paper, building material, food, and combustion for electricity production.[222] It can grow up to 12 feet tall and its stalks are about 3/8 inches in diameter[223], which is around the same diameter as *Arundo donax* cane for oboe reeds. Giant miscanthus essentially reproduces in the same way as the previous plants, from rhizomes underground that sprout new shoots.[224] It also grows like clumping bamboo. When looking at photos of the plant, it definitely looks more similar to corn

[219] National Rural, "Miscanthus Crop."
[220] Lewandowski et al., "Miscanthus," 35.
[221] Ibid, 36-38.
[222] Ibid, 41-42.
[223] Monsterbuck Supply, "Real World Giant Miscanthus."
[224] Ibid.

than the previous plants do, but it still has visible similarities to the other researched plants.

Figure 2[225] in Ji et al. shows images of Giant miscanthus cells, which are bundled similarly to the other plants investigated that have had microscopic photos taken. Images a and b are from raw tissues and the rest are from tissues that have been treated.

[225] Ji et al., "Visualization of *Miscanthus x giganteus* cell wall deconstruction subjected to dilute acid pretreatment for enhanced enzymatic digestiblity," 5.

Panicum virgatum

Switchgrass (Figure 21),[226] formally known as *Panicum virgatum*, is in the Poaceae family and thrives in warmer climates. It can grow between 0.5 to 2.7 meters tall.[227] Switchgrass is native to North America and appears stretching from Canada to Mexico.[228] *Panicum virgatum* is Latin for tall panic grass.[229] With grass in its common name, switchgrass does not look like what most would consider grass. It has stems that grow up to 8 or 9 feet tall and its roots stretch underground by the same length and "grows in thick, jungle-like tangles."[230] While it is a little bit shorter than the previous plants, it still grows similarly by producing new shoots from rhizomes. It also is more of a bunching and clumping grass. Switchgrass does not really need fertilizer, grows best in soil barren of nutrients and can live for up to ten years.[231]

Figure 21: *Panicum virgatum*



Contrary to how difficult it might be to grow some of the previous plants, switch grass is very hardy and even frost tolerant. It is also native to North America and benefits the environment and wildlife. Other benefits include, "ecological benefits…Its deep roots bind soil and block erosion. They also pump a lot of carbon into the ground, essentially

[226] Stang, "*Panicum virgatum* Rotstrahlbusch 1zz."
[227] Alexopoulou et al., "Switchgrass: From Production to End Use," 62.
[228] Ibid, 62.
[229] Secter, "A grass worth getting high on."
[230] Ibid.
[231] Ibid.

recycling carbon-based greenhouse gasses emitted when the plant is burned as fuel."[232] The premise of Bob Secter's article in the Chicago Tribune investigates whether switch grass can be used as a biofuel or not. Most of these plants are used for bioenergy, so burning the plants provides fuel and electricity. Not all plants can be burned for energy, but most of them are woody perennial grasses.

[232] Secter.

Sugarcane

The next plant may be shocking to many readers: sugarcane (Figure 22).[233] Sugarcane's scientific name is *Saccharum officinarum*. Sugarcane is primarily known for producing cane sugar. According to Moore, "Current sugarcane literature recognizes six species of *Saccharum*, two of which are wild and always recognized (*Saccharum spontaneum* L. and *Saccharum robustum* Brandes and Jewiet ex Grassl). The other species are cultivated. This review is restricted to only those *Saccharum* species generally recognized as sugarcane."[234] Though sugarcane looks quite different from what we have seen so far, it is still in the Poaceae family.[235]

Figure 22: Sugarcane



Since there is a wide variety of plants within the *Saccharum* name, their divergences include flowering characteristics, visible structure, chromosome numbers, sugar and fiber content, and diameter.[236] To an untrained eye, one sugarcane variety might be indistinguishable from another. Sugarcane is native to parts of Asia including the Malayan Archipelago, New Guinea, India, and some islands of Melanesia.[237] In the book *Sugarcane: Physiology, Biochemistry, and Functional Biology*, the authors say, "Cultivated sugarcanes of today are complex interspecific hybrids primarily between *Saccharum officinarum*, known as the noble cane, and *Saccharum spontaneum* with

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[233] Pratishkhedekar, "Sugarcane farm, Bhuinj 01."
[234] Moore et al., *Sugarcane: Physiology, Biochemistry and Functional Biology*, 2.
[235] Ibid, 3.
[236] Ibid, 4.
[237] Ibid, 9.

contributions from *S. robustum*, *S. sinense*, and *S. barberi*."[238] As are quite a few grass species, sugarcane today is a hybrid of many species in the *Saccharum* genus. Sugarcane, being in the Poaceae family, has the same structural characteristics as other plants in that family. The shoot, often referred to as a stalk in the sugarcane industry, contains a segmented culm with each segment having a node, leaf, and internode.[239] Referring back to Figure 3, many of these terms are identifiable in sugarcane. Sugarcane is also a clumping plant, so it does not rapidly spread laterally. Like bamboo, the different varieties are distinctive from one another based on culm number, culm diameter, leaf length and width, and other visible characteristics of the leaves.[240] Figure 1[241] in de Souza et al. shows the anatomical features of sugarcane leaves and culms. The leaves are images a, c, and e and images b, d, and f are the culms, which we are more interested in. Overall, sugarcane culms at the microscopic level have nearly identical structure to the other plants addressed so far.

[238] Moore et al., 9.
[239] Ibid, 20.
[240] Ibid, 20.
[241] de Souza et al., "Composition and Structure of Sugarcane Cell Wall Polysaccharides: Implications for Second-Generation Bioethanol Production," 568.

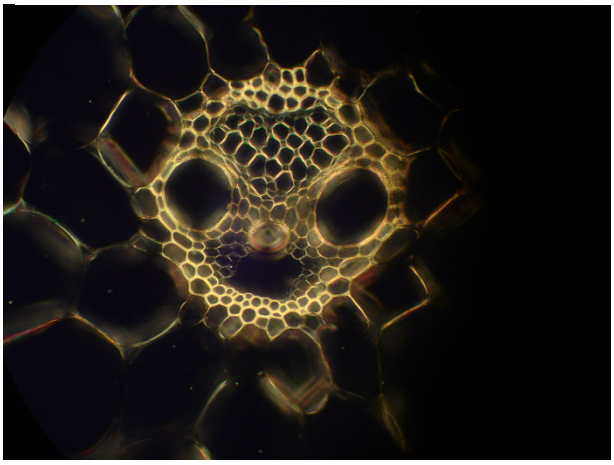
Corn

To continue with our exploration of food groups, the last plant we are going to investigate is corn (Figure 23).[242] In the Chicago suburbs in Illinois, there were corn and soy bean fields everywhere you looked. However, not all of it is for human consumption as about 95% of corn in Illinois is grown for animal feed. Since Matt Finstrom, Tuscon Bamboo Ranch owner, said corn is more related to *Arundo donax* than bamboo,[243] maybe corn could be a potential candidate for reeds. Just like all of the other plants, corn is part of the Poaceae family. Its scientific name is *Zea mays*, also known as maize. So technically, corn is a type of grass that we have cultivated for food over the span of the last several thousand years. Also in the Poaceae family are rice, wheat, millet, rye, barley, sorghum, and oats.[244] It might be an interesting venture to explore the possibility of

Figure 23: Corn Field



Figure 24: Corn Vascular Bundle



[242] Lenz, "Zea mays in Schönerlinde 2021-08-26 01."
[243] Finstrom.
[244] Piñeyro-Nelson, "There is More to Corn than Popcorn and Corn on the Cob!"

making oboe reeds from rice, wheat, millet, rye, barley, sorghum, and oat plants. From my physical experimentations with corn stalks being unsuccessful due to the stalks being too soft or having too much moisture to process into gouged cane, I doubt if rice, wheat, millet, rye, barley, sorghum, and oat plants would be successful. If in the proper environment, some varieties are perennial.

Since annual varieties are commonly grown in areas that are bitterly cold and subzero degree air temperatures during the winter, it dies after harvest and needs to be replanted the following growing season. This is in stark contrast to the rest of the plants that are perennials growing in the proper conditions, so they come back year after year. In Figure 24[245], you can see a cross section of a corn stem under a microscope. The vascular bundle has the same structure as previous plants. After brief experimentation, it was determined that corn cannot be considered as a potential candidate for now, especially since it is not grown as a perennial in most places globally. Despite minimal experimentation with dried corn stalks, corn should not be ruled out entirely since this is a preliminary investigation.

[245] Busch-Paulick, Helge. "Zea mays (312, 5x)."

Comparisons

Many sources that haven't been addressed yet compare different plants, including those with higher biomass and bioenergy potential. Therefore, to determine the suitability of these plants for making oboe reeds, we need to rely on the information available about their biomass and bioenergy characteristics. In the Burner et al. article, the authors conduct a study where giant miscanthus, miscane, and *Arundo donax* were grown with and without irrigation for potential use as bioenergy feedstocks.[246] In addition to the success of the plants with or without irrigation, there is more information provided that proves to be useful. The authors say, "Across all seasons and both irrigation treatments, stalk diameters averaged 23.2, 15.6, and 6.8 mm, for giant reed, miscane, and giant miscanthus, respectively. Giant miscanthus had smaller diameter stalks and giant reed had larger diameter stalks than the 9 and 14 mm, respectively…giant miscanthus nearly doubled in stalk diameter across seasons, but no significant differences in giant miscanthus stalk diameter were observed across seasons in this study."[247] With regard to giant miscanthus and its smaller diameter, the average diameter was only 6.8 mm, which is about 3 mm too small for oboe reeds. However, there are likely larger diameter stalks in the 9.5mm-11.0mm range despite 6.8mm being the average diameter. Additionally, there were no observations on significant differences in stalk diameter across seasons in this study but the authors still concluded that giant miscanthus almost doubled in stalk diameter across seasons. This further shows potential in giant miscanthus as a candidate for oboe reeds. "Miscane" in this article is simply a cross between sugarcane and giant

[246] Burner et al., "Biomass yield comparisons of giant miscanthus, giant reed, and miscane grown under irrigated and rainfed conditions," 1025.
[247] Ibid, 1030.

miscanthus. The stalk diameter is an average and still indicates potential for this hybrid as an oboe reed candidate. Irrigation methods, or a lack thereof, proved to not matter so much. While miscane was not an individual plant addressed, it still shows some promise as an alternative to *Arundo donax* for oboe reeds based on only this article.

In an article comparing *Arundo donax* and *Panicum virgatum* as use for energy crops, the authors say, "A slight decrease in RWC [relative water content] was observed…although no significant differences were found over time or between species. The RWC of giant reed decreased by approximately 18% in stress treatments…no significant differences were found between treatments. Otherwise, switchgrass showed a similar decrease in WS S- and WS+ (21%) with respect to the control…However, no significant differences were found between species for any treatment at any time."[248] A difference in the decrease of relative water content of only 3% between *Arundo donax* and *Panicum virgatum* is most likely a negligible amount when considering using both plants to make oboe reeds. The authors conclude that switchgrass has a great tolerance to water stresses, salinity stresses, and cold stresses and giant reed is more susceptible to all three stresses.[249] With switchgrass being better equipped to deal with climate stresses, that could show that as far as climate change goes, switchgrass would be a much better off option than *Arundo donax* long term for oboe reeds.

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[248] Sánchez, "The response of *Arundo donax* L. (C3) and *Panicum virgatum* (C4) to different stresses," 339.
[249] Ibid, 343-344.

Musical Sources

There were a few articles specifically on musical instrument reeds. The article written by Boichita Bucur involves an overview of traditional and new materials for reeds, but it is interestingly in the *Wood Science and Technology* journal. According to Bucur, "The substitutive species of cane (*Arundo donax*) are: common reed (*Phragmites*) *and* moso bamboo (*Phyllostachys pubescens*)."[250] This statement inspired my investigation into a second type of bamboo. As we have previously covered, *Phragmites australis* has a "continuous ring of fibers around the vascular bundle, the phloem and the xylem."[251] This structure of *Phragmites* is universal to all bamboo and bamboo-like plants, including *Arundo donax*. *Phragmites* has a finer structure of cell walls than *Arundo donax*, as Bucur concludes[252] and reinforces the hichiriki article referenced in the historical overview. Kawasaki's article mentioned the use of *Arundo donax* for hichiriki reeds is not feasible due to the larger cellular structures.[253] If *Phragmites* has more compact structure of its cell walls than *Arundo donax*, that could mean *Phragmites* is probably stiffer than *Arundo*. Oboists often prefer harder cane over softer cane, making *Phragmites*' hardness a potential benefit.

The thought-provoking information in Bucur's article continues with discussion of a timbral study on saxophone reeds from the Cheng et al. article.[254] The study consists

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[250] Bucur, 1179.
[251] Ibid, 1179.
[252] Ibid, 1179.
[253] Kawasaki et al., "Why are *Phragmites* australis Canes Grown in an Udono Reed Bed the Best for Reeds of the Japanese Wind Instrument Hichiriki?: A Structural and Biomechanical Study."
[254] Cheng et al., "Bamboos as the material for saxophone reed."

of saxophone reeds made from *Arundo donax* and moso bamboo.[255] As several double-reed instruments have successfully used *Phragmites* for their reeds, we draw a comparison between *Phragmites* and moso bamboo with *Phragmites* being used as the control in Figure 11[256] of Bucur's article. Though the images are not in the same color scale, the cellular structure of the culm in each image is clear. The vascular bundle in the moso bamboo seems to be more spread out around the edges, but equally as compact on the interior as *Phragmites*. Bucur then includes data from the Cheng et al. article on the moso bamboo saxophone reed versus the *Arundo donax* saxophone reed. Bucur says,

> The usual parameter for the characterization of the quality of reeds is its strength. The relationship between thickness or reeds (150-360 μ) and the strength of cane and bamboo is shown in Fig. 12. Both graphs show the same tendency, in spite of the fact that the results are quite scattered (35% specimens made of cane and 44% specimens made of bamboo, out of confidence limit of regression line). This can be explained by the anatomic structure of both species, which is composed of two typical elements, the vascular bundles and the parenchyma cells. Cane structure is relatively more homogenous and finer than that of moso bamboo structure. The vascular bundles are bigger in moso bamboo than in cane. The average distance between the vascular bundles in moso bamboo (1 mm) is larger than the thickness of the reeds. It was suggested the distribution of the small vascular bundle is one of the factors, which is consistent with the strength of reeds.[257]

Ideal cane has a more unified and tight structure along with smaller vascular bundles than bamboo. Though both cane and bamboo have parenchyma cells and vascular bundles, how those appear at such a small level can affect the quality of materials for making reeds. Regardless, the graphs in Figure 40[258] show remarkably similar results. *Arundo*

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[255] Bucur, 1179.
[256] Ibid, 1181.
[257] Ibid, 1180-1181.
[258] Ibid, 1182.

donax cane and moso bamboo cane for saxophone reeds are almost indistinguishable. Bucur continues,

> An objective comparison of the quality of reeds made from cane and from moso bamboo is given by the analysis of the acoustical spectrum of the saxophone, playing the same note with each reed. The timbre analysis was made for the lowest *D* note (nominal fundamental f∘=174 Hz, *F*3 in piano) and the highest note *D* (nominal fundamental frequency f∘=698.5 Hz, *F*5 in piano) that were played on an alto saxophone. [Figure 11B] gives the audio spectra for saxophone reeds made of cane and of bamboo of low, medium and hard strength, for the low *D* note, of frequency 174.6 Hz. This signal was processed and the spectral centroid frequency was calculated. The spectral centroid frequency is the weighted mean of the frequencies of the signal determined with a Fourier transform and with their magnitudes as the weights. The spectral centroid is a good predictor of the brightness of the sound and can be submitted to a statistical 't' test analysis…[259]

Essentially, the timbre of each type of reed was analyzed for playing the lowest D and the highest D on the saxophone. As a result, both the *Arundo donax* and moso bamboo had similar centroid frequencies on the low D. However, there was a 5% significant probability difference when a high D was played. The spectral centroid frequency for the moso bamboo was higher than *Arundo donax*, 4878 Hz and 4753 Hz, respectively.[260] The spectral centroid frequencies were averages, see Table 1 in Cheng et al.[261] Even though the high D was a bit brighter on the bamboo reed compared to *Arundo donax*, a few things need to be considered before ruling out bamboo entirely. Musicians are able to address and fix a large amount of problems from *Arundo donax* reeds—solutions include a mouthpiece change, ligature change, instrument adjustment, reed adjustment, etc. Since moso bamboo is entirely a different plant than *Arundo donax*, the setup of the

[259] Bucur, 1181-1182.
[260] Ibid, 1182.
[261] Cheng et al., 4.

saxophonist in this study is might not be ideal for moso bamboo reeds since their setup was formed with *Arundo donax* reeds in mind. Another potential solution to this problem is how the moso bamboo reed was made. Again, since it is a different plant, maybe the method of making the reed needs to change. Plus, a difference of 125 Hz between the spectral centroid features is almost certainly negligible. Centroid frequencies are a physical measurement of sound that may correlate with the perception of brightness. According to Heather Daly,

> Pitch is typically defined as the subjective experience of fundamental frequency (F0)…The perception of pitch is ordered from low to high, tracking the low to high ordering of frequency. Timbre, on the other hand, traditionally has been defined by what it is *not*, rather than what it is. The American National Standards Institute (ANSI, 1973) has defined timbre as 'that attribute of auditory sensation in terms of which a listener can judge that two sounds, similarly presented and having the same loudness and pitch, are different.' Similar to this interpretation, some researchers have defined timbre as the aspect of sound that differs between sound sources that have the same pitch, loudness, and duration. Other researchers have defined it more simply as tone quality, or the unique quality of a sound that contributes to its identification, such as the distinction between different musical instruments playing the same note.[262]

With the definition of timbre being somewhere around sound that has the same pitch and loudness but is slightly different, and Cheng et al. using the spectral centroid frequency to analyze the cane and bamboo reeds, we can draw the conclusion that moso bamboo saxophone reeds are a bit brighter in the upper range of the saxophone than *Arundo donax* reeds. As pitch ascends on any instrument the timbre generally gets brighter. Another manipulation that the player might have to make is with the speed of air and/or voicing of the note for it to be a closer spectral centroid frequency to the cane reed, unless

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[262] Daly, "The influences of musical training and spectral centroid on perceptual interactions of pitch and timbre," 1-2.

the brighter sound is acceptable to the player. Since Cheng et al. used means to measure the spectral centroid frequency, the likelihood that between-task variance impacted the results is minimal. Regardless, bamboo is a different plant than *Arundo donax*, so our current perceived conventions of playing and making reeds are built solely around *Arundo donax* and any changes that are made take time to get used to. When oboists experiment with different shapes or staples, for example, they need to adapt many aspects of their playing to see if the new shape or staple will work for them with ease.

PHYSICAL MATERIALS

Our Setups

To have a better idea when interpreting the results of our physical experimentation and sound analysis with bamboo and *Phragmites* cane, Martin and I will detail our preferences in our setups.

For myself, I play on a Lorée oboe, AK model. I purchased it new in December of 2015, so it is about 8 years old. My choice of staples is mostly silver Chudnow E staples and I prefer nylon FF thread as of recent, specifically the MusEcho brand. Prior to the nylon FF thread, I used thread from "reedesign.io," which is a single strand of nylon thread, as opposed to normal nylon thread which is several strands braided together. The goal of this thread was to make your reeds vibrate more freely, which I thought it accomplished quite well in the desert climate. Unfortunately, it seems that reedesign.io shut down their website and are no longer selling anything, so in order to conserve my all-time favorite thread, I switched to MusEcho nylon FF. I would not have enough of the reedesign.io thread for my reeds and the experimental reeds to remain as consistent as possible, so I started using MusEcho thread. The cane I usually buy is RDG from Midwest Musical Imports or Capitol Cane because I find RDG to be cheaper than other brands and it tends to be more consistent and reliable than others. I use a MP shape, Ando knife for rough scraping, and Edmund Nielsen knife for fine scraping. The gouging machines I use are the Ross and Innoledy. I used the Innoledy for all of the cane for the study and for the cane Martin and I experimented with.

Martin plays a Howarth XL oboe. His preferred staples are Rigotti brass 47mm with nylon FF thread. He usually purchases Rigotti cane from Woodwind and Brasswind. The shape he consistently selects is the Mack Pfeiffer. The gouging machine he regularly uses is the Reeds 'n Stuff 11mm bed and 11.6mm blade and he occasionally uses a profiler, but mostly does not. On his process for testing and playing reeds as he finishes them, Martin says, "I work mostly with the crow until the final steps. Then, I prefer to work with the reed for a few days practicing 'real' music and adjusting gently as needed. Overall, my process takes 3-5 days before I trust the reed in a rehearsal situation." The ideal features Martin looks for in his cane is structural density and resilience. He says, "I reject cane if the bark is ribbed, if the interior surface is very grainy (with celery-like fibers) or if there are notable discolorations. If in doubt, I check the cane on a hardness tester to confirm suspicions."

Before discussing processing the other types of cane, some points must be made. Since we are dealing with entirely different plants, the parameters we examine to determine if cane will be good or not is based solely on *Arundo donax* and might be irrelevant for other plants. It was incredibly difficult for me to not let my biased opinions formed for *Arundo donax* affect how I thought about the other types of cane when processing them. Additionally, the *Arundo donax* we purchase goes through such a rigorous sorting process that by the time we order it on the various websites that sell it, we receive the best tubes from that harvest. The *Phragmites* cane is marketed for bee hives and the bamboo is marketed as stakes for crafting or gardening. The people who harvest the bamboo stakes or *Phragmites* tubes do not care if the tubes are cracked, uneven diameters, crooked, and not great quality for making musical instrument reeds.

The people who harvest *Arundo donax* for the purposes of making musical instrument reeds “weed” out the curvy, cracked, unsatisfactory colored tubes that will never work for reeds before we have the ability to buy them. Both the idea that certain parameters might be entirely different for cane that will work for reeds for the different plants and the fact that the sorting processes for these different plants are not nearly as rigorous are important points that need to be taken into account.

EXPERIMENTAL MATERIALS

Arundo donax

I think my experience processing tube cane from *Arundo donax* is the universal experience all oboists have. The tubes, when dropped from a couple inches high onto a table, emit a certain frequency that we can use to determine if the cane is of good quality or not. We roll the tubes to ensure the roll is even, balanced, and the tubes are straight. When splitting, we feel the resistance to the splitter to determine the hardness of the cane. Upon splitting the cane, guillotining, pre-gouging, and gouging we examine the grains of the cane and the colors of the interior cane to better predict how the cane will vibrate if we make it into a reed. Of course, all these parameters oboists look at throughout the reed making process are learned by experience and we all have our preferences of what we think might be a good reed or might be a bad reed. Personally, I do not care about the exterior color of the cane for reasons previously expanded on, that the main color of the cane is due to sun exposure and the dark brown spots are from the decaying plant matter. Both have no impact on the quality of the cane. The interior color of the cane is better when it is lighter and the grains are close together and even. When scraping a blank, I look for curly bits of cane to just roll off my knife.

Phragmites

Processing Phragmites from Tubes to Gouged Cane

The first experimental material is *Phragmites*. I purchased *Phragmites* tubes on Amazon that are marketed for putting bee cocoons into bee hives. Upon opening the box, the tubes were nearly identical to *Arundo donax* oboe tube cane. A little over half of the box was unusable, as the diameters were too small, but again, this cane is not nearly as rigorously sorted as *Arundo donax*. The tube walls were noticeably thinner than *Arundo donax* and when splitting the tubes, the cane felt "soft," but it actually was not soft. The tube walls being thinner meant there was less material to get through when splitting, which makes sense. When using a guillotine, pre-gouging, and gouging the *Phragmites*, it still felt "soft" even though there just was not a whole lot of material to take off to begin with. The interior of the cane was a bit dark and it looked really grainy, so my suspicions of the cane being soft were starting to look like it was actually soft. It was not until I measured the hardness of the cane with two hardness testers that I was proven wrong (see the data in the Hardness Testing section). *Phragmites* cane that is pre-gouged is pretty soft, but gouged cane is in the same sweet spot as *Arundo donax*.

Making Phragmites Oboe Reeds

I have taken photos of the *Phragmites* reed I made at the same time as an *Arundo donax* and bamboo reed. The cane seems much more dense than *Arundo*, which aligns with what the consensus was in the analysis portion. I had little difficulty with scraping until I got to scraping the channels for the windows and heart of the reed, where I got a lot of catches. I had to repeatedly dust them with my fine knife to minimize the amount of catches. I assume the reason why there were so many catches was because the angle I was scraping might not have been conducive to the grains in the cane so if I could perfect the angle of scraping with the long scrape, that might solve the issue. I soaked the reed for 5 minutes, per the dry desert climate like I usually do. I used a fresh razor blade to clip it as close to 70 mm as possible. The opening of the reed was quite large after clipping, but not too large to be of concern. After gently smushing the opening down a little bit, I tested the reed to see if it would make a sound. It is hit or miss as to whether my normal reeds make a sound or not immediately after clipping. The reed did make a sound. I scraped mostly around the tip and let it sit overnight before finishing it. I also did the seal test and it sealed well.

The next day before soaking the reed, I noticed the blades were really flat with there were gaps between the blades in the tip. I did not touch the blades besides putting the reed in water. When I looked at the opening after soaking it, the opening went back to the normal football shape and the reed sealed. After soaking, the cane was much easier and smoother to scrape. Unfortunately, this reed also cracked as I was finishing it. I made another and instead of dry scraping it, I decided to soak the blank before scraping at all. The next reed cracked again, so knowing that this material is harder and more dense than

Arundo donax, I sharpened my knives in case my knives were too dull for the material. The cane did not crack after I sharpened my knives. The reed was harsh in sound and after drying, the blades were split open on the sides of the tip but it still functioned.

At first glance when I initially brought Martin *Phragmites* cane to observe, he looked at it with utter disgust. When he received gouged pieces to make reeds with, he said the *Phragmites* looked stringy and pale. He says, "*Phragmites* was much more challenging—the bark layer was very dense and difficult to scrape through, leaving an untidy surface behind. I wound up sharpening my knife 3-4 times just to make one reed." He thinks that having a rigorous sorting process for *Phragmites*, like we currently have with *Arundo donax*, would help provide better and more clear results. Additionally, he thinks, "we would surely benefit from more comprehensive information about these alternative materials."

Bamboo

Processing Bamboo from Stakes to Gouged Cane

The next immediate experimental material is bamboo. I purchased two batches of bamboo stakes before I bought a batch that was about the right diameter for oboe reeds. The previous batches' diameters were too small. As a result, the bamboo stakes that had the correct diameters for oboe reeds were 6 feet long. I purchased a small hand saw from Home Depot to cut the stakes into smaller tubes so it was easier to work with and would not crack upon cutting the stakes. When splitting the cane, the material in the middle of the tubes did not fully disappear like in *Arundo donax* so it made my desk quite dusty. The tube walls were significantly thicker than *Arundo donax* and when I pre-gouged the cane, it took off at least 2/3 of the material, if not more. The bamboo felt a lot more dense than *Arundo donax*, but usually *Arundo donax* tends to be on the softer side which tends to not work in oboists' favor most of the time. The color was also very dark. Upon visiting the Bamboo Ranch in Tuscon, I brought one of these stakes for Matt Finstrom to see if he could identify what species of bamboo it is. He informed me that a lot of commercial bamboo stakes are treated with chemicals unfit for human consumption, so my processing of those bamboo stakes I purchased on Amazon abruptly ended. However, Matt had bamboo stakes he grew himself that were untreated, so I purchased several and right away my results after processing to shaped cane were almost indistinguishable from *Arundo donax*. Besides the lack of chemicals, processing the untreated bamboo and the treated bamboo were identical. The bamboo felt and looks very similar to *Arundo donax*. The only two issues I experienced were cutting the stakes to be a manageable size, like oboe tube cane, without cracking and splitting the tubes straight. The grains in the

bamboo are not entirely straight, causing my splitter to move side to side too much which makes the pieces of cane very wavy. That results in cracking and the inability to process it further. I expected to discard more bamboo cane than I actually did, since a lot of the cracks in the tubes were only surface level and I was able to split along the larger cracks.

Making Bamboo Oboe Reeds

The bamboo cane reed was the smoothest piece of cane I have ever scraped. The shavings coming off the reed reminded me of the shavings coming off cane when gouging, except at a more miniscule level. It is a lot darker than Arundo and *Phragmites*, so it was a bit harder to see the structure under the light. I soaked it for 5 minutes before clipping the reed open, per the dry desert climate like I normally do. I used a fresh razor blade to clip as close to 70 mm as possible. The opening of the reed was a little smaller than the openings of my normal reeds on average, but it is definitely manageable. My normal reeds sometimes make a sound immediately after clipping, and the bamboo reed did but the resistance caused a lot of pressure in my head. So, I scraped mostly around the tip and let it sit overnight before finishing it. It also sealed well with the seal test.

The next day before soaking the reed, the opening was good and after I soaked the reed, it sealed really well. The cane was very hard, but it felt a lot nicer on my knife to scrape. As I was finishing the reed, it cracked down the middle of one of the blades. I decided to make another reed and instead of dry scraping it, I soaked the blank before scraping. The cane still cracked. Like I previously mentioned with *Phragmites*, I sharpened my knives. Unfortunately, there were already deep cracks in the cane so I had to start over with another blank. I realized that my knives were a bit dull and the cane was not soaked enough, so I soaked the cane for 30 to 40 minutes and sharpened my knives. I was able to get a bamboo reed to play and crow, but it was very hard likely due to how dense the material is. After letting the reed sit for a few days, I soaked it again to see where it was at and it was much more responsive, but very bright in tone.

Martin was more eager to make reeds from bamboo than the *Phragmites*. The bamboo was easy to work with and had great texture and structure with very neat scraping. Unlike the *Phragmites* material, the bamboo was crack-prone so Martin soaked it for a few hours before handling. He says, “This extra soaking might have affected the final result somewhat.” His statement regarding the rigorous sorting process for *Phragmites* is the same as bamboo, where we could benefit from a rigorous sorting process and more comprehensive information about these alternative materials.

My Reed Making Process

For the initial comparisons, I scraped an Arundo reed, *Phragmites* reed, and bamboo reed in the same sitting. I start with measuring 61mm, 65mm, and 70mm and mark the cane on the side with a pencil. Then, I start scraping with my rough knife at an angle at 65mm to define the shape of the tip. I usually scrape the tip at this stage pretty thin—as thin as possible without needing a plaque. After I got the desired and basic tip structure, I used my fine scraping knife to make it as thin as possible. Then, I go back to my rough scraping knife and use a long scrape to make the channels where the heart and windows will be. I usually count anywhere from 8-10 strokes per side per blade. Then I add the windows by scraping from the bottom until my 61mm mark and stop deliberately creating a catch. I take my fine scraping knife and dust over that catch at various angles until it is a smooth transition between the heart and windows. Throughout all of this, I avoid the middle of the tip, the spine, and the rails. After the catches have been dusted, I go back to the tip to see if I can get it any thinner and refine my roofline to make it more pronounced. Once it is thin enough, I soak the reed for about 5 minutes before clipping it open. Up until I clip the blank open, I dry scrape. Most oboists don't dry scrape that far, but I find that I have much more control over the amount of cane that I take off if it is dry. I'd rather remove too little cane the reed this early than too much and when I scrape a blank soaked, I tend to take off more cane than I'd like to. After soaking for 5 minutes, I draw a little dot where 70mm is and clip as close to 70mm as I can but still clipping slightly above 70mm. The length of my reed at this point is around 70.5-71mm, but no longer. I then scrape mostly around the tip, but I do scrape some out of the windows and back to see if I can get the reed to crow. Once there is a crow, regardless of the quality of

the crow, I set the reed aside for the next day to finish it. The next day, I continue chiseling away at the reed gradually until the crow is satisfactory and I test it on my oboe to further diagnose and fix any remaining issues. How defined the structure of my reed and how thin I scrape each section tends to vary with the quality of the cane, so I treat each reed individually when finishing them to get the best results possible.

Photos of Cane in Reed Making Process: *Arundo donax*, *Phragmites*, Bamboo

Gouging and Blanks

Figure 25: Tubes - *Arundo donax* (left, top), *Phragmites* (middle, middle), Bamboo (right, bottom)



Figure 26: Gouged Cane - Bamboo (top), *Phragmites* (middle), *Arundo donax* (bottom) *numbers correspond to hardness chart in Figure 52



Figure 27: Blanks - *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)



Scraping Stages

Figure 28: First Scraping Step with Corresponding Knife Shavings – *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)



Figure 29: Second Scraping Step with Corresponding Knife Shavings – *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)

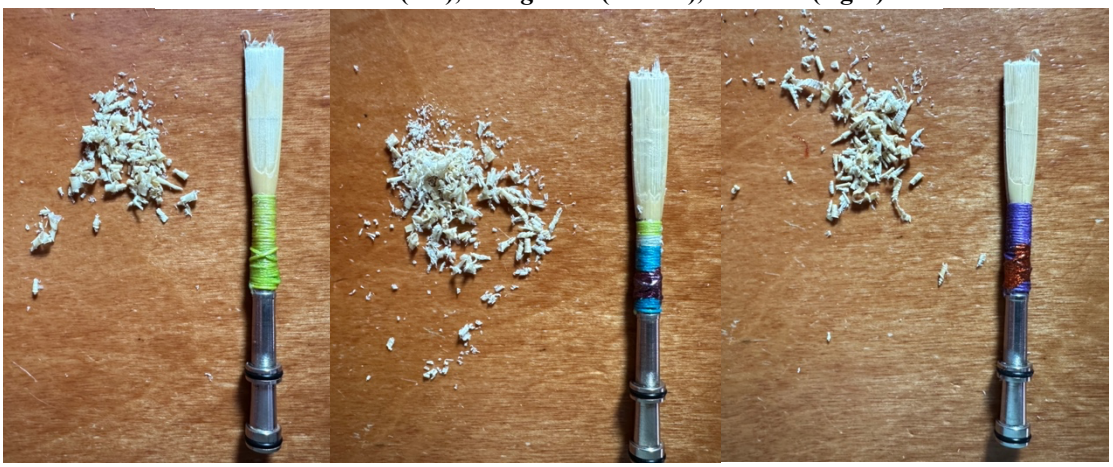


Figure 30: Second Scraping Step Under Light – *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)



Figure 31: Clipped Open Reeds – *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)









Figure 32: Dry Reeds After Sitting Overnight – *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)

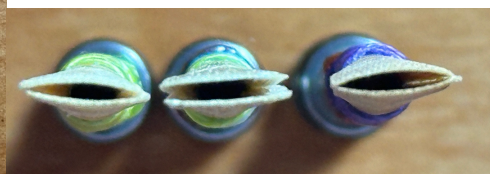


Figure 33: Reed Openings After Soaking – *Arundo donax* (left), *Phragmites* (middle), Bamboo (right)

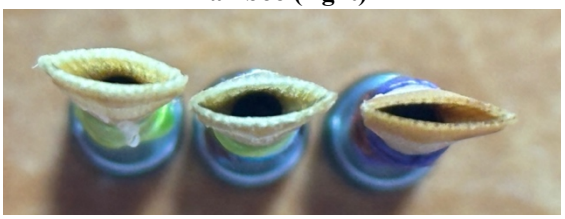
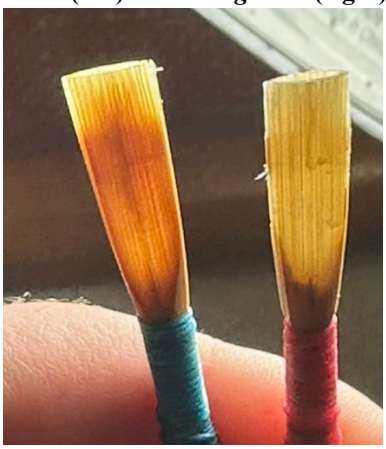


Figure 34: Finished Experimental Reeds Used in Timbral Analysis Section – Bamboo (left) and *Phragmites* (right)



Collective Discussions on Our Individual Results

After working with the *Phragmites* and bamboo, I can safely say that both plants have potential to be great alternatives to *Arundo donax* for oboe reeds in the future. I am not entirely sure if these two specific plants would ever replace *Arundo donax*, but if cultivated and sorted for musical instrument reeds, the results would be more accurate representations of the materials than the results from our preliminary research. Based on this experience, Martin thinks *Phragmites* and bamboo could possibly be groundbreaking in the reed making world, and of the two, he thinks bamboo would be more successful. The experimental cane was successfully processed, gouged, shaped, and tied onto staples with little to no issues. The issues arose in the scraping stages of the reeds, which could be due to both *Phragmites* and bamboo being more dense than *Arundo donax* and our delicately sharpened knives simply could not handle it. The density in the *Phragmites* seemed to only be in the outer layers of the bark due to the ease of splitting, pre-gouging, and gouging. The density in the bamboo was spread evenly throughout resulting in slightly more resistance than *Arundo donax* when splitting, pre-gouging, and gouging. However, the *Phragmites* tube walls were quite thin and the bamboo tube walls were quite thick, so the density of the materials might be more related to the tube wall thickness than density.

IRB STUDY: STUDY00018503

To have a wider reach with my dissertation, I received IRB approval from Arizona State University to conduct a study on *Phragmites* and bamboo. Dr. Joshua Gardner was the principal investigator. The study involved six participants, all consented to the study and disclosing their names. Each participant received three gouged pieces of *Phragmites*, *Arundo donax*, and bamboo cane labeled A, B, and C, respectively. They did not know which type of cane was which besides the letter labels. They also were not made aware that *Arundo donax* was one of the materials. The participants first completed a Google Form detailing their setup and level of reed making experience. As they worked with each material, they completed the corresponding Google Forms for each material, still labeled A, B, and C. The last Google Form detailed overall conclusions they drew from their experience. The participants are listed alphabetically with their job titles and responses in Appendix B.

Concluding Thoughts for STUDY00018503

To conclude the participants' responses, Material B (*Arundo donax*) was by far the best choice between the three materials and a few participants correctly guessed that it was *Arundo donax*. The general consensus is split between whether Material A (*Phragmites*) or Material C (bamboo) were the next best and then what was the worst. Some participants had trouble with bamboo cracking, some participants noted that the *Phragmites* cane split open at the sides of the tip, and some mentioned the pieces were warped or gouged poorly. Overall, participants were able to make reeds with *Phragmites* and bamboo that made sound and could play regardless of if the reeds played well or not.

There were some pitfalls to the study and aspects of the study that I would like to improve for future studies:

- The first is the quality of the cane. Ideally, I would have liked to purchase hundreds of dollars' worth of each type of experimental cane, sort it for the best pieces, and then use only the best pieces for the study. Unfortunately, I did not receive funding for the study and I could not afford to purchase that much cane, so I tried the best with what I had. Additionally, more research could be done to determine if the experimental cane had been aged like *Arundo donax* is and if not or if that is unknown, I would age it under the same or similar conditions as *Arundo donax*.
- I was not clear in the purpose of the study or I could have been more clear in the premise. I think most of the participants missed the point of the study, which was to see if we could gouge, shape, scrape, and make a reed that simply makes sound. Overall, the participants were successful in doing so which shows that the study was a success despite a lot of mixed opinions and feelings toward the materials. Maybe the right species of bamboo is not *Bambusa textilis*, but there are hundreds, if not thousands of other bamboo species so the best species for making oboe reeds just has not been identified yet. Maybe the *Phragmites* I purchased for the study was not aged or the plant was not grown in the ideal conditions that *Arundo donax* is, so unifying each parameter would benefit future studies.
- Upon deciding to add *Arundo donax* to the mix as a third material for the participants to work with, I knew that would be the best choice but wanted to provide a "control" for the study. In hindsight, the "control" could simply be that oboists always use *Arundo donax* for reeds and they did not necessarily need

Arundo donax to be one of the materials in the study. I also should have made it more clear that *Arundo donax* was in the mix so I could have asked the participants which material they thought was *Arundo donax* and then of the other two, which would have the most success as viable reed material if sorted as rigorously as *Arundo donax*. Either removing *Arundo donax* entirely or keeping it in the study with more clarity overall would provide better results.

For future studies, I will consider whether *Arundo donax* should be part of the study or not. I would also like to try to receive more funding so I could successfully find the best pieces of each experimental type of cane for the best and most accurate results. Though there were quite a few pitfalls, which there are in almost every study in every subject area, I would consider this study a success. The participants were able to make functional reeds with the experimental materials regardless of the reed quality, which is what the purpose of the study set out to achieve.

DATA COLLECTIONS

Hardness Testing

The Reeds N' Stuff Uhhto Cane Hardness Tester and KGE Hardness Tester (See Figure 35 for Results) were used to evaluate a random sample of 10 pieces of *Arundo donax*, *Phragmites*, and bamboo pre-gouged cane. Each piece was numbered 1-10 and the Reeds 'n Stuff machine was used to test the pre-gouged cane, which punctures the cane to determine the amount of resistance it receives. The ideal range for hardness numbers is between 20 and 25, with the higher numbers being softer and the lower numbers being harder. After gathering the data for pre-gouged cane, the cane was gouged and then the KGE machine was used to test the gouged cane. The KGE machine twists the cane to measure its level of resistance to twisting. The ideal range is between 70 and 100, with the lower numbers being softer and the higher numbers being harder.

The averages for the *Arundo donax*, *Phragmites*, and bamboo pre-gouged samples are 14.6, 22.3, and 12.8, respectively. The Reeds 'n Stuff machine's ideal range of hardness is between 20 and 25, so most materials measured outside of the acceptable range on the harder side. Interestingly, the *Phragmites* cane's average is in the middle of the acceptable range and the *Arundo* and bamboo cane's averages are much harder. The averages for the *Arundo donax*, *Phragmites*, and bamboo gouged cane are 98.4, 82.6, and 88.2, respectively. The KGE machine's ideal range of hardness is between 70 and 100, so all of the materials are within the acceptable range.

The standard deviations for the *Arundo donax*, *Phragmites*, and bamboo pre-gouged samples are 4.17, 4.24, and 2.70, respectively. If *Arundo donax* is the control, then the *Phragmites*' standard deviation is pretty close to *Arundo donax*. Essentially, the

variation of hardness levels for pre-gouged samples using the Reeds ‘n Stuff machine with a sample size of 10 is remarkably similar between the *Arundo donax* and *Phragmites* samples. The bamboo has the lowest standard deviation, meaning the amount of variation in the hardness levels of a sample size of 10 is much lower than the control, so the hardness is more consistent. The standard deviations for the *Arundo donax*, *Phragmites*, and bamboo gouged samples are 15.06, 10.32, and 17.76, respectively. The bamboo pre-gouged cane having a small standard deviation can lead to the assumption that the gouged cane’s standard deviation is also small. However, the bamboo gouged cane’s standard deviation was the highest of the three. This may indicate that some layers of the bamboo cane are more consistent in hardness levels than other layers. Of the pre-gouged and gouged cane, *Phragmites* was the most consistent with both standard deviation measurements.

Results indicate that the *Arundo donax* sample was on the harder side, with a few pieces being arguably too soft. The *Phragmites* sample was in and immediately around the acceptable range, but gave inconsistent results. The bamboo sample was overall very hard. This data shows that different layers in the cane tend to be differing hardness/softness levels, which logically could lead to bad results if made into a reed. However, like STUDY00018503, it is important to note that the experimental materials were certainly not cultivated for musical instrument reeds. Additionally, *Arundo donax* acting as our control was just as variable and out of acceptable ranges as the other two materials. A sample size of 10 pieces is also far too small to make conclusive generalizations about hardness level comparisons between all three materials.

Figure 35: Hardness Data							
Type	**#**	**Pre-Gouged Hardness**	**Gouged Hardness**	**Average PG Hardness**	**Standard Deviation PG Hardness**	**Average Gouged Hardness**	**Standard Deviation Gouged Hardness**
Arundo	1	20	90	14.6	4.17	98.4	15.06
	2	12	104				
	3	21	89				
	4	10	92				
	5	20	100				
	6	12	105				
	7	12	111				
	8	15	65				
	9	13	115				
	10	11	113				
Phragmites	1	20	65	22.3	4.24	82.6	10.32
	2	15	66				
	3	20	83				
	4	28	87				
	5	24	79				
	6	20	95				
	7	22	90				
	8	25	91				
	9	20	80				
	10	29	90				
Bamboo	1	12	74	12.8	2.70	88.2	17.76
	2	12	74				
	3	12	86				
	4	20	58				
	5	12	110				
	6	12	110				
	7	14	98				
	8	12	105				
	9	12	75				
	10	10	92				

Microscopic Imagery and Quality of Materials for Woodwind Reeds

Reeds contain pertinent information at the microscopic level that musicians do not often consider when analyzing their own reeds. As an additional method of gathering data on alternative materials, Professor Jeffrey Kleim and I used a Leica F12 scope image the plant samples I obtained. To get an idea of the scale of the scope, the lens is a Leica M320 and it is originally designed to perform eye surgery. Professor Kleim decided on using high magnification and low light to get as close of a picture as possible with minimal to no glare from the light. The plant samples we imaged include *Arundo donax*, *Phragmites*, bamboo, *Arundinaria gigantea*, Giant miscanthus, sugarcane, and corn stalks.

To aid in analyzing these microscopic images, we will use the results from Glave et al. to gauge the potential success or failure of using our materials for oboe reeds. According to the authors, partial occlusion of vessels by tylose formation tends to be related to low cane quality.[263] The authors further explain that occlusion usually occurs when plants are wounded or have an infection caused by bacteria or fungal pathogens.[264] Occlusion is new growth of woody material that covers up wounds or areas of infection.[265] In Figure 4[266] of the Glave et al. article, the image on the left is an electron micrograph of good tissue and the image on the right is bad tissue. The vessels in the good tissue are open, unified in size and spacing for the most part, and do not appear to have any deformities. The vessels in the bad tissue are a wide variety of sizes, some

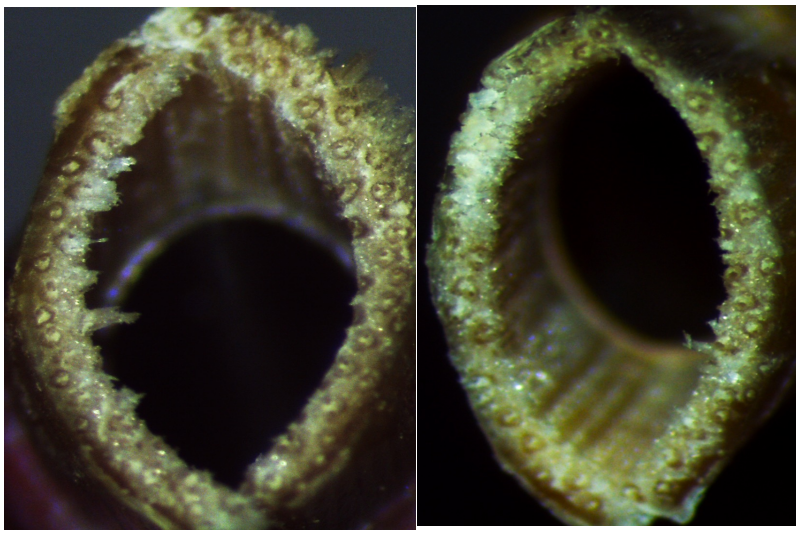
[263] Glave et al., "Quality indicators for woodwind reed material," 673.
[264] Ibid, 674.
[265] Wilson, *A-Z of Tree Terms: A Companion to British Arboriculture*, "occlusion."
[266] Glave et al., 675.

vessels are not as open as others, and generally looks unhealthy compared to the good tissue. These microscopic qualities may correlate to the characteristics of cane seen with the naked eye in determining quality for musical instrument reeds.

Control: Arundo donax

Since the authors of Glave et al. used a different scope than we used, I chose two of my normal reeds to take a cross section image of the thickest part of the cane just above the thread. Similar to Figure 4[267] of Glave et al., one of the reeds was one of my favorites from March 2024 and the other was a reed that had no potential despite many days of trying to get it to function well. The reeds are pictured in Figure 36.[268] The lighting of the images is slightly different, but the visible characteristics in our images correlate with the conclusions drawn by Glave et al. The good reed has vessels that are uniform in size, close together, uniform in color, and evenly spaced. The bad reed has vessels that vary more in size, the vessels are unevenly spread and unevenly spaced, and the color is not entirely uniform. The magnified images in Figure 37[269] even show the vascular bundles. Within the individual vascular bundles in the good reed, the structures' sizes are not irregular and overall the vascular bundles are very homogenous. Within the individual vascular bundles in the bad reed, the structures' sizes are quite irregular and the vascular

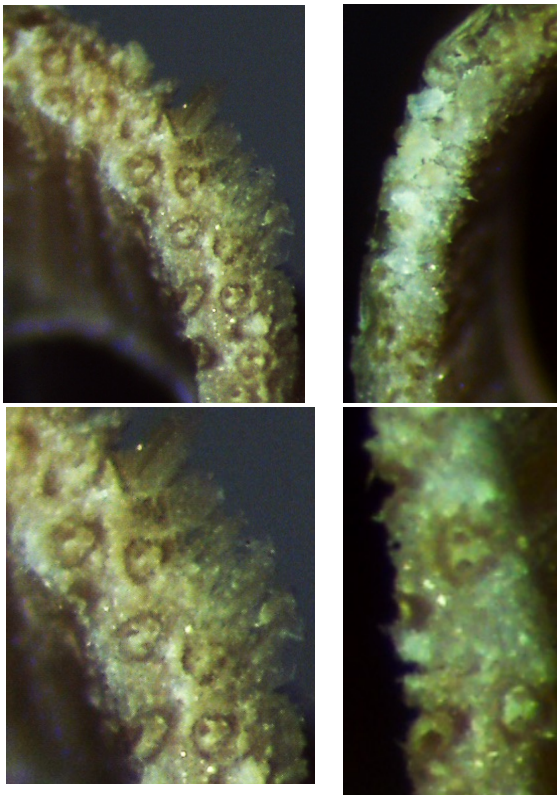
Figure 36: *Arundo donax* Reeds – Good Reed (left) and Bad Reed (right)



[267] Glave et al., 675.
[268] Kleim, Jeffrey. Leicam F12 with Leica M320 lens. High Magnification, Low Light. March 25, 2024.
[269] Ibid.

bundles are not homogenous. The top right image in Figure 37[270] looks like occlusion from an infection since the rest of the cane has suboptimal characteristics. An additional image of an *Arundo donax* tube is in Figure 38,[271] however it looks as if the ends of the tube were sanded during the initial processing stages, so the vessels and vascular bundles are more difficult to see.

Figure 37: *Arundo donax* Reeds Zoomed In – Good Reed (upper left), Good Reed Vascular Bundles (lower left), Bad Reed (upper right), and Bad Reed Vascular Bundles (lower right)

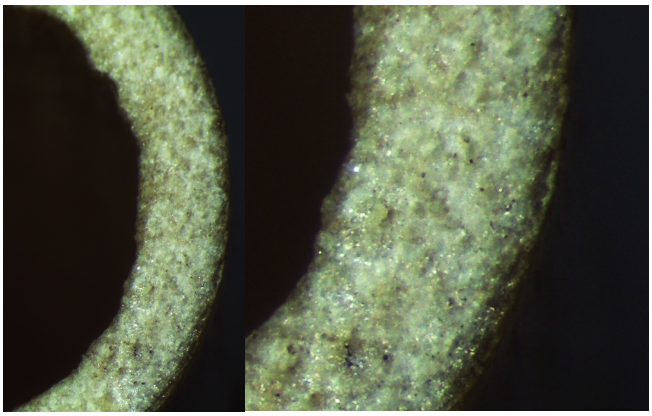


[270] Kleim.
[271] Ibid.

Phragmites

Like the *Arundo donax* tubes (Figure 38)[272], the ends of the *Phragmites* tubes (Figure 39)[273] were possibly sanded in the initial processing stages, making it more challenging to see the vessels and vascular bundles. Regardless, the vessels' circular shapes are still visible in both the *Arundo donax* tube and *Phragmites* tube. Considering the article reviewed previously on hichiriki reeds, the authors say, "The plant *P. australis* almost resembles *A. donax* in plant anatomical characteristics as previously reported, but is different not only in scale of outer shape but also size of cells, as their English names of 'common reed' for *P australis* and 'giant reed' for *A. donax* imply. This is a reason why *A. donax* cannot be used for *rozetsu* [hichriki reeds]."[274] The inference from why *Arundo donax* is referred to as "giant reed" and *Phragmites* is referred to as "common reed" might be due to the size of the shoots. While the diameters of both *Phragmites* and *Arundo donax* are similar and well within the acceptable measurements for oboe reeds, the tube walls of *Phragmites* are noticeably smaller than *Arundo donax*. The *Phragmites* tube wall in Figure 39[275] is between 1mm

Figure 38: *Arundo donax* Tube

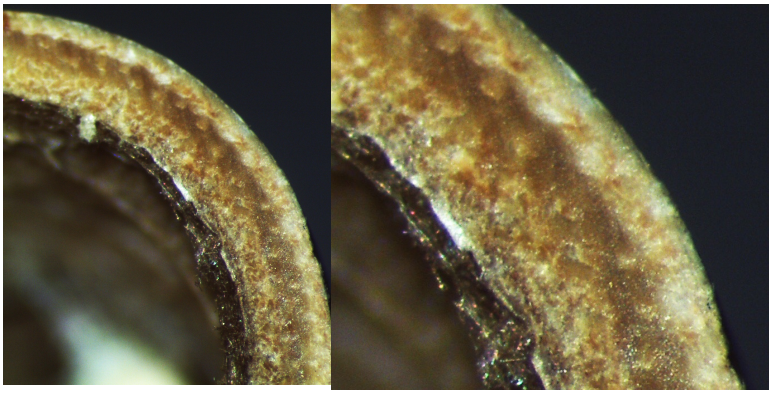


[272] Kleim.
[273] Ibid.
[274] Kawasaki et al., 48.
[275] Kleim.

and 1.5mm thick while the *Arundo donax* in Figure 38[276] is 3mm thick, so "common" and "giant," respectively.

The stark difference in thickness of tube walls is another potential reason why *Arundo donax* cannot be used for hichiriki reeds, so the rational hypothesis is that *Phragmites* cannot be use for oboe reeds. However, recall another source investigated earlier suggests that *Arundo donax* L. might be the result of natural cross-breeding between *Arundo plinni* and a diploid of the same species, or *Arundo plinni* and *Phragmites australis*.[277] *Phragmites* should not be ruled out this early in preliminary investigations due possibly incorrect hypotheses. There may be solutions that involve purposeful cross-breeding between *Phragmites* and *Arundo donax* to create a hybrid that encompasses the best qualities of both for oboe reeds.

Figure 39: *Phragmites* Tube

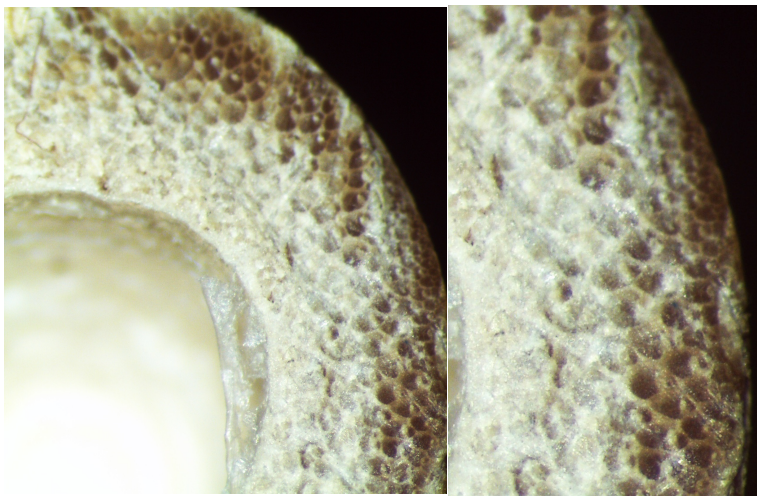


[276] Kleim.
[277] Christou "Giant Reed: From Production to End Use," 109.

Bamboo

The bamboo tube (Figure 40)[278] has much more pronounced vessels than *Arundo donax*. The structure of the vascular bundles is more visible too. Rehashing Perdue Jr.'s article on *Arundo donax* from earlier in this document, he says, "Although the vascular bundles are distributed freely throughout the cross-sectional area of fundamental parenchyma, those toward the periphery of the shoots are smaller and more numerous than are those toward the interior."[279] The vascular bundles in the bamboo seem to be distributed similarly with the bundles increasing in number and decreasing in size.

Figure 40: Bamboo Tube



Comparing Figure 40[280] to the good reed in Figure 37[281], it seems like the outer areas of the bamboo have a higher concentration of bundles than *Arundo donax*. However, the area captured in the bamboo image is about 3mm from the bark to the decayed pith and the area captured in the oboe reed image is a little less than .58mm. Without a comparable image and the *Arundo donax* tube being sanded, it is hard to say that the bamboo has a higher concentration of bundles toward the periphery of the tube

[278] Kleim.
[279] Perdue Jr., "Source of Musical Reeds and Industrial Cellulose," 371-372.
[280] Kleim
[281] Ibid.

than *Arundo donax* by only looking at these images. If the bamboo has a higher concentration of bundles toward the periphery than *Arundo donax*, that would account for the smooth knife scraping and the need to remove a lot of cane off for it to vibrate since the periphery is so dense.

Taking into account how the bamboo behaved in the early stages of the reed making process, the resistance from splitting, pre-gouging, and gouging is almost certainly from the large 3mm tube. The interior of the cane in the scope image looks quite weak with large vessels, almost like the area immediately surrounding the hollow part of the tube is a transitionary area between the decayed pith and the woody exterior. Therefore, that area of the tube might still be in the process of decaying which would make it soft and weak. So, it is not necessarily the density of the cane that made it more resistant to work with than *Arundo donax*, but rather the larger amount of surface area to get through in the early reed making stages.

Another observation is how suddenly the vessels shrink from the center to the periphery. With the limited area examined in the images of my oboe reeds, it seems like the vessels in *Arundo donax* might not shrink as significantly as they do in the bamboo. This likely accounts for why the bamboo reeds were so prone to cracking. Once the dense and heavily concentrated area of small vessels was scraped away, we were left with significantly larger vessels with empty space in the vessels and little to no tissue surrounding the vessels than around the same area in *Arundo donax* reeds, causing cracks to occur.

The high failure rate of the bamboo reeds should not be the only indicator that bamboo may not be a suitable material for musical instrument reeds. If the issues we

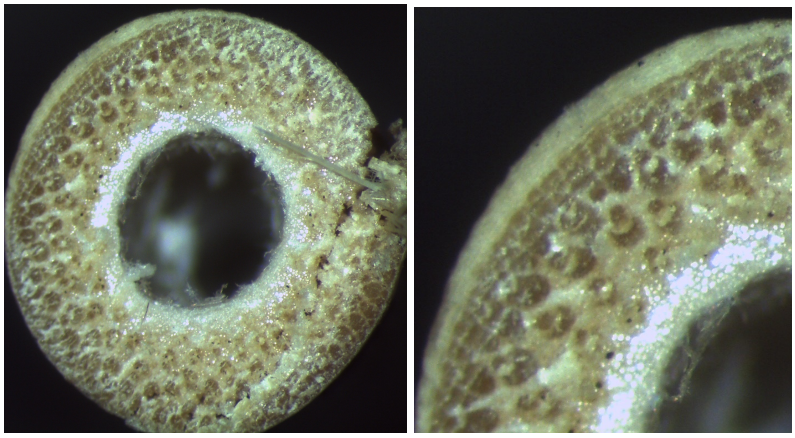
encountered with bamboo reeds were due to the observations from the scope imagery, there are likely remedial steps we could take to get results closer to *Arundo donax*. With increasingly innovative growing practices and hundreds of bamboo species, there is a very strong possibility that there may be a better bamboo candidate for reeds than *Bambusa textilis*. Another consideration is within the innovative growing practices. Since at least the baroque era, we have conclusively known that *Arundo donax* has been used for musical instrument reeds. Evolving woodwind instruments since the baroque era might have inadvertently evolved the cultivation of *Arundo donax* to continually fit instrumentalists needs. It also was not until the last century that Marcel Tabuteau developed the American scrape oboe reed and thereafter the inventions of our increasingly precise reed making machines.

Arundinaria gigantea

Since I could not obtain suitable *Arundinaria gigantea* tubes for making oboe reeds, hypotheses drawn from Figure 41[282]are only based on the images and the research earlier in this document.

The observations made on *Arundinaria gigantea* are nearly identical to the observations on bamboo. Similar to bamboo, the vessels in *Arundinaria gigantea* behave like *Arundo donax*, with the exception that the density of vessels in *Arundinaria gigantea* consistently increases and vessel size consistently decreases toward the bark of the tube. The only predicted difference in how an *Arundinaria gigantea* reed would behave versus a bamboo reed is that I do not think cracking would be as large of a problem. Like *Arundo donax*, the amount of parenchyma (permanent and woody) tissues between the vessels is larger than bamboo which will provide more support for our incredibly thin reeds and result in less cracking. In this image, and with this tube specifically, there must have been a wound that originated outside of the plant and the plant proceeded to heal itself causing occlusions in the lower right part of the

Figure 41: *Arundinaria gigantea* Tube



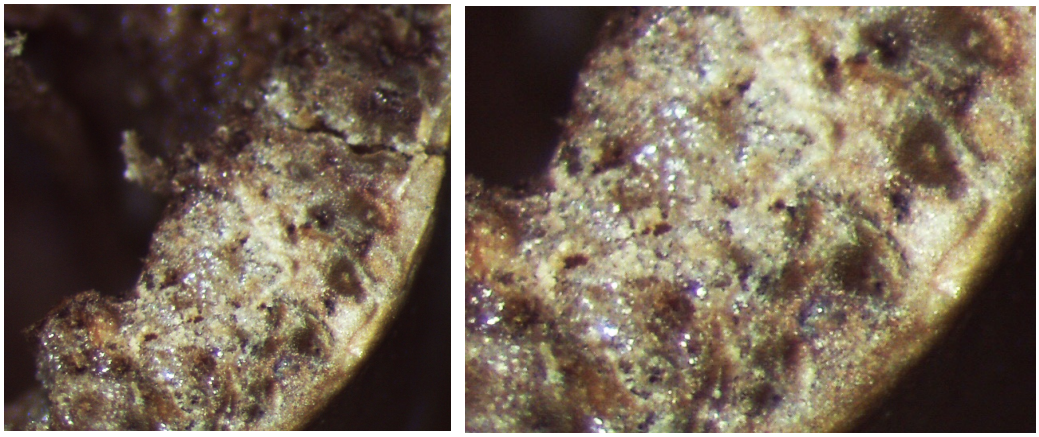
[282] Kleim.

image on the left. The rest of the tube looks quite healthy and unaffected which is why the occlusions are likely not from an infection.

Giant Miscanthus

The sample of the Giant Miscanthus shown in Figure 42[283] was the bottom part of an old shoot. The growers might have put one of the nodes of the plant in soil to grow a "new" plant, but left the part in the imagery. This specific shoot is perhaps in the process of decaying from the energy of the plant going toward new growth instead of maintaining old growth. Despite this, the vessels are still somewhat visible and are similar in appearance to *Arundo donax*, bamboo, and *Arundinaria gigantea*.

Figure 42: Giant Miscanthus Old Shoot Near Node and Roots

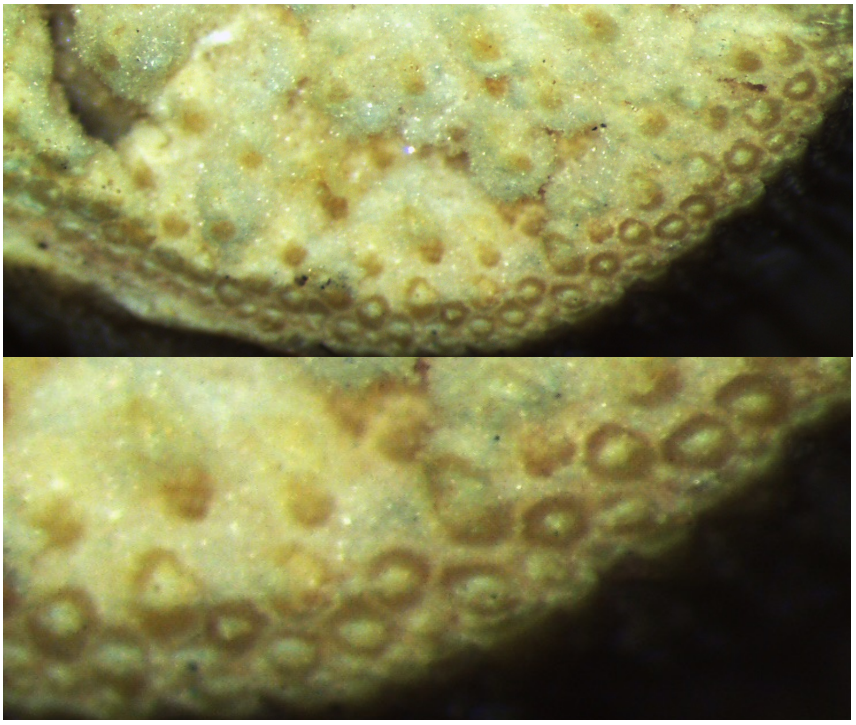


[283] Kleim.

Corn

Out of all of the materials put under the scope, I did not expect to see much from the corn stalk. Some varieties of corn are perennial but commercial farmers grow it annually, meaning the lifecycle of perennial corn varieties extends to more than one year. The vessels on the outer edge of the corn are not nearly as numerous or developed as the other plants, however that could be due to the plant's age rather than suitability for reeds. *Arundo donax* is grown for 2-3 years before it is harvested for reeds, the corn stalk in Figure 43[284] is likely less than a year old. It would be interesting to see a mature, perennial corn stalk to more accurately compare. Additionally, if the plant was grown for 3 years, it might end up being more woody when harvested and dried, like *Arundo donax*.

Figure 43: Dried Corn Stalk

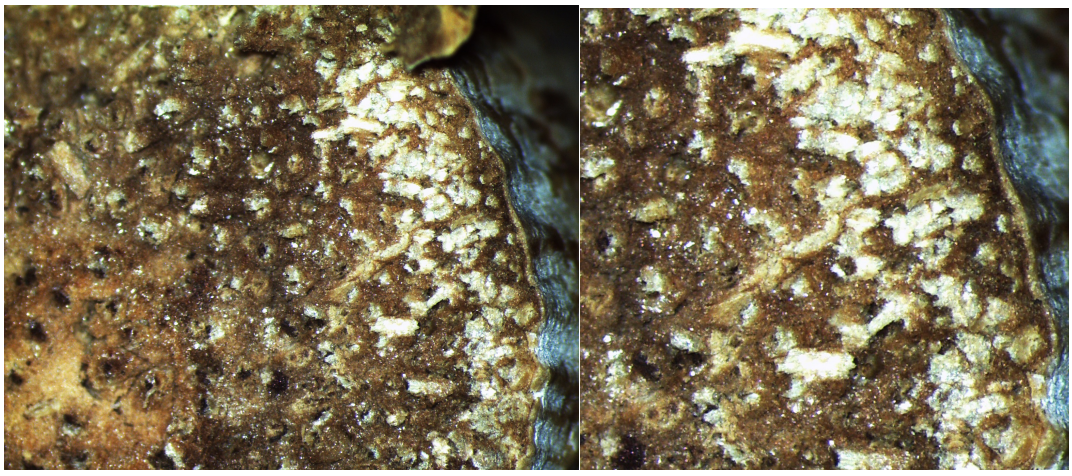


[284] Kleim.

Sugarcane

Similar to the giant miscanthus, this part of a sugarcane stalk (Figure 44)[285] looks old and decayed. This sample is also from an area close to a node resulting in the center of the stalk being solid. However, there are vessels still present and they do increase in concentration toward the periphery. Another observation is that it seems like the vessels are not entirely empty, but this could be due to occlusion and an infection of the plant. The sugarcane stalk I have is from the Bamboo Ranch in Tuscon, AZ and the owner gave it to me free of charge since it was from a dying plant. Despite this, sugarcane should not be ruled out in this preliminary investigation.

Figure 44: Old Sugarcane Shoot



[285] Kleim.

Sound Analysis

Methods

In this simple exploratory investigation, where Martin Schuring and I made one reed from each material—*Arundo donax*, *Phragmites*, and bamboo. The recordings in our sound analysis consist of six samples of a low, middle, and high D, three samples of a peep, three samples of a crow, two samples of a two-octave ascending C major scale, and one sample of Barber's Violin Concerto oboe excerpt. For each material and each person, we made 28 recordings. For each person and all materials, there are 84 recordings. Collectively, there are 168 recordings. The C major scale and Barber recordings are used to generate spectrograms and the single-note recordings of a low, middle, and high D are used to extract descriptors from the Timbre Toolbox in MATLAB.

Spectrograms

We used Sonic Visualiser for spectrograms on the C scales and Barber excerpt.[286] The spectrograms are in Figures 45, 46, 47, 48, 49, and 50. Each is labeled with our last names, the reed material, and type of excerpt. The fundamental frequencies at the bottom of the spectrogram correspond to the pitches we hear. The overtones or partials begin immediately above the fundamental frequencies, so the first partials are the lines right above the actual note.

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[286] Cannam, Chris, Christian Landone, and Mark Sandler. *Sonic Visualiser: An Open Source Application for Viewing, Analysing, and Annotating Music Audio Files*, in Proceedings of the ACM Multimedia 2010 International Conference.

Maes C Scale

The spectrograms from my reeds for the C major ascending scale (Figures 45, 46, 47) appear to reflect the data collected from MATLAB, which supports statistically significant differences between the reeds made from bamboo and *Phragmites*, and *Arundo donax* and *Phragmites*. The C major ascending scale and Barber's Violin Concerto oboe excerpt (see Appendix D for Barber spectrograms) in the spectrograms are single samples and not averages, so we cannot assume we would have similar results if we took an average of two or more samples. We also cannot generalize the spectrogram results to the whole population of these materials since we only made one reed per material. Furthermore, we cannot generalize that all oboists would produce similar results since there are many other parameters and confounding variables involved in reed making and playing the oboe.

In the *Arundo donax* and *Phragmites* spectrograms, similarities include more intensity in E5 and F5 in the first partial than similar partials around them and A4 and B4 are more intense the 2nd partial than similar partials around them. Another similarity is a vertical line between C5 and D5, which correlates to the break on the oboe where more keys are pressed on D5 than C5 causing the sound to travel further down the bore before escaping through vents and open key holes. Additionally, the C scale recordings involve transience from the keys closing the holes. On the other hand, the *Arundo donax* spectrogram indicated the upper partials are evenly spread and not as present as in the *Phragmites* spectrogram. The shape of the partials in *Arundo donax* indicate more energy between the partials and the shape of the partials in *Phragmites* are well defined, which indicates energy being confined to the partials. Additionally, E4 and F4 are more intense

in the 3rd partial than *Phragmites*. In *Phragmites*, the upper partials between 2700 Hz and 7300 Hz are more present overall, however the upper partials taper off in the second octave. The *Phragmites* base frequencies are more consistently shaped and colored than the *Arundo donax* base frequencies.

In the *Arundo donax* and bamboo spectrograms, the results are nearly identical. The partials with strong energy include E4 and F4 in the 3rd partial, A4 and B4 in the 2nd partial, and E5 and F5 in the 1st partial. Again, the break between C5 and D5 is exhibited in both spectrograms via a vertical line. Additionally, the 1st partial of A5 has an almost identical shape and color between *Arundo donax* and bamboo. The differences are quite minimal and include the *Arundo donax* partials overall having inconsistent shape, and the bamboo partials overall were slightly more defined than *Arundo donax*, indicating more energy between the partials for *Arundo donax* and more energy within the partials for bamboo. The bamboo also had more intensity in the base frequencies.

The bamboo and *Phragmites* differences include more emphasis in the *Phragmites* partials between 2700 Hz and 7300 Hz and the tail ends of the partials hang over into the following note more than bamboo. The lower partials and base frequency in bamboo have more emphasis than *Phragmites*. The only similarity is that the partials all have a clear and defined shape, which is something *Arundo donax* was lacking.

Figure 45: Kelsey Maes, Two Octave C Major Ascending Scale, *Arundo donax*

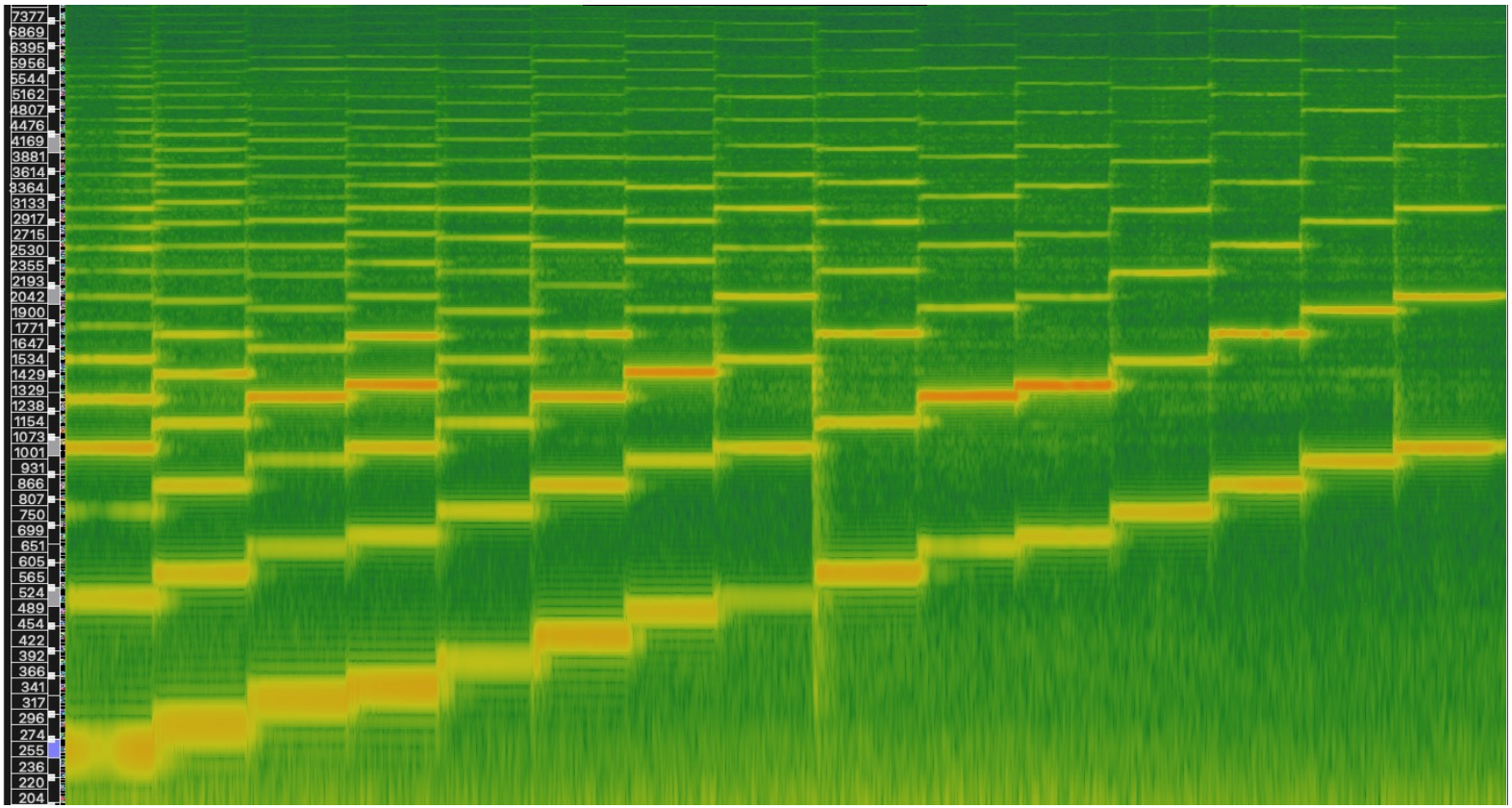


Figure 46: Kelsey Maes, Two Octave C Major Ascending Scale, *Phragmites*

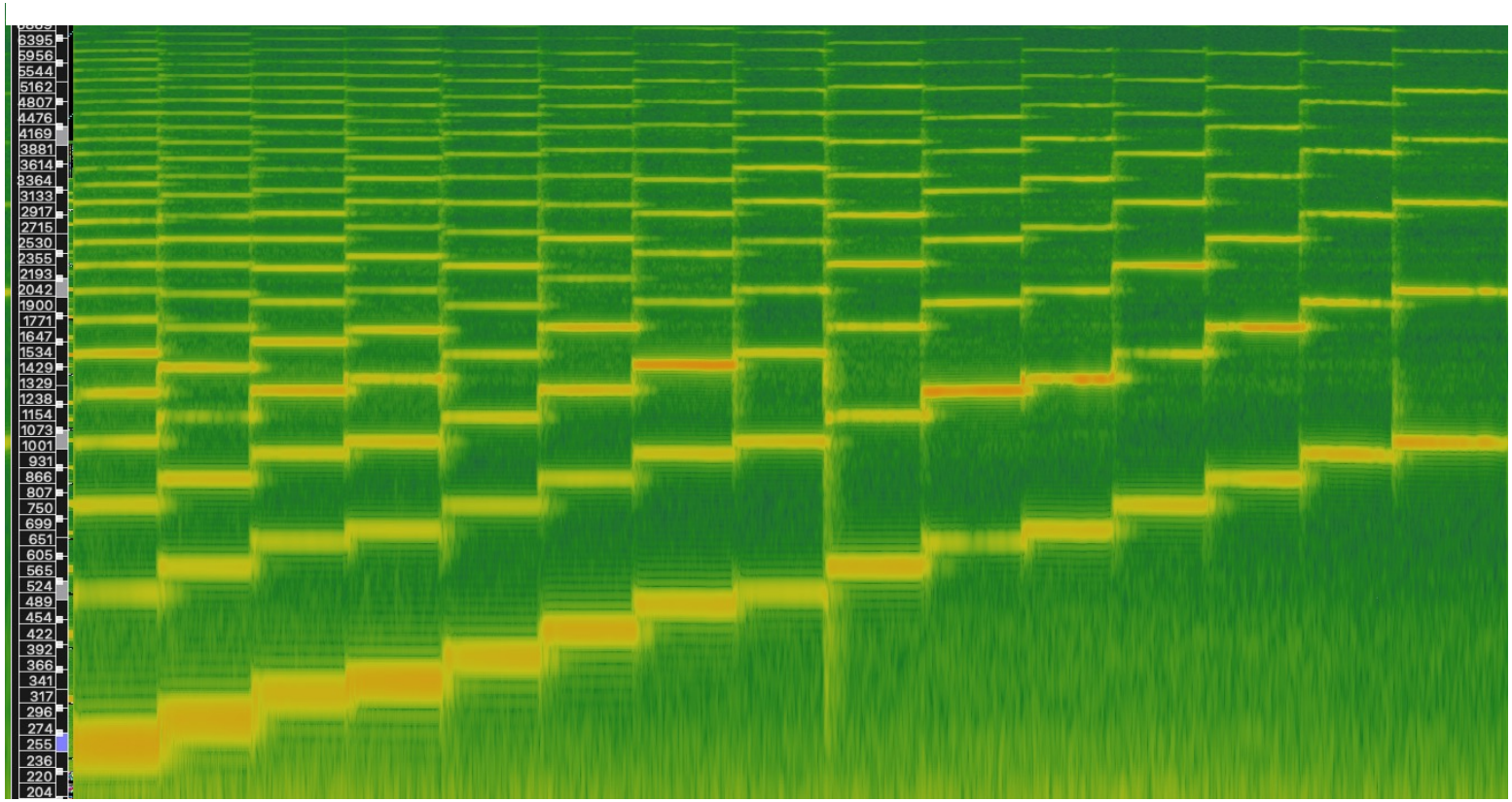
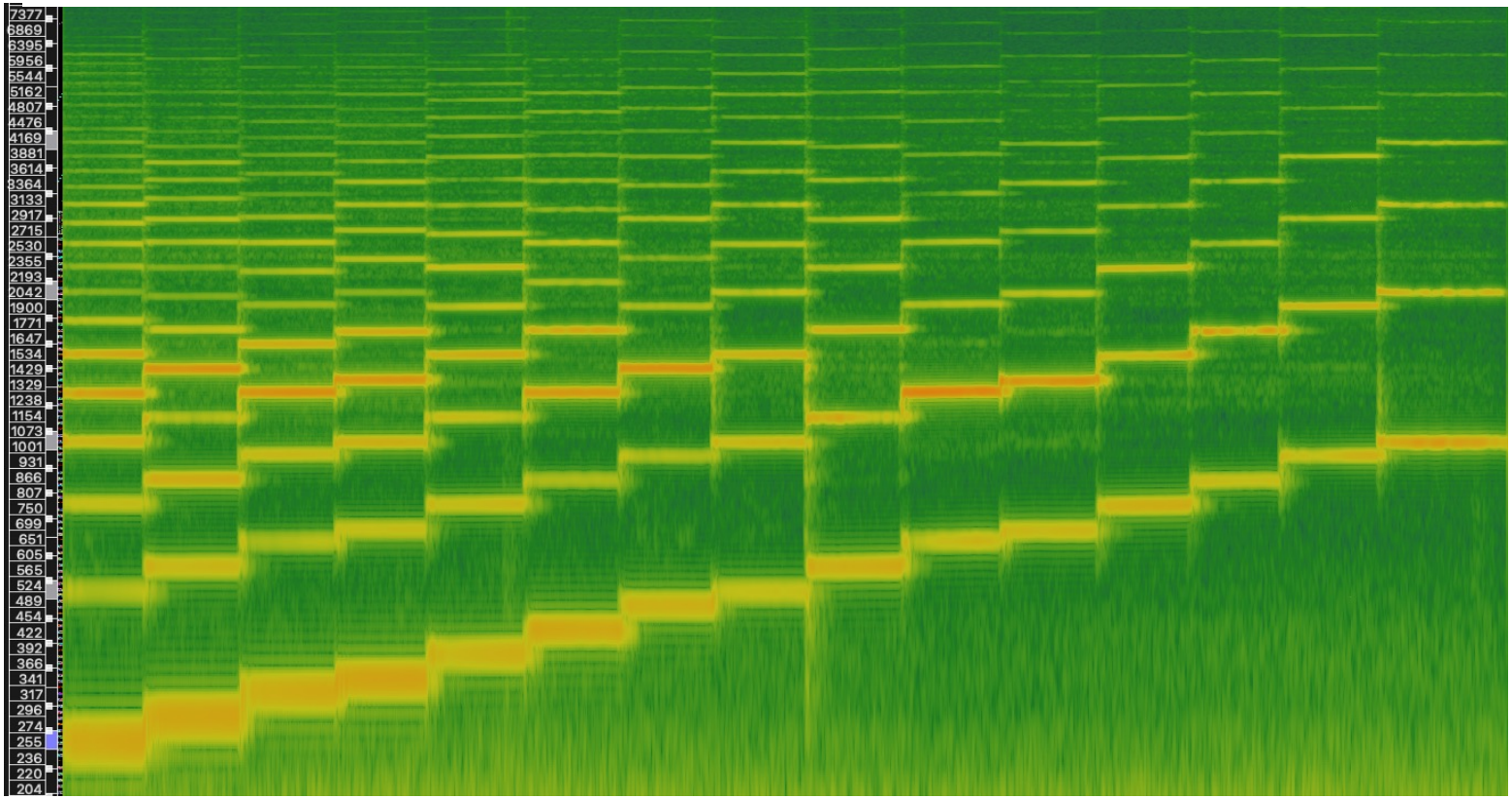


Figure 47: Kelsey Maes, Two Octave C Major Ascending Scale, Bamboo



Schuring C Scale

Martin's spectrograms of the two octave C major ascending scale (Figures 48, 49, 50) also provide support for the MATLAB results, but to a greater extent.

The *Arundo donax* and *Phragmites* spectrograms both showed stronger 1st partials in E5, F5, G5, and A5 and both also had the C5 to D5 break via a vertical line. *Arundo donax* had a thick 7th partial between C4 and D4 and the tail ends of partials were short or nonexistent. The 1st partial and above overall in *Arundo donax* tapered in thickness in the second octave, but the base frequency and 1st partial remained very intense throughout. The 7th partial between C4 and D4 is a bit thicker than the surrounding partials. *Phragmites* had a much stronger presence of upper partials between 1500 Hz and 7000 Hz with less energy between the partials. A stretch of partials with moderate intensity is in *Phragmites* from 2500 Hz to 4000 Hz, but immediately below this area in the 1700 Hz to 2500 Hz range, the partials are not as intense. 1700 Hz and below the base frequencies and partials are appropriately balanced. The tail ends of the *Phragmites* partials also tend to taper into the following notes more than *Arundo donax*.

In comparing the bamboo and *Phragmites*, bamboo does not have the same stretch of thick partials between 2500 Hz to 4000 Hz. The base frequency and 1st through 3rd partials for bamboo on F4 are more intense than the surrounding partials. The only similarities between bamboo and *Phragmites* are that E5, F5, and G5 show more energy on the 1st partials and the C5 to D5 break shows a vertical line.

General Conclusions

There were small, but noticeable differences according to the spectrograms. These differences were more apparent in Martin's reeds than my reeds. Surprisingly, my *Arundo donax* and bamboo reeds were nearly identical on the spectrograms. Additionally, the differences were much more noticeable between Martin's *Arundo donax* and *Phragmites* spectrograms, while the *Arundo donax* and bamboo spectrograms only have subtle differences. Both spectrograms indicated less energy inside of the base frequencies around D5-E5 with the D5 having less energy in *Arundo donax* and E5 being having less energy in bamboo. The base frequencies of *Arundo donax* are also not nearly as uniform in intensity as the bamboo base frequencies. The similarities include F4, E5, F5, and G5 having higher intensity in the 2nd partials and F4 having additional energy in the 2nd and 3rd partials. Both spectrograms also show that the tail ends of the partials tend to not taper into the next note. We recorded all of the samples in the same room within a time frame of about two hours. The room did have some noise from the air conditioning system, however room noise usually presents itself as higher energy between the partials over a large area in the overtones and does not impact the partials or partial length. The longer partials may be due to the reed's transience between notes. Regardless, we do not know with certainty what may have caused the lengthened partials.

These are preliminary and not necessarily generalizable since we only had one reed per material and six takes per octave. Multiple reeds made from each material and many more takes would lead to more definitive and generalizable conclusions.

Figure 48: Martin Schuring, Two Octave C Major Ascending Scale, *Arundo donax*

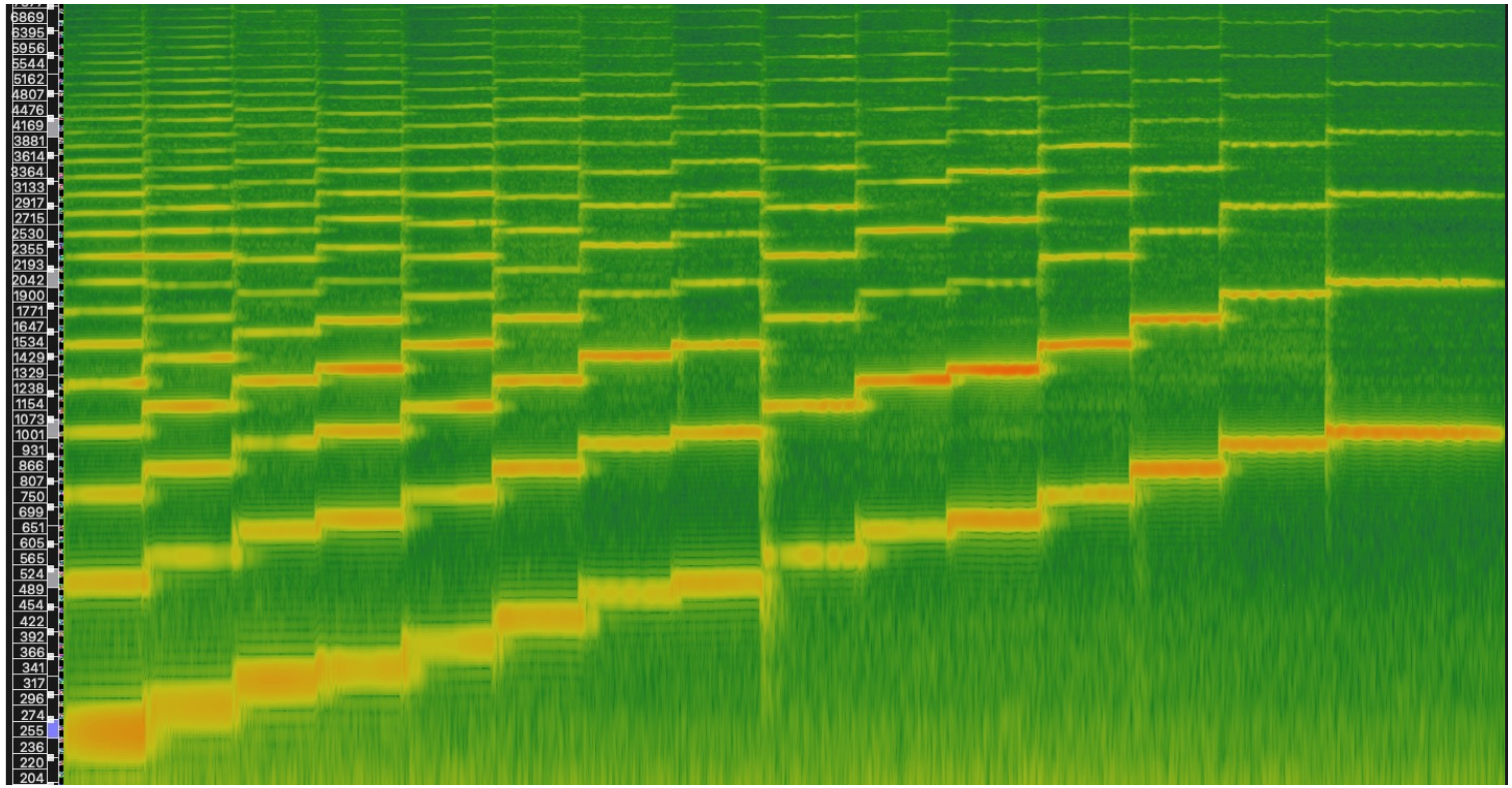


Figure 49: Martin Schuring, Two Octave C Major Ascending Scale, *Phragmites*

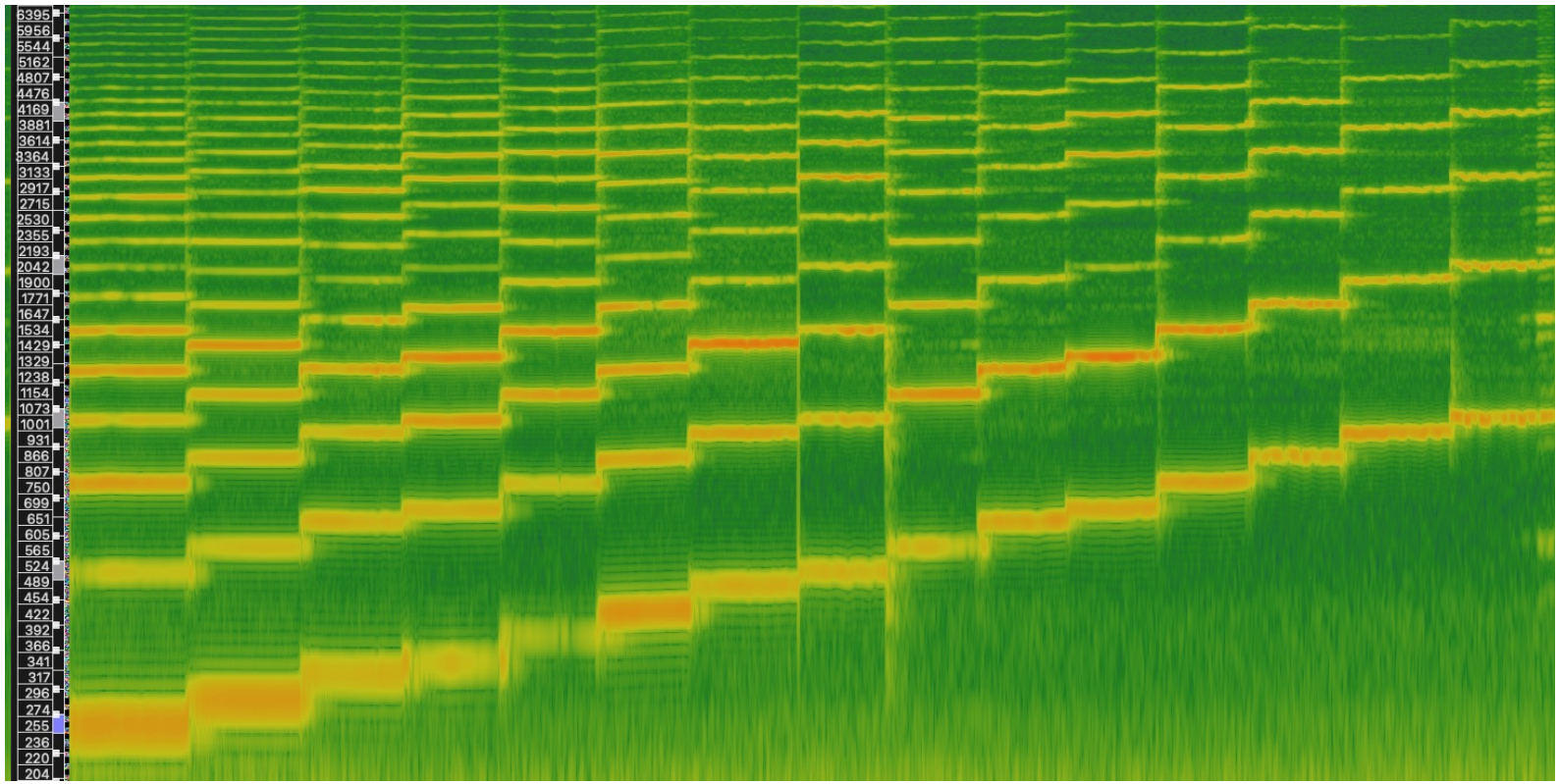
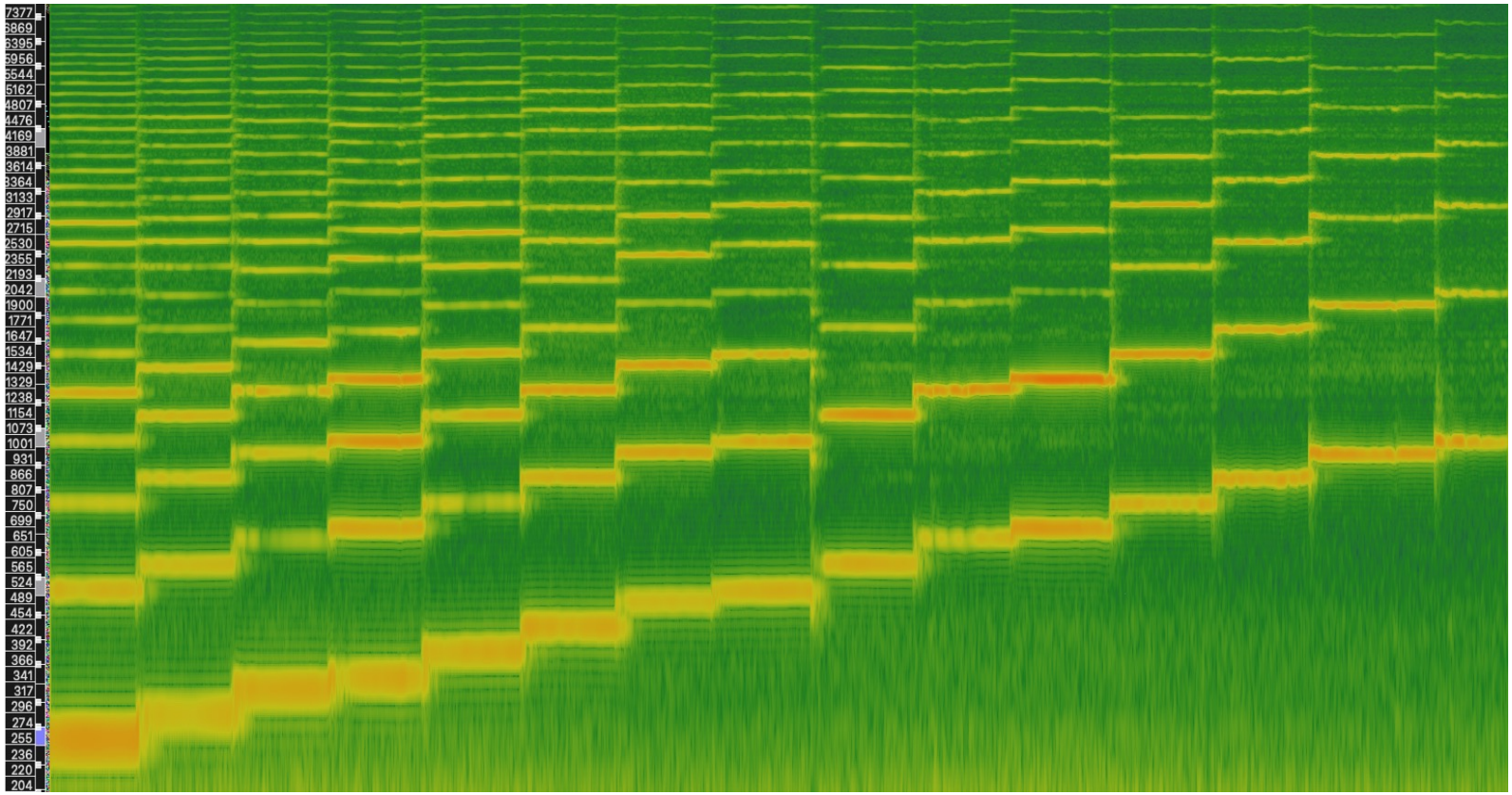


Figure 50: Martin Schuring, Two Octave C Major Ascending Scale, *Phragmites*



MATLAB Data

We extracted audio descriptors using Timbre Toolbox in MATLAB[287] for the low, middle, and high D single-note recordings. The recordings consist of six samples per octave and per person with a total of 36 samples averaged in MATLAB. The main source these descriptors' definitions come from is The Timbre Toolbox User's Manual.[288] The secondary source, Dr. Reymore's article entitled "Modeling Noise-Related Timbre Semantic Categories of Orchestral Instrument Sounds With Audio Features, Pitch

Figure 51: Audio Features Definitions from Timbre Toolbox

Audio features from Timbre Toolbox

Representation	Feature	Description
STFT	Spectral centroid	Center of gravity of the spectrum
STFT	Spectral spread	Standard deviation of the spectrum around the mean
STFT	Spectral skewness	Asymmetry of the spectrum around the mean
STFT	Spectral kurtosis	Flatness of the spectrum around the mean
STFT	Spectral flatness	Ratio of the geometric and arithmetic means of the spectrum
STFT	Spectral crest	Ratio of the spectral maximum to the arithmetic spectral mean
STFT	Spectral slope	Linear regression over the spectral amplitude values
STFT	Spectral decrease	Average of slopes between F0 and 2nd to *k*th harmonic
STFT	Spectral roll-off	Frequency below which 95% of the signal energy is contained
STFT	Spectral variation	A measure of variability of the spectrum over time: correlation between spectra in successive time frames
STFT	Spectral flux	A measure of variability of the spectrum over time: Euclidean distance between spectra in successive time frames
HARM	F0	Fundamental frequency of a periodic sound
HARM	Harmonic spectral deviation	Deviation of the amplitudes of the partials from a smoothed spectral envelope
HARM	Tristimulus 1	Ratio of energy of the 1st harmonic to total energy
HARM	Tristimulus 2	Ratio of energy of the 2nd, 3rd, and 4th harmonics to total energy
HARM	Tristimulus 3	Ratio of energy of remaining harmonics (above 4th) to total energy
HARM	Harmonic odd-to-even ratio	Ratio of energy of odd harmonics to even harmonics
HARM	Inharmonicity	Degree to which frequencies of overtones depart from multiples of the fundamental frequency
HARM	Harmonic energy	Energy of the signal explained by stable partials
HARM	Noise energy	Energy of the signal not explained by stable partials
HARM	Noisiness	Ratio of noise energy to total energy
HARM	Harmonic-to-noise ratio	Ratio between periodic and non-periodic components of a signal
TEE	Attack time	Duration of the attack portion of the sound
TEE	Log attack time	Logarithm of the duration of the attack portion of the sound
TEE	Attack slope	Rate of change of energy over time in the attack portion
TEE	Decrease slope	Measure of the rate of decrease of the signal energy
TEE	Temporal centroid	Center of gravity of the energy envelope
TEE	Effective duration	Time during which energy envelope is above 40% (intended to reflect perceived duration)
TEE	Frequency of energy modulation	Frequency of the modulation of energy over the sustained portion of the sound as represented using a sinusoidal component
TEE	Amplitude of energy modulation	Amplitude of the modulation of energy over the sustained portion of the sound as represented using a sinusoidal component

STFT, short-time Fourier transform; HARM, harmonic; TEE, temporal energy envelope. For further detail on how features are computed, see Kazazis et al. (2021).

STATISTICALLY SIGNIFICANT

NOT STATISTICALLY SIGNIFICANT

[287] Kazazis et al., "The Timbre Toolbox User's Manual."
[288] Ibid.

Register, and Instrument Family," compiled these terms into concise definitions in Table 3 of the article, pictured in Figured 51.[289] The descriptors relevant to our analysis are highlighted, green corresponds to not statistically significant results and red corresponds to statistically significant results. It is important to note that these descriptors are physical measurements of sound and the physical measurements do not always indicate perceptual characteristics in sound. The descriptions in Timbre Toolbox are the work of audio engineers and any perceptual characteristics assigned to the descriptions are not validated behaviorally and we do not have enough music research to support correlations made.

My hypothesis is that *Arundo donax* compared individually with *Phragmites* and bamboo will be slightly different. The minor variance predicted will be negligible when making reeds from alternative materials and might present in the same ways that *Arundo donax* produces a variety of outcomes for reeds. We test the null hypothesis that there are no differences in audio descriptors among the sample reeds made from *Arundo donax*, *Phragmites*, and bamboo. This preliminary analysis can suggest particular audio features of interest to investigate in future studies; however, without testing a larger set of reeds made from each material, the results are not generalizable.

To eliminate the possibility of outliers skewing the data, we compared median values using the Kruskal-Wallis ANOVA, which does not does not make assumptions about data's parameters, determines if groups tested have the same median, and is used with three or more independent groups that have a sample size greater than five.[290] We

[289] Reymore et al., "Modeling Noise-Related Timbre Semantic Categories of Orchestral Instrument Sounds with Audio Features, Pitch Register, and Instrument Family," 9.
[290] Lomuscio, "Getting Started with the Kruskal-Wallis Test."

considered 21 descriptors calculated using the STFT and HARM representations (see Figure 51)[291]. The STFT, short-time Fourier transform, is a "spectrotemporal representation obtained using a sliding-window analysis over the audio signal."[292] HARM, sinusoidal harmonic model, is a harmonic representation that uses frame analysis to estimate the slowly varying amplitudes and frequencies of harmonic components of an estimated fundamental frequency.[293] Overall, median values were computed on each of 21 potential descriptors of interest for the single-note recordings for a total of 108 notes analyzed. Our single-note recordings only contained 6 takes of a low D, middle D, and high D for each reed, so we tested to see if any differences were due to chance or if the material may have caused differences. We cannot generalize outside of the reeds we used, since there was only one reed per material tested. A priori, we set an alpha level at 0.1, due to the preliminary nature of the study. The single-note recordings contained 6 takes of a low D, middle D, and high D for each reed, so we tested the null hypothesis that all three materials would have equal median values for each descriptor analyzed. The Kruskal-Wallis ANOVA identified ten descriptors in the comparison of median values that showed statistically significant differences among the three materials, values listed in Figure 52. The descriptors that were not statistically significant and their data is in Figure 54. Since the initial Kruskal-Wallis ANOVA tested for any differences among the three plants and did not indicate where the differences were, we ran separate tests that pair the materials and the data is in Figure 53. The definitions provided in Figures 52-54 come

[291] Reymore et al., 9
[292]Peeters et al., "The Timbre Toolbox: Extracting audio descriptors from musical signals," 2904.
[293] Reymore et al., 5-6.

Figure 52: Statistically Significant Descriptors[294]						
Descriptor	**Definition**	***Arundo***	**Bamboo**	***Phragmites***	**p-value**	**H**
Harmonic Energy	Energy of the signal explained by stable partials	0.049	0.064	0.048	0.004*	11.23
Noise Energy	Energy of the signal not explained by stable partials	0.035	0.046	0.035	0.004*	10.98
Spectral Centroid	Center of gravity of spectrum	1210.748	1210.191	1202.604	0.06*	5.61
Spectral Spread	Standard deviation around the spectral centroid (higher = "richer")	684.606	690.256	885.016	<<0.001*	21.54
Spectral Skewness	Asymmetry around the mean	1.875	1.9	1.481	0.03*	6.91
Spectral Kurtosis	Flatness around the mean	8.344	9.8	6.193	0.005*	10.69
Spectral Crest	Ratio of max to mean ("tonalness")	0.344	0.356	0.296	0.04*	6.29
Spectral Slope	Regression over amplitude values (bigger magnitude = warmer, smaller = noisier?)	-2.45E-08	-3.14E-08	-2.39E-08	0.002*	12.69
Spectral Rolloff	Frequency below which 95% of the energy is contained	2390.186	2444.019	2960.815	0.03*	7.1
Spectral Variation	Correlation between spectra in successive time frames	1.26E-04	1.58E-04	3.23E-04	<<0.001*	17.08

[294] Reymore et al., 9; Kazazis et al.

Figure 53: Descriptor Testing Between Pairs for Statistical Significance[295]				
Descriptor	**Definition**	***Arundo*/Bamboo**	***Arundo*/*Phragmites***	***Phragmites*/Bamboo**
Harmonic Energy	Energy of the signal explained by stable partials	0.008*	0.84	0.008*
Noise Energy	Energy of the signal not explained by stable partials	0.009*	0.71	0.01*
Spectral Centroid	Center of gravity of spectrum	0.99	0.08*	0.08*
Spectral Spread	Standard deviation around the spectral centroid (higher = "richer")	0.63	<<0.001*	<<0.001*
Spectral Skewness	Asymmetry around the mean	0.23	0.23	0.025*
Spectral Kurtosis	Flatness around the mean	0.11	0.11	0.007*
Spectral Crest	Ratio of max to mean ("tonalness")	0.85	0.85	0.06*
Spectral Slope	Regression over amplitude values (bigger magnitude = warmer, smaller = noisier?)	0.003*	0.003*	0.003*
Spectral Rolloff	Frequency below which 95% of the energy is contained	0.28	0.28	0.099*
Spectral Variation	Correlation between spectra in successive time frames	0.66	0.66	0.0007*

[295] Reymore et al., 9; Kazazis et al.

from Dr. Reymore's article in the *Frontiers in Psychology* journal and the Timbre Toolbox user's manual.[296] The statistically significant p-values in Figures 52 and 53 are starred with an asterisk.

The statistically significant differences between *Arundo donax* and bamboo, *Arundo donax* and *Phragmites*, and *Phragmites* and bamboo are listed in Figure 53. Harmonic energy and noise energy between *Arundo donax* and bamboo, and *Phragmites* and bamboo exhibit statistically significant results. All three materials show statistically significant differences in their spectral slope. *Phragmites* and bamboo are the most statistically significant in their spectral skewness, spectral kurtosis, spectral crest, spectral rolloff, and spectral variation. *Arundo donax* and *Phragmites*, and *Phragmites* and bamboo's spectral centroid were statistically significant.

Arundo donax and bamboo overall seemed to be the most similar. Compared to *Arundo donax*, bamboo seems to have more harmonic energy and a steeper spectral slope. According to Figure 51, harmonic energy may be related to the presence of the partials[297], so the bamboo reed's upper partials are likely stronger than the *Arundo donax* reed's partials, leading to a louder sound overall. Spectral slope is an estimation of the spectral shape over time, with most instruments resulting in negative slopes due to upper harmonic energy decreasing by a harmonic number. [298] Spectral slope tends to be correlated with spectral centroid, which is the "spectral center of gravity," or the frequency weighted average of the (power) spectrum. [299] Perceptually, spectral centroid

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[296] Reymore et al.; Kazazis et al.
[297] Ibid.
[298] Kazazis et al., 23.
[299] Ibid, 22.

has been described as relating to the brightness of the sound, with higher values associated with brighter sounds. [300] Essentially, a steeper spectral slope relates to a warmer sound than a flatter spectral slope. A flat spectral slope means the energy across frequencies is the same and might indicate the level of noisiness. Since bamboo has a steeper spectral slope than *Arundo donax*, it is likely that the bamboo reed has a warmer sound than the *Arundo donax* reed due to weaker overtones. Surprisingly, *Arundo donax* and *Phragmites* were about as different as *Arundo donax* and bamboo. *Phragmites* has a greater spectral spread and variation than *Arundo donax.* Spectral spread measures the amount of variation around the spectral centroid. [301] Spectral variation is another measure of variance over time. [302] The *Phragmites* reed having a higher spectral spread and variation than the *Arundo donax* reed could indicate some instability in the *Phragmites* reed overall with the distribution of frequencies and overtones.

Bamboo and *Phragmites* exhibit the most perceptible differences out of all three pairs; *Phragmites* has a higher spectral spread and spectral variation, but lower harmonic energy, noise energy, spectral centroid, and a slope closer to zero. These measurements might suggest that the bamboo reed is more noisy within and between partials, and the *Phragmites* reed has a wider variation of frequencies and partials.

Regarding the descriptors overall, *Arundo donax* and bamboo are the most similar. On the other hand, bamboo and *Phragmites* exhibited the most differences. Individually, the spectral centroid of Martin's *Arundo donax* reed was the

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[300] Kazazis et al., 23.
[301] Ibid, 23.
[302] Ibid, 27.

lowest of his three reeds and the spectral centroid of my bamboo reed was the lowest of my three reeds.

For the nonsignificant descriptors, we do not know why there were no significant differences between the materials. The samples of each material might have been really similar, but we cannot generalize similarity for the whole population of each material. There could be other confounding factors we are not aware of, so more research is necessary to find out.

Figure 54: Non-Statistically Significant Descriptors[303]						
Descriptor	**Definition**	***Arundo***	**Bamboo**	***Phragmites***	**p-value**	**H**
Tristimulus 1	Ratio of energy of the 1st harmonic to total energy	0.312	0.316	0.303	0.49	1.41
Tristimulus 2	Ratio of energy of the 2nd, 3rd, and 4th harmonics to total energy	0.414	0.376	0.492	0.19	3.3
Tristimulus 3	Ratio of energy of remaining harmonics (above 4th) to total energy	0.187	0.147	0.182	0.53	1.27
Harmonic Odd-to-Even Ratio	Ratio of energy of odd harmonics to even harmonics	2.042	2.434	1.772	0.19	3.34
Inharmonicity	Degree to which frequencies of overtones depart from multiples of the fundamental frequency	0.055	0.0558	0.0569	0.42	1.73
Noisiness	Ratio of noise energy to total energy	0.416	0.416	0.417	0.18	3.44
Harmonic to Noise Energy	Ratio between periodic and non-periodic components of a signal	1.4	1.401	1.394	0.17	3.52
Spectral flatness	Ratio of the geometric and arithmetic means of the spectrum	1.11E-05	8.75E-06	1.02E-05	0.74	0.6
Spectral decrease	Average of slopes between F0 and 2nd to *k*th harmonic	0.0225	0.0234	0.0223	0.45	1.58
Spectral flux	A measure of variability of the spectrum over time: Euclidean distance between spectra in successive time frames	1.29E-06	1.00E-06	1.32E-06	0.33	2.23

[303] Reymore et al., 9; Kazazis et al.

Semantic Analysis

In a two-part study conducted by Lindsey Reymore and David Huron, participants described and rated sounds in order to construct a model of musical instrument timbres.[304] The first part of the study was a compilation of participants' descriptions of 20 contrasting instruments' sounds. The participants were only given the instrument's name in order for them to imagine the sound and then offer a brief description. The component ideas were then placed into 77 descriptive categories.[305]

In the second part of her study, Dr. Reymore created a model of timbre *qualia* to use in musical analysis, also known as Timbre Trait Profiles. [306] *Qualia*, what it is like to experience something, is a philosophical idea that music research uses to describe characteristics of sound.[307] Using the component ideas and descriptive categories from the first study, participants were asked to rate instruments based on their imaginary sounds to create an accurate model as a framework for timbral analysis. The final model settled on included 20 *qualia* dimensions "as a compromise between semantic richness and practicality."[308] For the purposes of this sound analysis, only a handful of the component ideas and descriptive categories will be addressed and defined. For reference, the table of these categories and terms come directly from the Reymore and Huron Model.[309]

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[304] Reymore and Huron. "Using auditory imagery tasks to map the cognitive linguistic dimensions of musical instrument timbre qualia," 124.
[305] Ibid, 130.
[306] Ibid, 124-125.
[307] Ibid, 124.
[308] Ibid, 142.
[309] Ibid, 136-139.

Based on the Reymore Huron Model, we can infer what terms matched each reed the best. The MATLAB data and spectrograms indicate that both of our *Arundo donax* reeds are clean, compact, and resonant. Both of our *Phragmites* reeds exhibited statistically significant differences with our *Arundo donax* and bamboo reeds. The MATLAB data indicated that the *Phragmites* reeds were bright, harsh, and somewhat pinched and constrained.

CONCLUSIONS

Taking into account all of the research and data gathered in this preliminary investigation on alternative natural materials for oboe reeds, there are plenty of potentially suitable candidates. With the extensive data collected on *Phragmites* and bamboo from the initial research stages, to the IRB Study, and to timbral analysis and scope imagery, it is a safe prediction that those materials could be great alternatives in the future. With the limited data collected on *Arundinaria gigantea*, *Phalaris arundinacea*, giant miscanthus, *Panicum virgatum*, sugarcane, and corn, at best is providing an educated guess that these plants might have potential to be made into playable oboe reeds.

Working backward with the plants we have minimal information on are *Panicum virgatum* and *Phalaris arundinacea.* From visible characteristics in photos down to some microscopic imagery, these plants might be suitable for oboe reeds. The most convincing evidence found for supporting the potential for *Panicum virgatum*, or switchgrass, is the image on page 175[310] of the Luo article. Though it is not a clear image, the shoot of the plant visually resembles characteristic found in *Arundo donax*. It is a type of woody grass, like *Arundo donax*, and the image has a node with two internodes, plus the shoot seems to be circular. Additionally, switchgrass is largely used for biofuel and most of the plants used for biofuel are woody grasses. On the other hand, reed canary grass, or *Phalaris arundinacea*, seems to present a slightly more convincing argument for oboe reed use. In the Zhang article on structural features of reed canary grass in the Jianghan

[310] Luo, *Compendium of Bioenergy Plants: Switchgrass*, 175.

floodplain, the wording the author uses when describing the plant involve lignified and "lysigenous cavities in stem pith," indicating that reed canary grass is woody with a hollow interior[311] like *Arundo donax*. The diameters of reed canary grass might also be in the acceptable range for oboe reeds. Further study on both of these plants is necessary to gather more data and make a more educated hypothesis about their suitability for oboe reeds. From the bare bones and basic preliminary research in this document, we simply do not have enough information to definitively rule the plants out as candidates for reeds, but we also do not have enough information to prove otherwise. Figure 2[312] in the Ji et al. article shows images of Giant miscanthus cells, which are bundled similarly to the other plants investigated that have had microscopic photos taken. Images a and b are from raw tissues and the rest are from tissues that have been treated.

The next four plants more data was collected on are *Arundinaria gigantea*, giant miscanthus, sugarcane, and corn. In addition to the research in the analysis section, these four plants were captured via scope imagery. *Arundinaria gigantea* was the most similar structurally to *Arundo donax* than the other three plants with vessels that gradually increased in density toward the exterior of the shoot, and vascular bundles intermittently within lignified tissue. The sugarcane and giant miscanthus samples were likely old and decaying, so the imagery was not as accurate as it could have been. Despite this, both still showed vaguely similar features. Additionally, corn being cultivated as an annual when it is really a perineal led to what looks like underdeveloped vascular bundles or potentially

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[311] Zhang et al., 103.
[312] Ji et al., "Visualization of *Miscanthus x giganteus* cell wall deconstruction subjected to dilute acid pretreatment for enhanced enzymatic digestiblity," 5.

lignified tissue, if the plant is grown to maturity. Similar to our previous conclusion, we still do not have enough information to rule out these four plants and we do not have enough information to support suitability for oboe reeds.

Based on the extensive preliminary data collected on bamboo and *Phragmites*, there is a lot of potential for these plants to be successful candidates for oboe reeds. The study with six participants was effective, despite many downfalls. Overall and including Martin Schuring and myself, oboists were able to soak, shape, tie a blank, scrape on bamboo and *Phragmites* reeds, and even produce reeds that made sound. Whether that sound was desirable or not and whether the materials behaved throughout the reed making process or not, does not matter for this initial study. The fact that we were able to make reeds with natural materials that made sound shows that these materials have a lot of potential. In processing the bamboo and *Phragmites* from tubes until shaping the cane, I had minimal issues with the materials. The bamboo tube walls were very thick, so I took extra care when gouging the cane. Most of the issues arose in the finishing stages of the reeds, of which I attribute to the imbalance of sizes and density of vessels and vascular bundles in the imagery. Sound analysis showed similarities between the materials, with the most statistically significant differences being between *Arundo donax* and *Phragmites*, and *Phragmites* and bamboo, with no statistically significant differences between bamboo and *Arundo donax*. Again, the high failure rate of both the bamboo and *Phragmites* reeds should not be the only indicator that these materials may not be suitable for musical instrument reeds.

To remediate any issues bamboo and *Phragmites* presented, I offer a few solutions. *Phragmites* and bamboo are not commercially grown with the specific use for

musical instrument reeds in mind, while it is highly likely that *Arundo donax* has been cultivated for that purpose over the last few hundred years, backed up by our literature. Many factors are involved with growing plants for oboe reeds that need to be minimized and mitigated, along with applying the same rigorous sorting process *Arundo donax* goes through before oboists purchase tube cane. If for whatever reason purposeful cultivation for reeds is not effective, there is the potential for hybridization. Hybridization tends to happen naturally without human intervention, however the idea presented in one of the sources in the analysis section that *Arundo donax* is possibly a hybrid between *Arundo plinni* and a diploid or *Arundo plinni* and *Phragmites australis*[313] leads me to propose purposeful hybridization of *Phragmites australis*. If we could produce a hybrid that has the best characteristics for music making and sustainability of *Phragmites* and *Arundo donax*, or even any combination of the plants analyzed in this document, that might be a revolutionary success for protecting our source of reeds, and also a step toward less stress in the reed making process. Another remediation I propose is a composite of bamboo and synthetic material. One of the sources addressed discussed a bamboo synthetic composite for nonmusical uses, however there are plenty of woodwind instruments made from composite materials that have become increasingly successful in recent years. Furthermore, Kaur et al. detail a mechanical method of extracting bamboo fibers without chemicals that might contribute to the development of a composite bamboo reed.

Future endeavors in this research include more study and experimentation. Collaborating with botanists and experts in plant sciences will be invaluable and a

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[313] Christou, "Giant Reed: From Production to End Use," 109.

worthwhile interdisciplinary subject. To have more control over the quality of materials to experiment with, growing my own plants to harvest and age could be key in more accurate and successful data. Additionally, considering the natural biodiversity of life on earth, the plants we research for alternative natural materials for oboe reeds do not have to only be in the Poaceae family. Outside of the Poaceae family, there are many other plants including the Mexican petunia, and plants in the cyperaceae family, graminoid family, and juncaceae family that show similar structure and characteristics of *Arundo donax*. The most important part of this area of research for the future is relying on interdisciplinary work and having an open mind when working with unfamiliar and odd materials.

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APPENDIX A

APPROVAL LETTER FOR STUDY 00018503

Joshua Gardner
APPROVAL: EXPEDITED REVIEW
HIDA: Music, Dance and Theatre, School of (MDT) 480/965-0324
Joshua.T.Gardner@asu.edu

Dear Joshua Gardner:

On 10/2/2023 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Oboe cane alternatives
Investigator:	Joshua Gardner
IRB ID:	STUDY00018503
Category of review:	7
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Guidelines for Working with New Materials.pdf, Category: Participant materials (specific directions for them); • IRB Social Behavioral Protocol KM Updated 9-28-23.docx, Category: IRB Protocol; • Maes_Participant Questions.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Maes_Short Consent Form_9-28-2023.pdf, Category: Consent Form; • Recruitment Script_JTG.pdf, Category: Recruitment Materials;

The IRB approved the protocol effective 10/2/2023. Continuing Review is not required for this study.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc:
Kelsey Maes

APPENDIX B

RESPONSES FOR STUDY 00018503

IRB STUDY00018503 Participants:

Laura Arganbright (Oboe Teaching Artist for Los Angeles Philharmonic YOLA Program and Principal Oboist of Bakersfield Symphony Orchestra, Arizona Philharmonic, and Opera Neo Orchestra)

Nikolaus Flickinger (Founder of OboNik Reed Making Business and Active Professional Oboist in the Phoenix Area)

Jared Hauser (Associate Professor of Oboe at Vanderbilt University)

Katherine Needleman (Oboe Faculty at Curtis Institute of Music)

Dane Philipsen (Chair of Woodwinds and Instructor of Oboe at Interlochen)

Phil Ross (Associate Principal Oboe of the St. Louis Symphony Orchestra and Maker of the Ross Gouging Machine)

General Questions

1. **What brand/model of oboe do you primarily play?**
   - LA: Howarth XL
   - NF: Loree AK bore. Serial number: PH08
   - JH: Yamaha 841LT
   - KN: Howarth custom XL with heavily modified bell
   - DP: Loree Royal, standard bore (VL76 & UV44)
   - PR: Laubin
2. **What staples/thread do you prefer to use?**
   - LA: Chiarugi 47mm #2 brass with GBS Nylon threadd or Squirrely Stash thread in FF thickness
   - NF: I use three types of staples. 1: synthetic cork brass staple from Advantage. 2: Rigotti brass 47-3 Ostoich model. 3: Sierra tube, by Chudnow, Brass
   - JH: Chiarugi 2+ (or Rigotti 2+, I think they're the same), FF nylon thread
   - KN: Old Stevens or Hiniker; EE nylon thread
   - DP: Chiarugi 2 staples, LC Double Reeds or Squirrely Stash
   - PR: Chiarugi 2, 2+, 5 / nylon FF
3. **Where do you purchase cane and what brand do you prefer?**
   - LA: Rigotti from Woodwind Brasswind
   - NF: I buy bulk Rigotti cane directly from France.
   - JH: I used to get Weber's Grimaud, and I'm using up my last stash of that. I also have/use alliaud purchased from the grower, and glotin from someplace or other(?), but I'm not sure where. I am about to purchase Rigotti cane directly from Rigotti. When I find something I have success with, I typically purchase a large amount and use over time. I don't prefer switching between types/brands, as I find I adapt my reed-crafting to the material over time more than finding the perfect cane that works for me.
   - KN: I have many types. My favorites have historically been Chinese and Turkish tube cane.
   - DP: Midwest Musical Imports (Pisoni & Rigotti); Advantage (Grimaud)
   - PR: Rigotti from them

4. **What shape do you use?**
    - LA: Joshua +2
    - NF: Joshua +2
    - JH: Typically I alternate between RDG 1, Caleb, and an old original Brannen shape. I have a collection of more shapes than I like to admit, but these three are the ones I always come back to.
    - KN: an original Mack Pfieffer tip
    - DP: This can vary based on what I need, but Mack + and Mack ++ are my most commonly used shapes
    - PR: Gilbert 1
5. **Do you prefer to use a profiler?**
    - LA: No
    - NF: I have a Reeds and Stuff profiler, but I don't use it that much.
    - JH: I do indeed use a Reed-n-Stuff profiler most of the time. On occasion I make a reed entirely by hand but I've been happy to have the machine take care of 3/4 of the work fairly quickly.
    - KN: Yes
    - DP: No
    - PR: No
6. **What gouging machine do you prefer?**
    - LA: Reeds n Stuff. 11.0 bed, 11.6 blade.
    - NF: I use Innoledy.
    - JH: Ross and occasionally Kunibert.
    - KN: Graf/Innoledy/Kunibert Michel
    - DP: Ross
    - PR: Ross
7. **Briefly discuss your expertise in the oboe field.**
    - LA: I am a busy performer and teacher in Los Angeles. I have been selling handmade oboe reeds since 2015, and, on average, sell about 60 reeds per month.
    - NF: I've been making professional reeds for 20 years at www.obonik.com I sell my reeds all across the country. I went to CCM (Cincinnati Conservatory of Music) for my undergrad. And Arizona State for my masters. I have performed all over the United states, Canada, Mexico, and Europe. I sub with the Phoenix Symphony and play regularly with Mill Ave Chamber Players. I have a full studio of private students and teach at both Glendale and Mesa Community Colleges. I am a member of IDRS. I worked for both Weber Reeds and also Hannah's Oboes where I expertly processed cane and adjusted oboes.

- JH: I've been a working-professional oboist for 3 decades, currently a full-time university instructor (for past 15 years), solo/chamber/orchestral and non-classical experience. Frequently active as performer and in recording studio. Frequent guest instructor at other institutions beyond my position at Vanderbilt University.
- KN: no expertise
- DP: https://www.danephilipsen.com/about/biography
- PR: Associate Principal Oboe of St Louis Symphony

8. Explain your process for testing/playing reeds as you finish them.

- LA: I make reeds over a few days. On the first day, I shape and tie. On the second day, I scrape and get the reed crowing, ideally at a sharpish B or low C with lots of vibration. On the third day, I get the reed playing to what feels like finished standard to me, meaning it plays in tune with a stable tone and responds to light articulation. On the fourth day, I finish again and make tiny adjustments to refine the tone or response as needed.
- NF: I tie all of my reeds at 72mm. I crape over three to four days. I get the reeds to crow really flat an (A) and then clip them up to pitch and then refine the heart, back and tip. I make sure they crow a concert (C) and make sure they respond properly. I do the squeeze test, to make sure each side is even. I make sure the crow is correct and then play test each one, making sure it functions properly, is up to pitch and in tune, and also sounds good.
- JH: Most of the reed-crafting decisions are based on various crows (pitch of crow, quality of crow, presence of 1/2/3 octaves of pitches, ease of response). Test playing on oboe: do resistant notes like D natural come easily, do low notes beginning with F come easily not droop flat, test octave trueness on A Bflat B C side octave notes. Feel/playability of reed: is the reed flexible fwithout being wild, is the sound pleasant enough, is there a variety of articulation available. There's an important kinesthetic component, does it just feel right based on experience.
- KN: I play the repertoire I am working on on the reeds as I make them and improve the reeds until they suit that repertoire
- DP: After constructing the reed to vibrating/crowing, I test primarily with a thread crow to evaluate the reed without any embouchure influence. I am listening and feeling for stable crow pitch (a "c+" suits my oboes and playing), easy response, comfortable resistance. On the oboe, I am testing primarily for articulation--clean sound and quick response; I will do this mostly on notes with shorter fingerings to highlight the worst of all possible sounds that the reed might make on the oboe.

- PR: I make reeds very quickly. My philosophy is simple, it must sit up to pitch on it's own, even when trying to force the crow down. A "pitch floor" of C is a must with my oboes. I then balance stability/resistance until I have a comfortable reed. If those basic criteria are met, the reeds usually perform well all around.

9. **For a baseline response, briefly describe your reed making experience with *Arundo donax*. What good qualities in cane do you look for throughout the reed making process? What bad qualities make you dispose of cane?**
   - LA: I am not too picky with cane quality, as I make reeds for such a variety of customers, and my reed-making often involves an adjustment session with customers where I finish reeds to their liking. When I encounter a piece of cane that feels slightly soft, stringy, or grainy, I typically use that reed for a younger student, or customer who has requested lighter strength reeds with smaller tip opening. I have less luck working with exceptionally hard or brittle cane - for me, this often results in a reed that is shrill with difficulty refining the tone. I rarely dispose of pieces of cane before I have made them into a reed.
   - NF: I've been making reeds with *Arundo donax* for more than 25 years. I use Rigotti cane at 10-10.5 mm in Diameter. I'm not as picky as many players, as I have to make so many reeds. They always say, "You can make a reed out of anything." So I make sure the cane is straight and flat. Anything curvy or bent, I throw it out. I also look at density, though both hard and soft cane can make a reed. The softer cane won't last as long and the denser cane takes longer to break in. I was also told the if you find a piece of purple cane, it will be an amazing reed. So I look at color as well. I don't care too much about dark spots, those typically scrape out. Most of the cane we get here in the US is from just a few companies in France or Spain. I've been to France and Rigotti and learned so much. The cane that we purchase has been aged for at least 4 years. So if you buy a 2020 vintage its actually four years older than that.
   - JH: In gouging process: curvy or bowed, twisted or otherwise typically undesirable pieces are discarded. Cane that seems very shred-y, soft or twisty in the gouging process is discarded. Gouged cane: I like medium density cane, with good springiness. Color and appearance (gold-ish with slight brown crosswise stripes) can be a promising indicator, but not always a true factor. One important and telling factor is the type of blank the cane makes: the best reeds are strong enough in the throat area, but flatten out proportionally and lave a nice flat hinge at the tip. I don't prefer (but honestly still use) blanks that seem too have too much arch/open throughout

with a snapped open tip-hinge, or the opposite, blanks that seem to be flat and weak without much arch past the throat. Despite all that, not all cane scrapes the same, and I try to make a reed out of every good piece of gouged cane that yields a blank, even if it's not a fabulous reed, and I have a pretty high success rate. Usually, if the scraping process fails it is because of cane quality, or structural issue like loose sides.

- KN: It must gouge smoothly. I prefer a hardness measurement between 9-11, sometimes also using 8 or 12. Grains must run straight.
  DP: I sort for "diameter" (and at multiple points along the length of the cane for consistency), straightness (or slight "smile" curve with barkside on flat surface), color (not too pale, not too dark), and bark texture (prefer smooth without pronounced grains in surface bark, consistent texture without patchiness).
- PR: I am rather laid-back about cane. It must be straight and the correct diameter. Otherwise as long as it's not too hard or soft, I will likely find the cane acceptable.

Material A (Phragmites)

1. **What are your initial thoughts upon opening the envelope?**

- LA: Looks grainy! (mentioned in Material B form: "I forgot to mention that material A looked quite pale.")
- NF: I wasn't sure what to expect, but it all looks like something a reed could be made out of.
- JH: I was excited to try all of the materials. Each A, B, C seemed clearly different.
- KN: I would never choose to make reeds with Cane A based upon the appearance of the gouge and the cane. The gouge is very uncentered, overly thick, and the cane appears very rough.
- DP: Material A looks to be more grainy and "stringy" than cane that I would usually accept to make reeds. The color is pale relative to my typical cane, the surface substantially less smooth. As the material dried and aged after gouging, the edges curled in, tightening the appearance of the "diameter" of the cane and leading me to question the material's ability to consistently hold the form of a reed as it soaks/dries between uses.
- PR: I was excited to try something new!

2. **As you are examining Material A, what do you think about the visual qualities?**
    - LA: Grain lines look consistent, a little bit rough on the edges, perhaps from gouging.
    - NF: A is the lightest in color. The grains are more pronounced and the curve is tighter than the other two. The grains are quite straight.
    - JH: Visually, it looks fine with respect to grain on the inside. The bark looked fine but doesn't quite look like Arudno Donax in color.
    - KN: Very rough, stringy, soapy looking. Poor cane selection – not straight. Poor gouge.
    - DP: The appearance of the cane challenges my concept of what an acceptable material for reeds is. Given the pronounced stringy/grainy qualities, my assumption is that the scraping will be less detailed, (lower "resolution" possible to borrow a concept from the digital age) as the knife navigates over peaks and valleys and removes cane in shreds.
    - PR: It seemed hard, but nice
3. **This question is optional to answer: Feel free to use any tools (methods without physical tools or physical tool) you have to test the cane before you use it. This might include the hardness test where you flick the cane or using a hardness testing machine that spits out a number. If you investigated the**

cane before shaping and tying a blank, what did you do and what were your results?

- LA: I fold by hand prior to shaping, so these are my notes from that process. A1: cracked immediately upon the gentle folding bend before shaping A2: Lots of tension when folding the piece of cane. The bark layer seems thick so the initial "crack" of the fold was very strong. A3: Similar experience to A2 on folding. The bark seems very hearty, and thus holds a lot of tension for the first fold.
- NF: I soaked it for the normal amount of time. It bends properly (gouged to the right depth). It looks good to go.
- JH: All 3 pieces were quite a bit thicker (measured wet) than indicated. .64, .65, and .65. Perhaps they compressed during gouging?
- KN: Hardness measures quite differently on the same piece of cane from side to side. First piece 13/14. Second 13/16. Third 17/18.
- DP: Beyond visual inspection (and other sorting for diameter, straightness before gouging--not applicable in this study), my main opportunity to get to know a piece of cane comes from folding. I do not score the cane, and bending the cane around my finger and then "squashing" to make the fold allows me to feel the relative resilience/hardness/spring in the cane. Material A was more brittle/snappy and less pliant than the cane I usually use; it resisted curving and snapped rather suddenly producing a fold more jagged than I usually see.
- PR: I didn't test hardness, but the thickness was very thick. My average pieces were .68mm

4. **As you shape and scrape Material A, what are your thoughts? Are there similarities/differences to *Arundo donax*?**
    - LA: Shaping & scraping the ends of the cane on an easel A2: Slight issues shaping due to the cane being narrower than my shaper tip's ears. I may not have gotten a perfect shape as the cane slipped a bit on one side. Scraping the ends of the cane seems to be smooth A3: On scraping the ends, I almost have a hard time getting the knife to grab the surface of the bark. Beneath that layer, the cane feels smooth Tying: A2: immediately cracked at the bottom of the cane above the thread tie. The sides of the reed seem quite open with my standard measurements A3: did not notice any lower cracks when tying, but on inspection after tying, there are two surface cracks above the thread. Seals nicely on the sides, though. Scraping and playtest: A2: Bark layer feels very crumbly. Prominent grain lines once into the second layer. Playing feels quite buzzy but sounds dead. Finishing A2: very stuffy. Feels like it just doesn't want to vibrate. Because the cane feels so

brittle, it is difficult to make small scraping adjustments A3: Similar impression as scraping the ends: even my sharp knife has a hard time "grabbing" the cane to remove smoothly on the bark layer. Once bark is removed, the cane comes off smoothly. Playing is vibrant and focused. Finishing A3: Pleasantly surprised! Very different from A2. I think because the bottom of the reed did not crack, the opening is more relaxed.

- NF: The gouge was a little too long for my shaper, but I made it work. It shaped just the same. The bark as I was thinning the ends was a little denser that *Arundo donax*. I'm using a synthetic cork. Rigotti tube 47-3, and Chudnow Sierra tube. Initial scrape to open it up, the bark is a lot harder and took more scrapes to get it to where it needs to be to open it up. First scrapes, the bark was much more difficult to get through. The grains look like celery. And it has a very different smell.
- JH: A big test for me is how the material folds over. Material A was difficult to fold over, ridged and stiff. Of the 3 pieces, one folded decently with a bit of effort, decent flat hinge at end; one folded but the hinge opened, didn't stay neatly folded; and the 3 piece folded difficultly. This 3rd piece cracked while shaping, very odd! All 3 pieced folded more difficulty than I am accustomed, but the shaping was typical. On the remaining two, both pieces seemed very grainy, and were difficult to scrape, and difficult to judge visually because of the graininess. Due to the graininess, it was difficult to scrape wet in particular, and had to scrape the tip when dry.
- KN: This is terrible. There is a huge underlayer that prevents things from scraping smoothly. Despite excellently sharp knives, it's difficult to scrape.
- DP: Shaping material A was the step in the process most similar to the cane I usually use. The material shaped well; using a fresh blade, I was able to match the material to the contour of the shaper tip. Scraping the blank, I notice that the knife blade catches and chatters more easily than the cane I'm accustomed to scraping. It takes an adjustment to pressure and motion to keep the knife moving smoothly and continuously as intended. My process includes shaping, tying, blank scraping, and clipping open in one session, and then allowing the blanks dry and settle before returning to scrape them to vibration (reeds dry/settle in a reed case that is in a container sealed with a Boveda humidity control pack that maintains approximately 49% humidity). Very concerning with Material A: all three blanks opened astoundingly wide on the sides; none of the pieces yielded blanks that sealed tightly from staple to tip--absolutely necessary to me for acceptable reeds. With my typical cane and process, every blank seals tightly from

staple to tip. With my students, if they have a blank that does not seal tightly at this stage, I encourage them to abandon the reed and try again. I proceeded, though, for the purpose of this trial. I soaked the three blanks, and the sides opened more. I went ahead and scraped A1, with some difficulty as the plaque struggled to stay in the reed. The sides never settled down on A1, so the reed never made it past a "duck call" sound. I tried soaking A2 & A3 more than I normally would, and eventually the sides came together, albeit with substantial (humongous) tip openings. After that, I was able to get A2 to come together into a more functional reed. Looking at A2's tip opening, one blade had a "peak" in the curvature--which I usually associate with a flaw in cane that may lead to a crack. Indeed, in the initial finishing stages, A2 did crack at that weak spot in the material. I managed to get A3 to come together into a state where it functioned as a reed on the oboe.

- PR: It was too hard. The structure was not cooperative to making a good reed.

5. **Were you able to make a reed that produces sound out of the three pieces of cane? If so, how does it feel to play? Do you like or dislike the results?**
   - LA: Yes. A3 only. Feels vibrant and stable. I probably would not use it myself, but it functions. Both pieces feature the prominent thick grain lines visibly. A2 was barely playable, while A3 was just fine.
   - NF: I was able to make reeds that produced sound on all three pieces. It was easy to play, however the sound was very bright on all three. I wasn't completely pleased with the results, however you can make a reed on this material. I don't think I would want to use them in a concert, but for practicing or even student reeds, it could work.
   - JH: As mentioned, one piece oddly cracked during shaping. One piece had such open sides there was no hope for a working reed. This particular piece was very soft, hardly any functional vibrations. The one piece that produced a reed also had loose sides, but it worked. It is very flat in pitch, and has an unappealing sound.
   - KN: They all make sound. I had to fill the second one in with wax on one side because it was so warped to get it to seal. But the response, pitch, and sound are terrible. These are the worst reeds I've made in memory.
   - DP: Yes, A3 is functioning as a reed. The reed certainly vibrates and resonates differently than the cane that I usually use. The vibration doesn't seem to have the same depth to which I'm accustomed, the sides are barely closed, so I don't trust the reed fully, and tone and pitch lack the same stability I'm accustomed to.
   - PR: No

6. **Considering *Arundo donax* goes through a rigorous sorting process, do you think you would get better results if Material A went through the same sorting process?**
    - LA: Perhaps sorting would have eliminated A2 but I would not have guessed that it would be so bad based on its appearance. Especially considering how well A2 functioned, the inconsistencies concern me.
    - NF: I don't know if these pieces went through the same sorting process or not. But I would definitely do the same process as *Arundo donax*.
    - JH: Perhaps that would make a difference, as this material didn't yield any usable, or functional reeds.
    - KN: Perhaps, but I wouldn't want to do the sorting after seeing this piece (pieces.)
    - DP: Yes. I'm curious about what controlling for growing conditions, sorting, aging, drying, and other conditioning might do. Altogether, though, this material seems to be much more affected by outside variables--weather, soaking/drying, etc. I seek more stability in my reed making, not more variability.
    - PR: No
7. **Do you think this material is suitable for making oboe reeds?**
    - LA: I would be open to experimenting more and curious what additional steps could be taken to sort the cane based on quality.
    - NF: This material will make reeds, but I don't believe it would be the best choice. If *Arundo donax* didn't exit, then yes you would be able to make it work, with adjustments to your reed making style.
    - JH: No, I'm afraid not.
    - KN: Hard no.
    - DP: Can it make a reed? Yes. With practice and more controls, could it be more reliable? Probably. Does it show the promise that it could supersede my typical cane? Probably not.
    - PR: No

Material B (Arundo donax)

1. **What are your initial thoughts upon opening the envelope?**
   - LA: Looks very similar to my typical cane!
   - NF: Same as A. We will see how this all works out.
   - JH: I was excited to try all of the materials. Each A, B, C seemed clearly different.
   - KN: This was the best looking of the three options by a long shot.
   - DP: At first sight, material B appears to be *Arundo donax*. The surface of the cane looks smooth and is a coloration typical to what I usually see. One of the pieces (eventually B3) has some streaks of darker coloration, but very consistent with the material I usually use.
   - PR: Excited to try them all
2. **As you are examining Material B, what do you think about the visual qualities?**
   - LA: Appeared slightly more yellow (I forgot to mention that material A looked quite pale). Consistent grain lines, smooth gouged surface.
   - NF: Material B looks more like *Arundo donax*. The color and the density is very similar. It also bends like *Arundo donax*.
   - JH: This looks like nice cane. Good color, nice grain.
   - KN: Fine, smooth, acceptable. Gouged decently.
   - DP: All visual qualities--from the bark surface to the smoothness of the gouged surface--suggest that this will be familiar scraping territory; looks like decent cane overall.
   - PR: It looked very nice
3. **This question is optional to answer: Feel free to use any tools (methods without physical tools or physical tool) you have to test the cane before you use it. This might include the hardness test where you flick the cane or using a hardness testing machine that spits out a number. If you investigated the cane before shaping and tying a blank, what did you do and what were your results?**
   - LA: no answer
   - NF: I don't do hardness tests, as long as it is to length and gouge depth, and bends the right way, I can make a reed out of it. Every piece of cane is different and you have to scrape it for what it needs. I've soaked both B and C and B floats like *Arundo donax*, and C sank to the bottom, it must be much denser.
   - JH: thickness as indicated (measured wet).
   - KN: Hardness of 10, 11, and 13 on these pieces.

- DP: Again with the folding technique (described with the A material), material B had a good, stiff quality without being rigid, took a good curve, and led to a satisfying fold.
- PR: Again, very thick center measurement

4. **As you shape and scrape Material B, what are your thoughts? Are there similarities/differences to *Arundo donax*?**
   - LA: B1: tied easily, no surface cracks - cane feels flexibly enough to seal easily around the staple while thread is pulled tight. Scraping feels very close to what I am most familiar with. I use Rigotti cane and this could easily have been a piece of my cane and I would never know the difference. Plays readily with my typical scraping pattern. Finishing: stable, resonant. B2: feels just like Rigotti. tied easily with no cracks. Scraping feels smooth, cane comes off evenly. Plays a little noisy but stable. Finishing: not my favorite in tone, but functions just fine. B3: What appeared to be a surface crack near the fold point after shaping turned out to be a full crack.
   - NF: B feels exactly like *Arundo donax*. The way it was shaped, scraped, the way the blades lay, and how the knife takes the cane off is almost exactly the same as *Arundo donax*.
   - JH: Very nice fold over on all 3 pieces. Nice flat hinge. This is similar to cane I'm used to. Material shaped well, tied a nice blank, and scraped nicely.
   - KN: Completely similar.
   - DP: My experience shaping was as with *Arundo donax*; fine experience with shaping as expected.
   - PR: It seemed very good
5. **Were you able to make a reed that produces sound out of the three pieces of cane? If so, how does it feel to play? Do you like or dislike the results?**
   - LA: Yes, B1 and B2 were fine reeds. Visibly, they look almost identical to my own produced reeds. I cannot identify any visual differences in cane quality from my Rigotti reeds.
   - NF: Yes, I was able to make three good reeds on this material using different staples. I might even use them for personal use. The sound was nice and dark and it feels exactly like *Arundo donax*.
   - JH: All three pieces produced good reeds. One piece was a bit softer and grainier than the others, but all have appeal sounds, good pitch, tight sealing sides. I was also able to make each reed fairly quickly, without unexpected issues.
   - KN: I made three quite nice reeds. They are a little small for my taste, but I believe this may be a function of a larger diameter cane than I choose for myself and/or a lighter gouge.

- DP: These pieces all sealed well from thread to tip, typical tip openings, and scraped well. I'm three for three with material B. The reeds don't feel like my typical gouge, but the material feels good, vibrates well with warmth, stability, and ease, and this feels like what I'm used to--which makes me comfortable.
- PR: Yes, all three turned out and I thought they all had great potential

6. **Considering *Arundo donax* goes through a rigorous sorting process, do you think you would get better results if Material B went through the same sorting process?**
   - LA: Perhaps! In my own reed-making business I very, very rarely have reeds crack. It is interesting to me that of the 9 pieces of cane I was sent, 3 (1 from each batch) cracked even before the scraping process.
   - NF: Yes I would use the same sorting process for this material as you would for *Arundo donax*. I'm not sure if you would get better results as these three pieces worked very well.
   - JH: This cane seems well sorted and processed. Made 3 nice reeds.
   - KN: Yes
   - DP: Yes, and I'm always interested to learn more about the sorting processes as well.
   - PR: Yes
7. **Do you think this material is suitable for making oboe reeds?**
   - LA: Yes.
   - NF: Yes, absolutely.
   - JH: Yes. My guess is that this is indeed *Arundo donax*, and I'm curious to know from grower/brand.
   - KN: Yes, on the basis of these three pieces I used. I can speak beyond that.
   - DP: Yes, I think this is suitable material for oboe reeds!
   - PR: Yes

Material C (Bamboo)

1. **What are your initial thoughts upon opening the envelope?**
   - LA: Cane seems dark in color.
   - NF: Same as A and B. We'll see where this goes.
   - JH: I was excited to try all of the materials. Each A, B, C seemed clearly different.
   - KN: I've described this in the other two. This was not a material I thought would work well, along with Cane A. I thought Cane B had potential.
   - DP: Material C has a darker, deeper yellow-brown color than the material I am accustomed to working with.
   - PR: Excited
2. **As you are examining Material C, what do you think about the visual qualities?**
   - LA: Darkest of the 3 categories, also very prominent grain lines that look quite thick.
   - NF: Material C is the darkest of the three. One piece has very curvy veins. It looks a lot harder than the other two. The curve is good. Before soaking, it feels like I could crack it faster. More brittle.
   - JH: The bark color seems plain, and pale. The underside looks grainy and mushy.
   - KN: For this material: looked like very, very old around donax. Very dark color and smooth gouge on very warped cane, one piece which was visibly cracked already. Looks like enormous diameter cane. Looks very hard.
   - DP: After waiting some weeks to make the reeds after receiving the cane, one of the pieces cracked through—just sitting in the case on the desk. This makes me hesitant to trust the material, but worth noting that nonetheless.
   - PR: It seemed very hard
3. **This question is optional to answer: Feel free to use any tools (methods without physical tools or physical tool) you have to test the cane before you use it. This might include the hardness test where you flick the cane or using a hardness testing machine that spits out a number. If you investigated the cane before shaping and tying a blank, what did you do and what were your results?**
   - LA: Folding by hand before shaping C1: very firm bend when folding. Felt like it was going to crack! C2: very firm, cracked immediately in 2 places when trying to fold C3: feels slightly wider (wider diameter?), but bend is similar - I can fold the cane all the way in half without the bark even breaking. I have a photo of this if you want - folding by hand gives me a

sense of the hardness of the cane. Interesting that the cane feels so hard yet has this much flexibility in it before it "cracks" for the shaping fold.

- NF: Soaking up C sank faster in the water and to soak. I'm going to shape and tie all the same. Joshua+2 and three different tubes.
- JH: All 3 pieces measured (wet) slightly thicker than indicated.
- KN: Hardness of 5,6, and 6. (Extremely hard.)
- DP: In folding, the C material was very stiff; it took patience to get the cane to bend/fold without cracking.
- PR: Too thick

4. **As you shape and scrape Material C, what are your thoughts? Are there similarities/differences to *Arundo donax*?**
    - LA: Shaping: C1: Shaping slightly difficult. Had a hard time getting the razor blade (brand new) to catch on the edge of the cane. C3: Difficult to shape, in that I feel like I am dulling out my razor blade much quicker! I typically use 1 blade per piece of cane, but had to get a fresh blade to smooth out the edges on this piece of cane Tying: C1: cracked at the base. C3: surface cracks at the base on both sides Scraping and playing C1: The bark layer feels crumbly and underneath that, the cane feels quite hard, but scrapes smoothly. Initial crows are rattly and chirpy. Difficult to get vibrating, feels very sharp and shrill. Felt like I had to remove a lot more cane to get the reed vibrating at a stable pitch. Finishing C1: decent sound, still a bit bright and treble-y feeling C3: The cane scrapes nice and smooth. This reed is quite closed and also difficult to get to vibrate, shrill and sharp to play. Even when it vibrates, it feels quite stiff and closed. There is a lack of flexibility in the bright tone.
    - NF: I had two pieces completely split on me, so those won't be anything. The other tied on ok, however the opening is very small. I think the material is too dense.
    - JH: This cane was difficult to fold (needed extra encouragement), though it created a nice hinge in the end.
    - KN: I shaped 2/3 pieces and opted not to make reed on the visibly cracked and warped piece despite Kelsey's encouragement. One more piece cracked irreparably upon folding it over despite being soaked for an hour. The last piece cracked irreparably when doing final scraping.
    - DP: Material C was most resistant to shaping. It took me a couple of razor blades per piece to be satisfied that I had cleanly shaped each one.
    - PR: Way too hard
5. **Were you able to make a reed that produces sound out of the three pieces of cane? If so, how does it feel to play? Do you like or dislike the results?**

- LA: Perhaps. I have never used a hardness tester in my reed-making practice, but if there were softer pieces of cane, I would be interested to experiment more.
- NF: I was able to make the only piece that didn't crack into a reed that made sound. However I was unsatisfied with the results. It was very stuffy, didn't vibrate and the opening was very closed that I could hardly make much noise. The crow was only a high pitched single tone crow.
- JH: Loose sides on all 3 pieces, but functional. I had to scrape this cane more than usual to get enough vibration, the tips were quite thin. Each piece did, however, produce functional reeds, with decent sound. They were all a bit flatter in pitch than usual, perhaps because of how much scraping was needed.
- KN: I made 0/3 reeds out of this material, not even bad reeds, because of the cracking issue.
- DP: No, I wasn't able to make a working reed out of this material. The critical challenge was tip opening. After tying the blank and clipping open, I noticed that the reeds had absolutely no tip opening. I let the blanks rest for several days, and the reeds opened up during this time. However, once I soaked the blanks to scrape, they flattened out again. I scraped the reeds (the two blanks I was able to make, less the one piece that cracked), and they simply would not vibrate because they were completely closed.
- PR: no

6. **Considering *Arundo donax* goes through a rigorous sorting process, do you think you would get better results if Material C went through the same sorting process?**
   - LA:
   - NF: I'm not sure sorting would help at all, the material isn't flexible enough to make reeds, so why waste the time.
   - JH: Yes, I think this material needs more sorting to find denser, more appealing pieces. The Bark seemed quite brittle (maybe thicker), while the grain was soft and mushy. Perhaps there are examples of this that are more suitable to scraping, but these aren't the best. they took a long time to make, too.
   - KN: No, but maybe there was something fixable wrong creating the cracks here. This looks better than Material A to me in terms of the way it scrapes.
   - DP: I really don't see the potential in Material C since it did not hold an opening.
   - PR: no

7. **Do you think this material is suitable for making oboe reeds?**
    - LA: It could be. I would be more open to experimenting more with C than A.
    - NF: Not at all. You could maybe use it for basket weaving!
    - JH: No, I'm afraid not the best.
    - KN: No, not based upon these three pieces.
    - DP: No.
    - PR: no

Concluding Questions

1. **Do you think any of these materials have the potential to be groundbreaking in the reed making world?**
   - LA: Groundbreaking? No. Suitable if we come to a moment in time where *Arundo donax* is gone? Yes.
   - NF: I believe that material B would work well for reed making. The other two not so much. Material A was really grainy when scraped and the openings were very closed. Material C was too dense and since 2 of the 3 pieces cracked on me, it was difficult to have a successful outcome.
   - JH: Material B made very nice reeds. I would definitely use this, and am curious to know what kind of cane it is. I would use this in the future.
   - KN: potentially Cane B
   - DP: Groundbreaking? No, not particularly. After resting the reeds I made with A, the tips opened up quite widely again, so I'm hesitant to trust that material from day to day. I wasn't able to get anything to work with Material C. Material B seemed to be fine!
   - PR: Possibly B
2. **Of the three, which do you predict will have the most success?**
   - LA: B was the best for me. The closest in feel and function to the Rigotti cane that I routinely purchase for my business. C was second place for me, and A was least desirable.
   - NF: Material B has the most potential for success.
   - JH: Material B definitely produced the best reeds of these options. I would use this material regularly. Material A was unusable. Material C was not so great.
   - KN: Cane B-only Cane B.
   - DP: Material B
   - PR: B
3. **Do you have any other thoughts that these questions have not asked about?**
   - LA: I think it is important to note that as someone with a reed-making business, I am used to a much more consistent result after my routine shaping/tying/scraping process. However, I pride myself on the ability to "make a reed out of anything," or rather, "make an improvement on even the worst reed." So, this was definitely interesting! It is atypical that 1/3 of the cane pieces cracked and were not usable. It is also atypical that I dislike a majority of the reeds from a finished batch (LOL). Both reeds from material B are 100% usable. Honestly I will probably sell them to a student. Both reeds from material C are functional, just unpleasant in tone. I could probably continue to work them over a few more days (perhaps they will

settle more, being such hard pieces of cane), but I am trying to base my analysis on these materials considering my usual methods. From material A, one reed was just awful in a way that I would say is unusable, and one is totally fine. The inconsistency is interesting, and visibly, the reeds from this material are the least appealing. I take great care in the neatness of my reeds, especially commercial, and the reeds from material A appear rather chunky looking from the bark scraping coming off uneven. When dry, the tips are also VERY open and spread. I took some pictures throughout the process if you'd like to discuss sharing those! I'm also happy to do some playing demos if you want to hear them. I numbered each piece of cane and took notes in my phone as I worked, then came to your google docs a few days later.

- NF: It was really interesting to try different materials and see if they actually worked. There is an obvious reason why *Arundo donax* has been cultivated for reed making. It has the right density and squishiness to make successful reeds.
- JH: No, good questions.
- KN: I am not sure if I failed so badly with Cane A (disgusting reeds) because of the cane selection and poor gouging or because of the material itself. Similarly, all three reeds cracked with Cane C so badly that I can't judge the material as anything other than something which cracks terribly. The reeds from cane B were very promising.
- DP: Please feel free to reach out for clarification on anything. I hope this information is useful to your study, and I look forward to reading your findings; best wishes!
- PR: No, thank you for doing this!

APPENDIX C

SIGNED CONSENT FORMS FOR STUDY 00018503

Consent Form

My name is Kelsey Maes and I am a Doctor of Musical Arts student under the direction of Professor Martin Schuring, Dr. Joshua Gardner, Dr. Lindsey Reymore, and Dr. Caslor in the School of Music, Dance and Theatre at Arizona State University. I am conducting a research study to determine if there are viable natural materials we could use for oboe reed making besides *Arundo donax*.

I am inviting your participation, which will involve shipment of gouged cane from various plants free of charge. You will then make reeds from the provided gouged cane and then fill out Google Forms with questions about your set up (brand of oboe, type of staples, what gouge you normally use, shape, thread, etc.) and questions about your experience with the new materials. You can take as much time making the reeds (expect approximately 15-25 min per reed) and filling out the Google Forms (expect approximately 30 minutes for each of the three materials). The deadline to submit your is January 31, 2024. You have the right to stop participation at any time.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. You must be 18 years of age or older and an oboist who successfully makes their own reeds in order to participate in this study.

A possible benefit to your participation is the potential to take part in a study on oboe reed materials that revolutionizes how oboists today make their reeds. A known benefit to your participation is being shipped gouged cane free of charge and your ability to freely experiment with the cane on your time in your own home. There are no foreseeable risks or discomforts to your participation.

This study will be documented in my DMA research project, and may be used in reports, presentations, or publications, but your name and any identifiable information will not be used if you wish to remain anonymous. You may choose to remain anonymous or disclose your name by checking the appropriate option below. I will de-identify your responses and use generic descriptors, such as "Professor at the Collegiate Level" or "Orchestral Oboist," to only identify your level of expertise and the validity of your responses. If you choose to remain anonymous, only the researchers will have access to data that links your responses with your identity.

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By signing below you are agreeing to be part of the study. Please select whether you would like to disclose your identity or remain anonymous by selecting the appropriate option below.

☒ I agree to disclose my name in this study.
☐ I wish to remain anonymous in this study.

Name: Laura Arganbright Signature: Laura Arganbright Date: 11/10/2023

ASU Knowledge Enterprise Development

ASU IRB IRB # STUDY00018503 | Approval Period 10/2/2023

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Name: Nikolaus Flickinger Signature: [signature] Date: 10-31-23

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☐ I wish to remain anonymous in this study.

Name: Jared Hauser Signature:  Date: Nov 21, 2023

ASU Knowledge Enterprise Development

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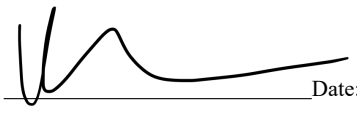
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☐ I wish to remain anonymous in this study.

Name: Katherine Needleman Signature:  Date: 12/13/23

ASU Knowledge Enterprise Development

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☐ I wish to remain anonymous in this study.

Name: Dane Philipsen Signature: [signature] Date: 26 Oct 2023

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Consent Form

My name is Kelsey Maes and I am a Doctor of Musical Arts student under the direction of Professor Martin Schuring, Dr. Joshua Gardner, Dr. Lindsey Reymore, and Dr. Caslor in the School of Music, Dance and Theatre at Arizona State University. I am conducting a research study to determine if there are viable natural materials we could use for oboe reed making besides *Arundo donax*.

I am inviting your participation, which will involve shipment of gouged cane from various plants free of charge. You will then make reeds from the provided gouged cane and then fill out Google Forms with questions about your set up (brand of oboe, type of staples, what gouge you normally use, shape, thread, etc.) and questions about your experience with the new materials. You can take as much time making the reeds (expect approximately 15-25 min per reed) and filling out the Google Forms (expect approximately 30 minutes for each of the three materials). The deadline to submit your is January 31, 2024. You have the right to stop participation at any time.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. You must be 18 years of age or older and an oboist who successfully makes their own reeds in order to participate in this study.

A possible benefit to your participation is the potential to take part in a study on oboe reed materials that revolutionizes how oboists today make their reeds. A known benefit to your participation is being shipped gouged cane free of charge and your ability to freely experiment with the cane on your time in your own home. There are no foreseeable risks or discomforts to your participation.

This study will be documented in my DMA research project, and may be used in reports, presentations, or publications, but your name and any identifiable information will not be used if you wish to remain anonymous. You may choose to remain anonymous or disclose your name by checking the appropriate option below. I will de-identify your responses and use generic descriptors, such as "Professor at the Collegiate Level" or "Orchestral Oboist," to only identify your level of expertise and the validity of your responses. If you choose to remain anonymous, only the researchers will have access to data that links your responses with your identity.

If you have any questions concerning the research study, please contact the research team at: joshua.t.gardner@asu.edu for Dr. Joshua Gardner, Principal Investigator, or myself at kamaes@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.

By signing below you are agreeing to be part of the study. Please select whether you would like to disclose your identity or remain anonymous by selecting the appropriate option below.

☒ I agree to disclose my name in this study.
☐ I wish to remain anonymous in this study.

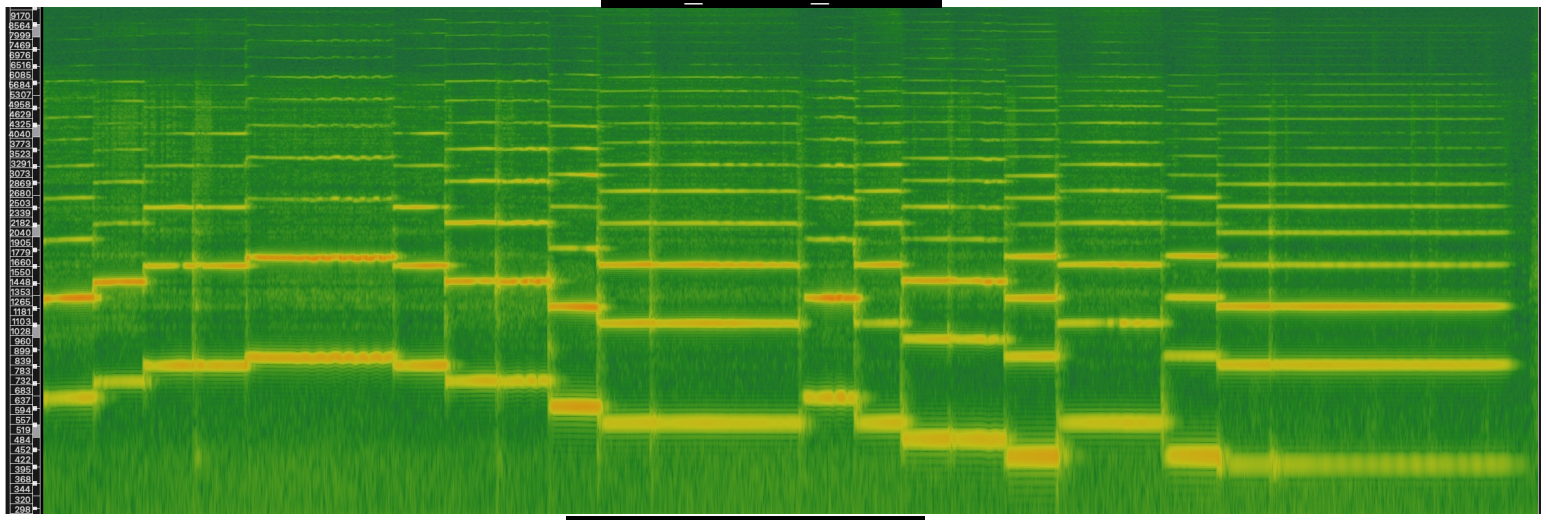
Name: Philip Ross Signature:  Date: 11/22/2023

ASU IRB IRB # STUDY00018503 | Approval Period 10/2/2023

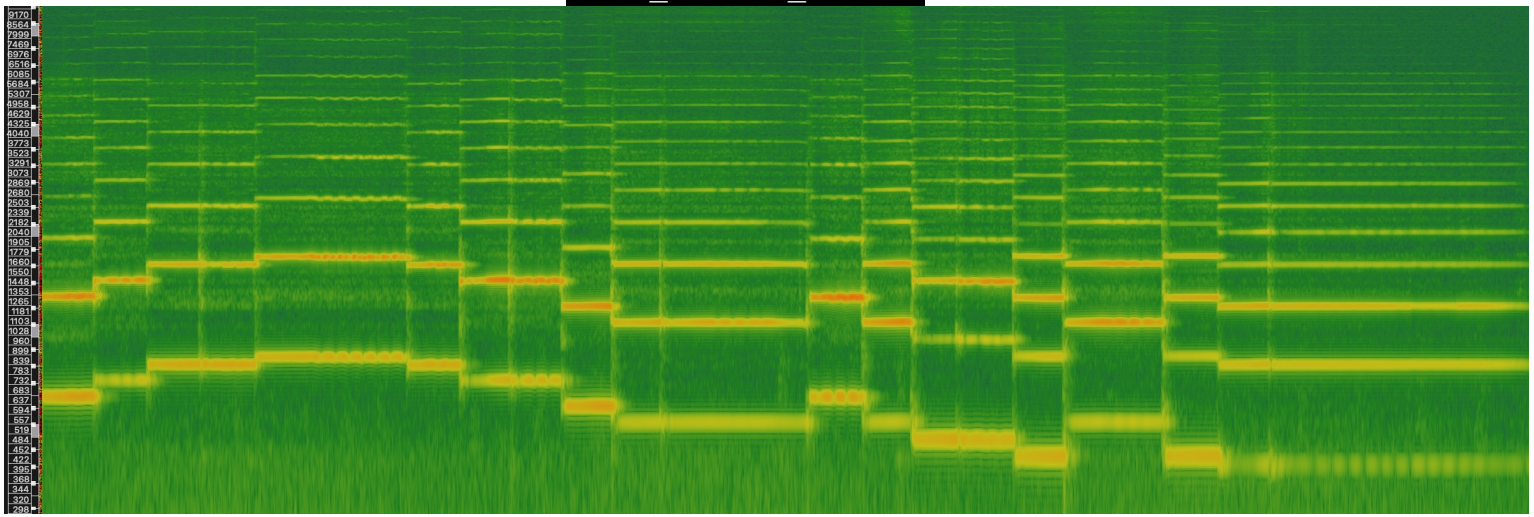
APPENDIX D

OTHER SPECTROGRAMS

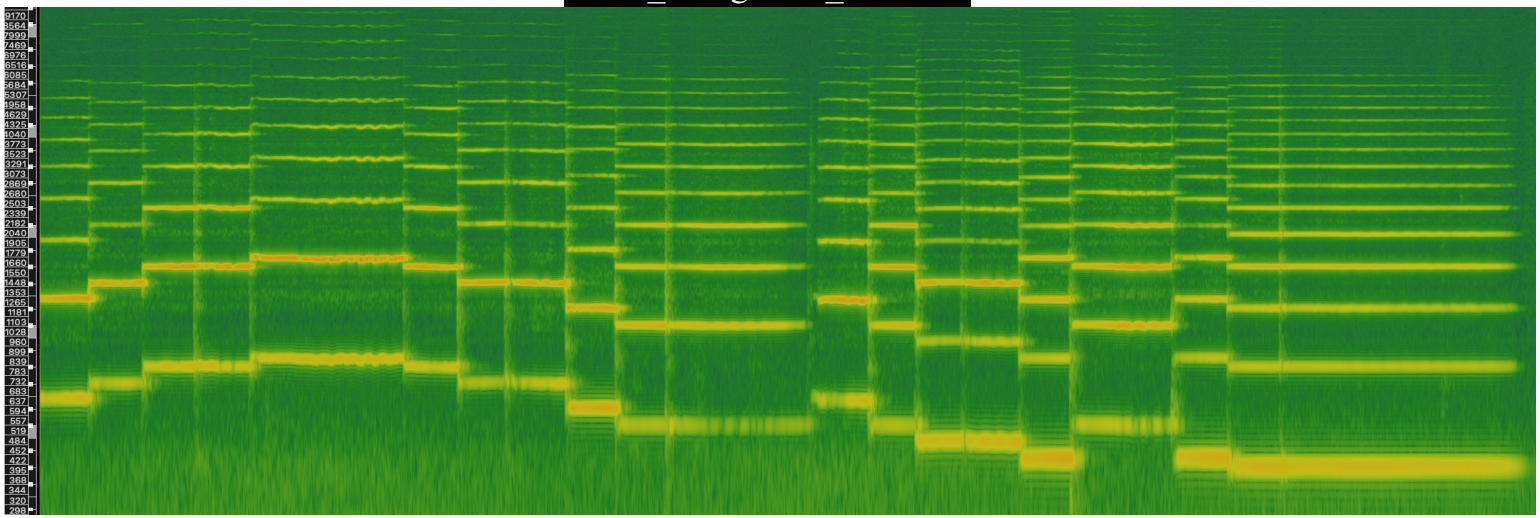
Maes_Arundo_Barber



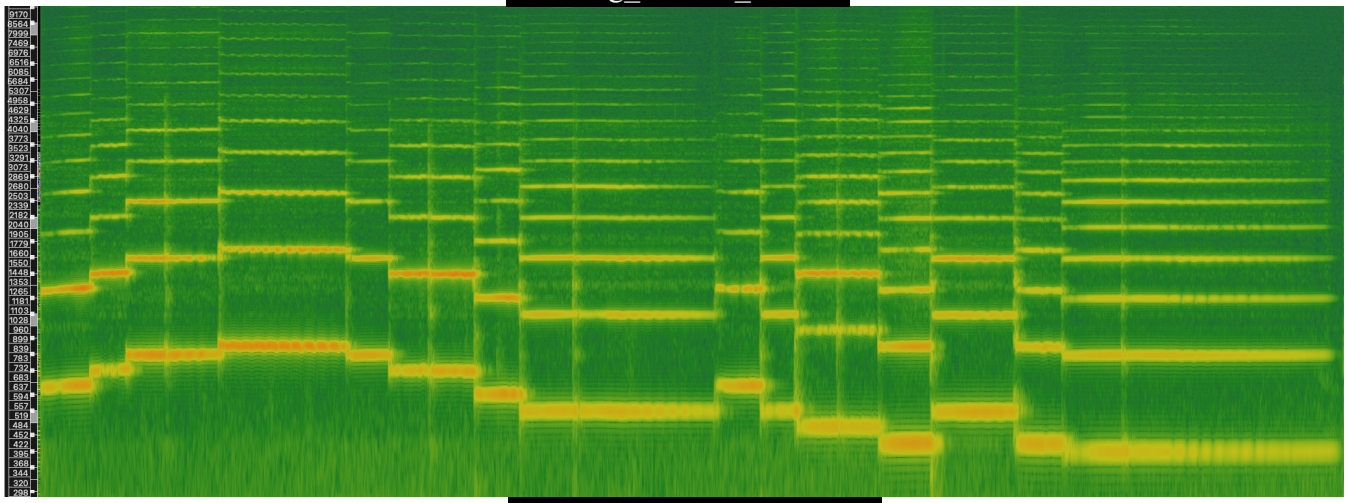
Maes_Bamboo_Barber



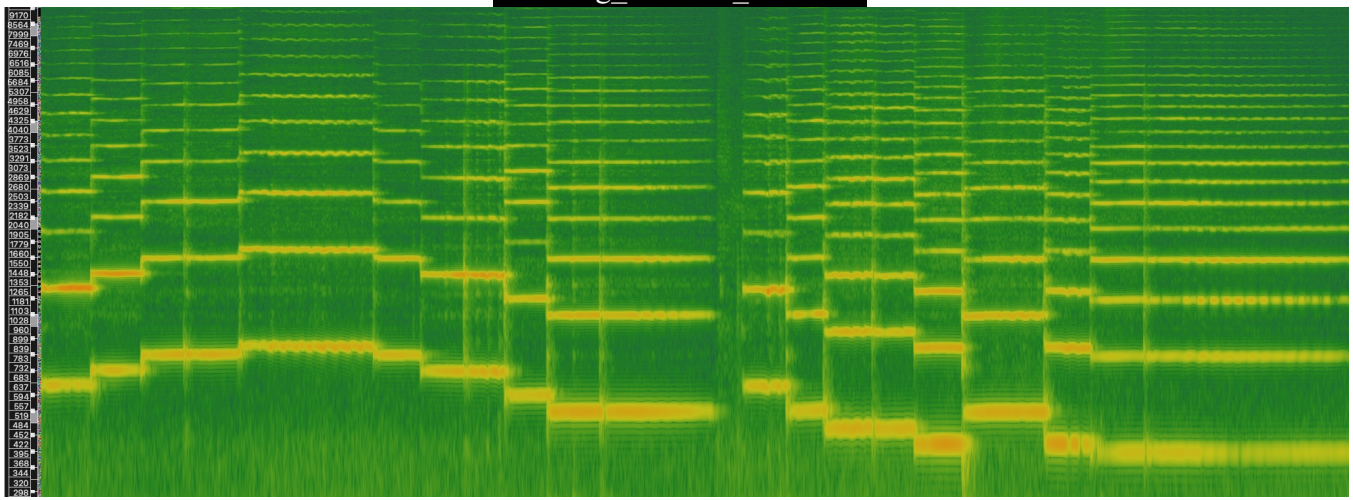
Maes_Phragmites_Barber



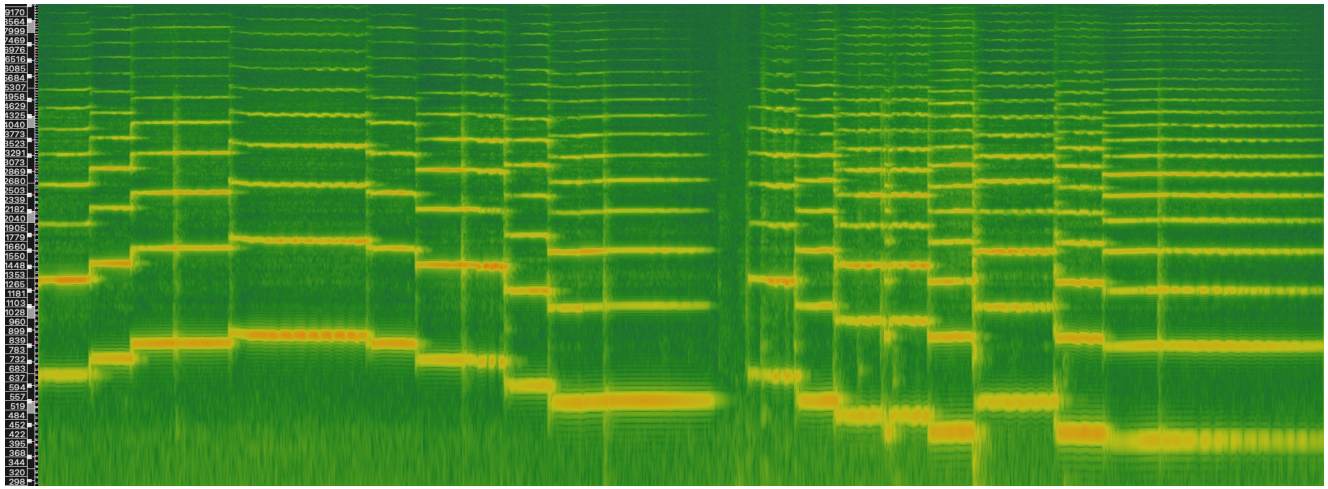
Schuring_Arundo_Barber



Schuring_Bamboo_Barber



Schuring_Phragmites_Barber



APPENDIX E

GLOSSARY

TERM	DEFINITION
angiospermous	any of a class (Angiospermae) of vascular plants that have male and female reproductive structures enclosed in a flower, that have seeds which arise from ovules contained in the ovaries, and that produce dry or fleshy fruits after double fertilization: flowering plant
cellulose	a polysaccharide $(C_6H_{10}O_5)x$ of glucose units that constitutes the chief part of the cell walls of plants, occurs naturally in such fibrous products as cotton and kapok, and is the raw material of many manufactured goods (such as paper, rayon, and cellophane)
clumping	a compact mass: to form clumps
composite	a solid material which is composed of two or more substances having different physical characteristics and in which each substance retains its identity while contributing desirable properties to the whole: a structural material made of plastic within which a fibrous material (such as silicon carbide) is embedded
cotyledon	the first leaf or one of the first pair or whorl of leaves developed by the embryo of a seed plant or of some lower plants (such as ferns)
culm	a monocotyledonous stem (as of a grass or sedge)
ecotype	a population of a species that survives as a distinct group through environmental selection and isolation and that is comparable with a taxonomic subspecies
fiber caps	Homogenously thick-walled fibers resulting in stiff stem at the periphery, providing high flexural stiffness to the stem
fibril	a small filament or fiber: such as root hair
germinate	to cause to sprout or develop
herbaceous	having little or no woody tissue and persisting usually for a single growing season: having the texture, color, or appearance of a leaf
hybrid	an offspring of two animals or plants of different subspecies, breeds, varieties, species, or genera
internode	an interval or part between two nodes (as of a stem)
irrigation	the watering of land by artificial means to foster plant growth
laminae	a thin plate or scale; the expanded part of a foliage leaf as distinguished from the petiole: BLADE (laminar, adjective)
leaf sheath	an investing cover or case of a plant or animal body or body part such as the lower part of a leaf when surrounding the stem
lignification	to convert into wood or woody tissue
lumen	the cavity of a tubular organ or part, the bore of a tube (as of a hollow needle or catheter)
lysigenous cavities	type of cavity formed in the bodies of plants that form due to the breakdown of certain cells
microfibril	a fine fibril, especially one of the submicroscopic elongated bundles of cellulose of a plant cell wall
monocotyledonous	any of a class or subclass (Liliopsida or Monocotyledoneae) of chiefly herbaceous angiospermous plants having an embryo with a single cotyledon, usually parallel-veined leaves, and floral organs arranged in cycles of three
node	a discrete mass of one kind of tissue enclosed in tissue of a different

	kind: a point on a stem at which a leaf or leaves are inserted
parallel venation	an arrangement or system of veins (as in the tissue of a leaf or the wing of an insect)
parenchyma	a tissue of higher plants that consists of thin-walled living photosynthetic or storage cells capable of division even when mature and that makes up much of the substance of leaves and roots, the pulp of fruits, and parts of stems and supporting structures
perennial	persisting for several years usually with new herbaceous growth from a perennating plant
phloem	a complex tissue in the vascular system of higher plants that consists mainly of sieve tubes and elongated parenchyma cells usually with fibers and that functions in translocation and in support and storage
pith	a usually continuous central strand of spongy tissue in the stems of most vascular plants that probably functions chiefly in storage: the soft or spongy interior of a part of the body
rhizomes	a somewhat elongated usually horizontal subterranean plant stem that is often thickened by deposits of reserve food material, produces shoots above and roots below, and is distinguished from a true root in possessing buds, nodes, and usually scalelike leaves
riparian	relating to or living or located on the bank of a natural watercourse (such as a river) or sometimes of a lake or a tidewater
shoot	a sending out of new growth or the growth sent out such as a stem or branch with its leaves and appendages especially when not mature
taxonomy	the study of the general principles of scientific classification especially orderly classification of plants and animals according to their presumed natural relationships
tracheid	a long tubular pitted cell that is peculiar to xylem, functions in conduction and support, and has tapering closed ends and thickened lignified walls
transverse	acting, lying, or being across: set crosswise
vascular bundle sheath	a compact layer of commonly parenchymatous cells forming a sheath around a vascular bundle
vascular system	the part of the body of a vascular plant that is made up of vascular tissue (vascular: of, relating to, or affecting the channel for the conveyance of a body fluid, such as blood of an animal or sap of a plant, or a system of such channels)
xylem	a complex tissue in the vascular system of higher plants that consists of vessels, tracheids, or both usually together with wood fibers and parenchyma cells, functions chiefly in conduction of water and dissolved minerals but also in support and food storage, and typically constitutes the woody element (as of a plant stem)
frequency	the number of complete oscillations per second of energy (such as sound or electromagnetic radiation) in the form of waves
nominal frequency	an ideal frequency with zero uncertainty
spectral centroid frequency	measure of the amplitude at the center of the signal distribution over a window calculated from the Fourier transform frequency and amplitude information

SOURCES FOR GLOSSARY

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BIOGRAPHICAL SKETCH

Kelsey Amber Maes earned her Doctor of Musical Arts degree from Arizona State University in May 2024, completing the Instrumental Music Performance program in exactly two years while concurrently working on her Music Theory Pedagogy Certificate. She previously received her master's degree from Arizona State University and her bachelor's degree from the University of Illinois at Urbana-Champaign. In her time at Arizona State University, she was an oboe studio teaching assistant and a music theory and aural skills teaching assistant. She is a member of the International Double Reed Society and the College Music Society. Kelsey competed at the 2023 Coltman Chamber Music Competition and the 2023 Fischoff National Chamber Music Competition being awarded as a semifinalist and quarterfinalist, respectively. She also has been a substitute in a range of orchestras across the country including the Millikin-Decatur Symphony Orchestra, the Danville Symphony Orchestra, the Champaign-Urbana Symphony Orchestra, the Scottsdale Philharmonic Orchestra, the Chandler Symphony Orchestra, the Gilbert Symphony Orchestra, Symphony of the Southwest, and West Valley Symphony Orchestra. In July 2024, Kelsey will give a lecture on this research paper at the International Double Reed Society Conference at Northern Arizona University. Her professional career goals involve further research into alternative natural materials for oboe reeds, pedagogical research in performance and music theory on effective teaching methods for neurodivergent and disabled students, and writing an English horn etude book like 48 Famous Studies by W. Ferling. She also has an extensive garden and plant collection. Her obsession with plants is what motivated her to write this research paper.