Doublepipe Reeds: *Phragmites*, Straw, and Data-Logging for Distributed Reed Research

Marco Sciascia
Lotos Lab Limited (instruments)
marco@lotos-lab.com

Barnaby Brown
Royal Conservatoire of Scotland
Lotos Lab Limited (learning experiences and performances)
barnaby@lotos-lab.com

Abstract

This article focuses on some questions that fundamentally shape the revival of ancient double-pipes. These surround the choice of material used for reed-making, interrogating what ancient Greek sources, specifically Theophrastus, report in this regard. These testimonies are interpreted through the lens of our own experience as reed makers and performers of ancient doublepipes, comparing the results obtained from culms of different species, growing locations, and harvesting times. Issues that negatively influence the research aiming to develop reliable reconstructions of ancient reeds are discussed. These include *ad hoc* gathering of data, less than rigorous analysis, and knowledge silos prone to bias. This leads the authors to propose a method of cataloguing culm harvests and manufactured reeds that uses accessible technology to facilitate collaboration and build stronger data with an open science ethos.

Keywords

Double reeds – Reed making – Doublepipes – Aulos – Tibia – Phragmites – Avena

1 Introduction

Doublepipes were played all over the ancient Mediterranean and beyond. Some doublepipes used mouthpieces made from a flattened tube of straw or reed to produce sound. The flexibility of this 'embouchure' type of mouthpiece allows the player to tune the pipes while playing, altering pitch by adjusting lip compression, air pressure, and placement (the degree of insertion into the mouth).

© M. SCIASCIA – B. BROWN, 2024 | DOI: 10.1553/JMA-002-01

It is also possible to articulate the sound using the tongue, separating musical notes with silence. Other doublepipes apparently used mouthpieces made from a tube of harder material into which a vibrating 'tongue' has been cut. This 'non-embouchure' type of mouthpiece – made by slitting rather than squeezing – cannot be tongued by the player or tuned by adjusting lip compression. It lends itself to a style of music constrained by a smaller range of dynamics, pitches, and playing techniques – but (as evidenced by the Sardinian launeddas tradition) these constraints in no way lower the levels of virtuosity or musical complexity possible on the instrument. The embouchure type mouthpiece predominates in archaeological evidence in the period 1500 BCE – 400 CE. The non-embouchure type mouthpiece, although having a wide diffusion in the present, is scarcely attested in antiquity.[1]

We intentionally avoid here the terms 'double reed' and 'single reed' in this binary division of doublepipe instruments in order to avert confusion with 'doublepipe' and 'singlepipe'. We will, however, follow convention by calling the mouthpieces of both types 'reeds' (without forgetting that the Ancient Greek term was *glôttai*, 'tongues'). Like other musical items (e.g. Latin *tibia*, English 'horn', etc.), the English term 'reed' is named after the material used to make it. To avoid ambiguity, reed makers conventionally call the stems from which reeds are made 'cane'. In the direction of the airstream, we call the parts of an ancient double reed as follows: tip, blades, bulge (or onion), waist, stem, and exit. Essential to form the blades, control their behaviour, and protect them when not in use are reed caps; these fit over the tips, press the blades together, and since at least the Hellenistic period were tied in twos, which helps to keep a good pair of reeds together. Reeds are made from internodes cut from culms that are harvested, dried, and prepared in ways that have changed significantly over time. All these technical terms are illustrated in Figure 1, which shows a half-made 'yoke' of reeds.

In this article, we will make frequent use of botanical terms: 'epidermis' for the outer skin, 'cortex' for the harder fibres below the epidermis, 'xylem' for the softer fibres below the cortex, 'internode' for the section between two nodes, 'leaf-sheath' for the tubular part of the leaf that encases the stem, and 'culm' for any stem with a jointed appearance and hollow internodes.[2] The term 'culm' is particularly useful in technical discussions of reed making because it includes oat, barley, and wheat – species excluded by the word 'cane' – and because 'stem' generally denotes the short tubular part of a reed below the waist binding.

We will use the term 'yoke' in a technical sense, specific to the field of doublepipes, for a working pair of reeds that is subjugated and conventionally tied together using a pair of reed caps.[3] Like

[1] A thorough examination of Hellenic evidence for both reed types concludes that non-embouchure reeds "did not belong to the cultural contexts typically represented in elite discourse" (Wysłucha and Hagel 2023: 398). We introduce the labels 'embouchure' and 'non-embouchure', shifting focus from how reeds are manufactured to how their sound can be manipulated (or not) by the lips of the player, to mitigate the problem of the 'single reed' category being unhelpfully diverse.

[2] We model our usage on Shtein et al. 2021: 3–4.

[3] Several fourth-century BC vases show a string linking the two pipes together, presumably tied to reed caps. Examples include Melbourne NVG D17-1972, Naples 80084, Naples 9015 (cf. Naples 111473), Taranto 28246, and Vienna IV 1009. See Wysłucha and Hagel 2023: 377.

Figure 1: Pair of reeds for a "Megara" aulos in mid-manufacture, 30 August 2019, made by Barnaby Brown using *Phragmites australis* harvested on Camí de Can Alegria, Palma de Mallorca, 4 July 2019. Top to bottom: Internode with leaf-sheath attached; internode with leaf-sheath removed and wrinkling (useless for reed making); root-end reed with unscraped stem, waist binding, bulge, and scraped blades (removing epidermis and cortex); tube partially scraped to make the partner reed, retaining the flower-end node at the reed exit; driftwood reed caps to 'educate' and protect the blades; offcut showing wall thickness of 1.1–1.2 mm. External tube diameter 13.0–13.5 mm; waist internal diameter 4.5 mm; length of scrape 23 mm; tip to top of waist binding 34 mm; total reed length 97 mm. For further details and images, see Brown 2019. © B. Brown.

'reed', this meaning of 'yoke' is derived by a shift from its basic field of reference and carries a connotation shared with the ancient term, *zeûgos*, which was used by Greek doublepipers in the fourth century BC and basically means 'a coupling'. The craft of reed-making was called *zeugopoiḯa*, literally 'coupling-making'.[4]

In 2018, when the aulos revival was at an earlier stage, we wrote: "The value to society of Very Early music lies more in enriching the present than in illuminating the past".[5] Our view has changed. It is now clear that embedding practical experiments (or at least the insights of specialist practitioners) in the design and conduct of research does not necessarily lower the quality of the science when developing interpretations of instrument finds; on the contrary, it may help scholars interpret available evidence and find solutions that may not be obvious based on evidence alone.[6]

Obviously, the validity and effectiveness of any practical experiment aspiring to advance research in the field of doublepipes depends on the use of reeds that closely correspond to ancient evidence. Being very fragile, few reeds survive. Fortunately, those that do (or did before their loss

4 Wysłucha and Hagel 2023: 391–2; cf. below, pp. 13 and 21. Reed makers were also called *glōttopoioí* (cf. Pollux 2.108; 4.71; 7.153).

5 Brown and D'Angour 2018: 7.

6 Historically, involving practitioners in research has been fraught with problems; for discussion and eight recommendations, see Brown and D'Angour 2018: 5–8.

in the modern era), are consistent with much of the available iconographic evidence (paintings, relief carvings, and mosaics) and with the singular outstanding item of literary evidence we have in Theophrastus' account of the procedures preparing cane for reed making. Although widely read, Theophrastus' *Historia Plantarum* ("Enquiry into Plants") poses interpretational difficulties in places, leading to competing readings and misapprehensions of crucial passages.[7] In many ways, the present article is fundamentally a report of what we learned in wanting to follow Theophrastus to the letter but realising, circling back to the text with the benefit of experience, that this is not so easy. In the following, we will begin with an analysis of the critical portions of Theophrastus' text, looking into some technical, botanical, and manufacturing details that previous translations failed to fully address. We do this by evaluating the results of fieldwork and practical experiments conducted between 2016 and 2024, and by integrating the sensitivities and concerns of linguists with those of a reed maker and a doublepipe teacher funded by patrons desirous of instruments that are rigorously evidence-based. We will then consider the materials from which doublepipe reeds are made, suggesting that straw merits more attention than it has hitherto received; and conclude with a mechanism designed to make this particular endeavour easier, raising the quality, accessibility, and trustworthiness of historically accurate doublepipe reeds.

2 *Auletikos kalamos* according to Theophrastus

In the longest passage of ancient literature devoted to aulos reeds, Aristotle's student, Theophrastus of Eresos, describes a species of cane called *auletikos* (*Historia Plantarum* 4.11). Its identification with anything currently found in the Mediterranean is problematic. Until recently, makers of experimental ancient reed reconstructions have been using *Arundo donax* – a species widespread in the Mediterranean for millennia and commonly utilised in recent centuries by makers and players of bagpipes, oboes and clarinets.[8] The choice of *Arundo donax* was expedient as it can be acquired from suppliers in pre-processed forms, commercially grown, cured, and prepared to meet the requirements of woodwind instruments with large player communities. However, scholars have long noted that details in Theophrastus' passage speak against the identification of *Arundo donax* as the material of ancient reeds, leading to another species native to the region, *Phragmites australis* (=*communis*), to be suggested instead. [9] Although *Phragmites* is indeed a stronger candidate

[7] For instance, some researchers suggested that the passage describes the making of single reeds rather than double, see Becker 1966: 58; Steinmann 2021: 36–9.

[8] On the ancient distribution of *Arundo donax*, see Hardion 2014.

[9] The 1994 doctoral thesis of Stelios Psaroudakēs devotes a section to the surviving Greek terminology relating to aulos design and the interpretation of Theophrastus' account of auletic cane processing. Psaroudakēs (1994: 357–8; 500–501) was troubled by the assumption that the *auletikos* should be identified with *Arundo donax* (a position echoed by our reed-making mentor, Robin Howell, in personal communications from May 2016 – March 2018). He argued that, based on Theophrastus' text, the choice between *Arundo* and *Phragmites* is not straightforward, as both modern cane species display a combination of features that goes against the description of *auletikos kalamos*. On the whole, Psaroudakēs considered that the case for identification with *Phragmites australis (= communis)* would be superior, were it not for the assertion by Tutin (1980) that its culms do not overwinter.

than *Arundo*, its identification as Theophrastus' *auletikos* is complicated by the fact that the species exhibits significant genetic, morphological, and cytological variations.[10] We will evaluate the evidence for *Arundo* and *Phragmites* in the following section. But before we do so, it should be pointed out that it is possible that Theophrastus' report on the cane processing procedure comes from a specific reed maker informant who acquired his skills from his master as part of the craftsmanship transmission process. It cannot be ruled out that other reed-makers operating at that time may have used different techniques or plant species specific to their inherited schools of practice or as result of innovation. We should be cognizant of the fact that Theophrastus' account on processing reed cane is ultimately time and place specific, describing reed-making procedures presumably used by a specific, anonymous fourth-century Greek craftsman using local species and variants growing at that time around Lake Copais.

Figure 2: Reedbeds of *Phragmites australis* (foreground, with drooping panicles) and *Arundo donax* (background), growing near Lake Vadimone, Orte, Italy, September 2023. © M. Sciascia. Cf. Figure 6.

According to Theophrastus, there are two species of cane:[11]

> Τοῦ δὴ καλάμου δύο φασὶν εἶναι γένη, τόν τε αὐλητικὸν καὶ τὸν ἕτερον· ἓν γὰρ εἶναι τὸ γένος τοῦ ἑτέρου, διαφέρειν δὲ ἀλλήλων ἰσχύϊ ⟨καὶ παχύτητι⟩ καὶ λεπτότητι καὶ ἀσθενείᾳ· καλοῦσι δὲ τὸν μὲν ἰσχυρὸν καὶ παχὺν χαρακίαν τὸν δ᾽ ἕτερον πλόκιμον· (4.11.1)
>
> They say there are two kinds of cane [*kálamos*], the auletic [*aulētikón*] and the other; the other cane, they say, constitutes a single species internally differentiated by strength, ⟨thickness,⟩ tenuity and weakness. If strong and thick they call it stake-cane; but the other type they call weaving-cane.

Based on this passage, the "other cane" could perhaps be identified as *Arundo donax*, as it is described as strong and thick enough to be used as stake-cane. This certainly excludes *Phragmites*, which is too flexible and quick to rot to be useful as a stake. A *Phragmites* stem is characterised by a thin xylem tissue layer, which makes it more delicate and flexible, easier to squeeze flat and rendering a *Phragmites* reed more responsive to lip pressure and diaphragm support, which allows the

[10] On the variation among *Phragmites* subspecies, see Sturtevant et al. 2024; Kew 2024 (*Phragmites australis*); Lambertini et al. 2012; Hansen et al. 2007.

[11] For all the passages from Theophrastus, we use the edition by Hort (1916). The translations are a collaborative effort, building on those by Andrew Barker (1984), Stelios Psaroudakēs (1994), and Stefan Hagel (unpublished, kindly shared with us by the author).

Figure 3: Secondary growth either side of the tenth internode of a culm, green under the leaf-sheaths, cut from a stand of *Phragmites australis* on the banks of the river Gravina di Matera, Italy, 21 February 2024. © B. Brown. Cf. Video 1.

player to achieve a greater variety of pitch and timbre effects. An *Arundo* stem, on the other hand, is stiffer with a thicker xylem tissue layer, which certainly helps to maintain a stable pitch but also makes the tube more susceptible to cracking when it is squeezed flat to form the blades. Figure 2 and Figure 6 show the difference in the flower, or panicle, and Video 1 shows the difference in secondary growth habit, comparing stems of *Phragmites* and *Arundo* growing in Matera in February (see also Figure 3).

As with *Phragmites*, there is an enormous variety of strength and thickness to *Arundo donax*. The thinner culms that grow in the middle of an established stand, stretched by searching for light and as a result more flexible, are split and woven to make mats and baskets in many Mediterranean communities. Thicker-walled *Arundo donax* would lend itself to the manufacture of aulos *bombykes* (the body of the instrument with fingerholes), but although the species is widely used in living piping traditions throughout the Mediterranean, Theophrastus reports that *auletikos* was also used for the bodies, not the other cane (see the discussion of *bombykes* below).

Botanically, the description of Theophrastus presupposes a non-herbaceous perennial habit for *auletikos*, as may be seen in the description:

> γίνεται δὲ ὅταν ἐπομβρίας γενομένης ἐμμένῃ τὸ ὕδωρ δύ᾽ ἔτη τοὐλάχιστον, ἂν δὲ πλείω καὶ καλλίων. (4.11.2)
>
> It grows whenever there is an abundance of rain and the water remains for at least two years; if water remains longer [πλείω= more years], it grows even better.

According to this passage, in order to thrive, the *auletikos* species requires constant proximity of water. We have found usable *Phragmites* cane close to larger water bodies, for instance, rivers and lakes, while reedbeds with less access to water produce lower and thinner cane stems, unsuitable for reed making. *Arundo*, on the contrary, easily adapts to drier conditions, thriving in soil far from water sources, where its roots retain water for a longer period of time even when it vanishes from the ground surface. In such conditions it is able to grow very tall, in some cases reaching 5 metres.

Figure 4: Cross sections showing variability in the thickness of walls, peripheral cortex fibres, and inner xylem tissue of *Arundo donax* and *Phragmites australis* growing in different environmental conditions. Left to right: Sardinian *Arundo* selected for a pipe body; *Phragmites* harvested at Lago di Nemi, Rome, at Calore Irpino, Benevento, and at Lago Vadimone, Orte. © M. Sciascia.

This effectively excludes it from consideration, because in Theophrastus' account of the *auletikos* species, the depth of surface water makes a significant difference:

> φασὶ γὰρ καὶ δοκεῖ βαθυνομένης τῆς λίμνης αὐξάνεσθαι τὸν κάλαμον εἰς μῆκος, μείναντα δὲ τὸν ἐπιόντα ἐνιαυτὸν ἁδρύνεσθαι· (4.11.3)
>
> They say, rightly it seems, that the cane grows to the right length when the lake becomes deep, and if the cane remains, it matures in the following year.

We posit that the condition "if the cane remains" refers to the partial dieback of the aerial parts of *auletikos*. While both *Arundo* and *Phragmites* are rhizomatous perennials, *Arundo* culms overwinter much more successfully than *Phragmites* culms, which generally die back completely. Our field observations, however, show that this habit is not universal. Under certain environmental conditions, *Phragmites* culms can produce secondary growth and overwinter, growing thicker in the second year. [12] However, this habit is exceptional and has not been reported in the *Phragmites* literature that has come to our attention, but is evident in Figure 3 and Video 1.

For both *Arundo* and *Phragmites*, the longest stems can be found in the heart of a reedbed, where they grow the tallest in search of sunlight. The culms most suitable for reed-making are the ones without visible defects, perfectly round, with appropriate diameter and long internodal sections. Theophrastus goes on to note the following dimorphism of *auletikos*:

> καὶ γίνεσθαι τὸν μὲν ἁδρυθέντα ζευγίτην, ᾧ δ᾽ ἂν μὴ συμπαραμείνῃ τὸ ὕδωρ βομβυκίαν.
>
> In mature form it becomes reed-cane [*zeugítēs* – 'pair-cane', i.e. for pairs of aulos reeds], but those canes where the water does not stay become pipe-cane [*bombukías* – 'cane for tubes', i.e. the pipes with fingerholes into which the reeds are inserted].[13]

During our harvesting excursions, we were able to note differences in characteristics of culms, which apparently depended on water conditions during their growth. From our observations har-

---

[12] Cf. Wang et al. (2006).

[13] Psaroudakēs (1994: 349) believes the text means that the *bombykias* is produced when the lake withdraws at some stage during the growth.

Figure 5: Marco Sciascia and Barnaby Brown harvesting *Phragmites australis* near Lake Vadimone, Orte, September 2018. © B. Brown and M. Sciascia.

vesting *Phragmites* in Paphos, Athens, Palma de Mallorca, Orte, Rome, Benevento, and Matera, Theophrastus' text is most easily harmonised with botanical reality as follows: when there is little rain between May and October, potentially none at all, and the surface water of a lake or river bed recedes, leaving the culms dry at the base, the growth habit of *Phragmites* changes. Compared to culms growing where surface water remains for two summers in a row, these culms have a narrower diameter but greater wall thickness; this makes them less suitable for reeds, more suitable for pipes.

Figure 4 shows the cross sections of one *Arundo* and three *Phragmites* internodes. Second from the left is the first internode of a giant culm, four metres high, that grew 30 cm from the edge of lake Nemi near Rome.[14] It has a thick xylem layer and a diameter of 12 mm; reeds produced from this material require considerable embouchure stamina from players. The third tube was harvested in the riverbed of the Calore Irpino in central Benevento. It has a similar diameter but a much thinner xylem layer. The stand it comes from was growing in the riverbed among pebbles and sand deposits in close proximity to flowing water. Depending on the season of the year, the riverbed fills with water or partly dries out. The culms that grow in these changeable conditions reach medium height and provide material for the production of lighter reeds, well suited for beginner aulos players. The smaller tube of *Phragmites australis* was harvested from a stand growing around Lago Vadimone (see Figure 5), a small lake near Orte. The culms here reach only about 2 metres in height.

14 Lotos Lab harvest ID H0004, co-ordinates 41.720609, 12.701255.

Harvesting in four Septembers (2019 and 2022–2024), we observed that its roots at that time of the year were entirely immersed in water, but the ground surface was basically dry. To find taller culms of larger diameter, we had to descend into a ditch where water was draining out of the lake, and cut stems growing in the rich silt beneath a few centimetres of running water. On the higher ground, where it was more convenient to harvest, the stems were thinner, not exceeding 9 mm in diameter, with a harder cortex. The fact that different environmental conditions produce culms of such differing characteristics, even at the same site, combined with its high genetic variability, promiscuity, and invasiveness, mean that further taxonomic work would be required to provide clarity across the biogeographic lineages of the *Phragmites* genus.[15]

Theophrastus provides us with further clues that may help to identify the *auletikos* cane:

> Διαφέρειν δὲ τῶν ἄλλων καλάμων ὡς καθʼ ὅλου λαβεῖν εὐτροφίᾳ τινὶ τῆς φύσεως· εὐπληθέστερον γὰρ εἶναι καὶ εὐσαρκότερον καὶ ὅλως δὲ θῆλυν τῇ προσόψει. καὶ γὰρ τὸ φύλλον πλατύτερον ἔχειν καὶ λευκότερον τὴν δὲ ἀνθήλην ἐλάττω τῶν ἄλλων, τινὰς δὲ ὅλως οὐκ ἔχειν, οὓς καὶ προσαγορεύουσιν εὐνουχίας· ἐξ ὧν ἄριστα μέν φασί τινες γίνεσθαι τὰ ζεύγη, κατορθοῦν δὲ ὀλίγα παρὰ τὴν ἐργασίαν. (4.11.4)

> They say it generally differs from other cane species by a kind of inherent thriving condition, being fuller [*euplēthēs*], more fleshy [*eúsarkos*], and overall having a feminine appearance. It also has a broader and brighter leaf [*phýllon*], but a smaller plume [*anthḗlē*] than that of the other kinds, some stems having no plume at all; they call these 'eunuch-reeds' [*eunoukhías*]. Some maintain that the best pairs [*zeúgē*] are produced from these stems, though few work out right during the process of manufacture.

Previous translators have rendered *zeúgē* as 'mouthpieces'. This is open to misinterpretation. The Greek word for the working frame that connects two oxen to a plough or carriage is slightly different: *zygón* or *zugós*. In order to convey in translation the sense of a connected pair, we would prefer to render the ancient term *zeûgos* or *zeugítēs* with the English word 'yoke' in its long-attested but now rare meaning of "any pair of people or things".[16] Although not a literal translation, this captures the sense of *zeûgos* more fully by invoking the idea of yoking two animals and gives modern players a one-syllable term with a richer meaning: a balanced pair of doublepipe reeds.

As well as documenting a technical term, this passage presents vital morphological information about the species. *Phragmites* and *Arundo* differ significantly in the size and shape of the blossom, or panicle. *Phragmites* has a shorter, fluffier plume, which droops to one side. Meanwhile, *Arundo* has a longer, erect plume that opens out evenly in all directions when mature (Figure 6). We have yet to investigate the properties of the flowerless stems which are mentioned in the last sentence of this passage. The flowerless culms stand out as taller and stronger in the wild, but become indistinguishable from the others as soon as the drooping panicles have been trimmed off,

[15] A helpful factsheet distinguishing native and introduced lineages in North America is Sturtevant et al. 2024, https://nas.er.usgs.gov/queries/greatlakes/FactSheet.aspx?Species_ID=2937.

[16] https://www.oed.com/dictionary/yoke_n, meaning II.7.b, with citations from 1425.

Figure 6: Left: panicles of *Phragmites australis*. Right: panicles of *Arundo donax*. Lago di San Liberato, Fiume Nera, Italy, April 2023. © M. Sciascia.

which is necessary to fit harvested bundles in a car. A scientific investigation requires that they be separated from the rest and carefully labelled before the panicles are cut off. Our research on this is in progress, as systematic harvesting only began in September 2023.

3 Preparing cane for reed-making

In this section we will report our experiments in preparing the cane for reed-making, in which we tried to follow the process described by Theophrastus as closely as possible. The first step is drying the cane without removing its protective leaf sheaths:

> ἡ δ᾽ ἐργασία γίνεται τοῦτον τὸν τρόπον· ὅταν συλλέξωσι τιθέασιν ὑπαίθριον τοῦ χειμῶνος ἐν τῷ λέμματι· τοῦ δ᾽ ἦρος περικαθάραντες καὶ ἐκτρίψαντες εἰς τὸν ἥλιον ἔθεσαν. (4.11.6)
>
> The manufacturing is done in the following manner: once they have harvested [the aulos cane], they put it in the open [ὑπαίθριον = under the sky] in its leaf sheaths (?) [λέμμα = husk, rind, bark] for the winter. In the spring, after thoroughly cleaning [περικαθαίρω = clean all around] and scraping it [ἐκτρίβω = rub out, destroy, wear out, polish], they place it in the sun.

The leaf sheaths and leaf blades provide a coating and cushioning that protect the culm from scratches, dents, dust, bird droppings, and other hazards of winter storage. The Greek ὑπαίθριον implies the open air, i.e., not under any kind of roof, so the leaf sheath also protects against rain. In the spring, the protective leaf casing is removed and the water-repellent outer layers of the stem are scraped away – at a minimum the shiny epidermis, and probably the outer cortex too – to reduce the risk of cracks when forming the blades. This leaves the softer internal fibres exposed to the sun. In our experiments, we have generally left the outer fibre ring immediately under the cortex, with its closely-packed vascular bundles, undisturbed in order to avoid exposing the paler ground tissue, which has larger vascular bundles spaced further apart. The extra effort involved in removing the outer fibre ring does not appear to produce any advantage, only a loss of strength and degradation of the exterior finish. A possible exception to this may be made when scraping the lowest internodes, or an unusually hard culm. Removing more material will soften the reeds and may increase success rate.

We find that letting sunlight cure the xylem layer beneath the cortex is an efficient way of refining the evenness of the scrape and exposing defects, such as dead fibres, which are often darker in colour. Over time and under strain, these develop into cracks that can be catastrophic for the reed if they occur in the vibrating part of the blade. A crack at the tips will accelerate the reed's demise if not end its life immediately. A longer period in the sun allows lower-quality internodes to be discarded, saving time (and heartache) in the long run. The lost labour of manufacturing and breaking in reeds that develop cracks before reaching maturity is significantly more costly than curing scraped culms in the sun for six weeks.

At this point in the process, the culms are still intact. Theophrastus continues:

> τοῦ θέρους δὲ μετὰ ταῦτα συντεμόντες εἰς τὰ μεσογονάτια πάλιν ὑπαίθριον τιθέασι χρόνον τινά.
>
> In the following summer, they cut it into internodes [μεσογονάτια = between the joints] and place these once more outside in the open air for some time.

Following these instructions, we harvested stems of *Phragmites australis* in September 2022 and 2023, left them to dry in their leaf sheaths over the winter, and removed the leaves in March. We then removed the tough outer skin by vigorously scraping it away with a knife (Theophrastus uses the verb ἐκτρίβω to describe this process which may denote rubbing as well as perhaps sanding or polishing), then left the culms out in the sun. Exposure to ultraviolet and other rays has two noticeable effects on the xylem tissue. First, the contrast in colour between different depths of scrape increases, making it easier to finish consistently to the same depth. Secondly, the loss of moisture produces a slight shrinking of the xylem vessels, so that any remains of the outer fibre ring stand out, easier to see and to remove. If the scraping has gone deeper, sunlight will also expose the fibres surrounding the larger vascular bundles that increase in size and reduce in density towards the hollow interior. In other words, leaving scraped culms in the sunshine (presumably turning them occasionally so that all sides are evenly 'cooked') makes it easier to achieve a consistent wall thickness. This is crucial to achieve the desired response when the reeds are eventually broken in by the player, a process familiar to modern reed players.

After dividing the culms into internodes, leaving them outdoors allows warm summer air to penetrate the interiors of each tube, removing any residual moisture.

> προσλείπουσι δὲ τῷ μεσογονατίῳ τὸ πρὸς τοὺς βλαστοὺς γόνυ· τὰ δὲ μήκη τὰ τούτων οὐ γίνεται διπαλαίστων ἐλάττω.
>
> Each internode retains the node nearer the blossom [βλαστός = shoot, bud, blossom]; their lengths are no less than two palms [8 fingers, roughly 15 cm, or 6 inches].

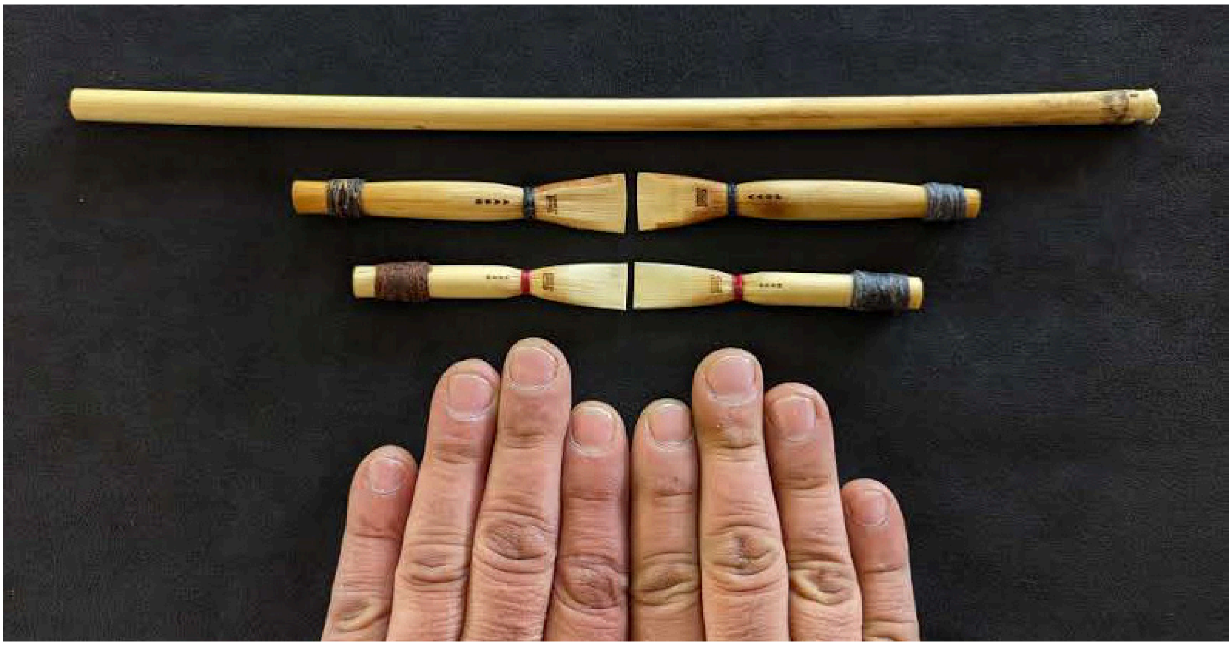


Figure 7: A *Phragmites australis* internode with two 'yokes' (pairs of reeds made from a single internode) suitable for 'Pydna' and 'Selinus' auloi. The 'yokes' are respectively ten fingers and two palms long. © B. Brown.

The term βλαστός (*blastós*) almost certainly refers to the blossom (plume) at the top of the stem. Depending on environmental conditions, the mature stems we harvested have yielded between six and thirteen internodes that are at least two palms in length. This is sufficient for the sixth-century 'Giglio' and 'Selinus' *auloi*, but the 'Pydna', 'Elgin' and 'Megara'[17] *auloi* proved to require longer internodes of nine, ten, or eleven fingers (see Figure 7).[18]

We were initially curious as to why when cutting each culm into sections, it was important to cut above each node ('each internode retains the node nearer the blossom'). Why not cut below the node? Or above and below, removing the node? Is the node nearer the blossom retained permanently, left there throughout the life of the reed? What initially seemed an arbitrary detail to us was apparently important enough to be communicated to Theophrastus by his informant(s) and deemed worthy of transmission by him. To the best of our knowledge, the first practical experiments testing possible answers to these questions began in 2017, when Barnaby Brown commissioned Robin Howell to produce a stock of reeds for Hellenic *auloi*: a sufficient quantity to permit experimentation. At the time, no-one in the doublepipe revival apart from Chrēstos Terzēs and Stefan Hagel was making 'Theophrastian yokes' (ζεύγη): pairs of reeds squeezed from a single internode with the blades kissing at the midpoint. If made any other way, Theophrastus cautions, the reeds will not sound well together. He saves this nugget of cultural wisdom for the conclusion:

---

17 On the 'Selinus' fragments, see Bellia 2015; the 'Pydna' aulos, see Psaroudakēs 2008; on the 'Elgin' aulos, see Schlesinger 1939: 411–13; Reichlin-Moser and Reichlin-Moser 2015; on the 'Megara' auloi, see Terzēs and Hagel 2022.

18 There was a significant variation with regard to the length of διπαλαίστων (two palms). In Aegina, two palms was approximately 167 mm or 6.6 inches, whereas in Athens it was about 148 mm or 5.8 inches; cf. *Oxford Classical Dictionary*, 2015, *s.v.* Measures; Hagel 2021b: 428. Evidence that pre-Hellenistic auloi used reeds with long stems is overwhelming, cf. Hagel 2021b: 428–30; 433–35.

Figure 8 Seventeen uncut 'Theophrastian yokes' made by Valentina Grossi and Simone Mulazzani in March 2024, from *Phragmites australis* harvested by Marco Sciascia in Benevento, September 2022. The colour of the waist binding records which internode the 'yoke' is made from (see Table 2 below). © B. Brown.

> Τμηθέντος δὲ δίχα τοῦ μεσογονατίου τὸ στόμα τῆς γλώττης ἑκατέρας γίνεσθαι κατὰ τὴν τοῦ καλάμ τομήν· ἐὰν δὲ ἄλλον τρόπον ἐργασθῶσιν αἱ γλῶτται, ταύτας οὐ πάνυ συμφωνεῖν. (4.11.7)
>
> When the internode is cut in two, the mouth of each reed comes to be at the cut of the cane. If the reeds are manufactured in another way, they are not in good concord, it is said.

When we switched in 2024 to a manufacturing method where we no longer cut the internode before squeezing to form the blades, but rather squeezed while the two reeds were still connected, we found the process to be overwhelmingly advantageous for three reasons. First, it minimises the physical differences between the left and right reeds in the critical area manipulated by the player's lips. Secondly, it reduces the risk of cracks forming during moments of peak stress, such as when the blades fan out as they are flattened. During the days, weeks, or months prior to coming into service, reeds may be stored in a player's case travelling the world; as long as the yoke is left uncut, the longitudinal fibres and vascular bundles at the tips – where the fan is most splayed out, halfway between the waists – are held together laterally by the partner reed (as in Figure 8). And thirdly, forming two blades simultaneously reduces production time significantly. Figure 8 shows a wide range of undivided 'yokes' made for different Hellenic and Roman-era *auloi*, in all cases retaining the node nearest the blossom.

However, the equality between the pairs of reeds produced by this method has a downside. If the pipes held in left and right hands were identical, there would be no problem, but the pitches of the fingerholes differ between the pipes of all surviving *auloi*. Notes of different pitches sounded with identical reeds produces an inequality in the relative loudness of the pipes, with the high pipe tending to overpower the low pipe. If ancient players, like the reconstructionist community, sought to amplify the bass and/or attenuate the shrillness of the treble, they would have ideally found a way to achieve this without compromising the perfect balance between the blades achieved by cutting them from the same internode. The site for adjustment least likely to upset this balance is the opposite end: the reed exit. In 2017, the reeds in our pipes were balanced at best for only a short window of time and perfect 'yokes', working well together, day in day out, were almost unknown. The first 'Theophrastian yokes' shipped from Robin Howell in Toronto and Marco Sciascia in Orte to Barnaby Brown in UK, had no clear markings to reveal which reed belonged in which pipe; this made it impossible to observe another tradition reported by Theophrastus:

> συμφωνεῖν δὲ τὰς γλώττας τὰς ἐκ τοῦ αὐτοῦ μεσογονατίου, τὰς δὲ ἄλλας οὐ συμφωνεῖν· καὶ τὴν μὲν πρὸς τῇ ῥίζῃ ἀριστερὰν εἶναι, τὴν δὲ πρὸς τοὺς βλαστοὺς δεξιάν. (4.11.7)
>
> Reeds [*glôttai*] from one and the same internode, they say, are in concord, but not others; and the one closer to the root is the left-hand, the one closer to the blossom the right-hand.

At the time, our decision on which reed to put in which pipe was made by ear and the wisdom accumulated over generations in a Panhellenic tradition was overlooked or undervalued. Initial progress was made by Howell, who observed that for equal voicing the high pipe always needed a reed that was slightly quieter, or darker in timbre, in order to achieve an optimal balance with the low pipe. For perceptual equality, it follows that the low pipe requires a slightly louder or brighter reed. In the case of an *aulos* 'yoke', visual and material equality does not produce acoustic equality. Reedmakers whose skills were shaped making embouchure reeds for singlepipes (piri, duduk, oboe, bassoon, etc.) attempted to achieve better voicing by making the blades of each reed slightly different, only to find that this threw other aspects of balance out of kilter, such as one reed speaking sooner on a crescendo, stopping earlier on a diminuendo, or (most distressingly) opening faster and becoming harder during a performance. These aspects of balance are unique to the doublepipe and the method of achieving balance reliably had to be rediscovered. The design of a 'yoke' reported by Theophrastus provides the answer as it ensures that the blades could not be more equal.

The process of learning between 2016 and 2024 was one of informal experimentation, exchanging results and evaluating each other's playing. Some of us were able to achieve virtuosic results, consistently in different venues and seasons, through intensive practice. The collective understanding that emerged from this process is that leaving the node on the high pipe reed only, thereby narrowing the exit bore of the reed, corrects the balance of the whole instrument; in other words, neither left nor right pipe overpowers the other. But why should the reed made from the blossom end go in the right pipe, and the reed made from the root end go in the left pipe?[19] There is usually a subtle organic swelling in the lower region of an internode, resulting in a wider bore. Putting the reed with the wider bore in the lower pipe will make it slightly louder, increasing the vibrancy of the bass notes, just as putting the reed with the narrower bore in the high pipe will reduce the stridency of the top notes. But with internodes that are beautifully straight, the effect is slight. We conjecture that ancient players combined the two methods to increase the relative loudness of the low pipe. Neither method sacrifices equality of behaviour at the tips, and together they produce about the right correction, amplifying the bass somewhat, but not too much.

A final point is worth making here in order to save others from repeating our mistakes. Without some handmade mark, or a prominent organic feature like a node, it is difficult to distinguish the left reed from the right. There are therefore two compelling reasons for leaving the node permanently on one reed (rather than cutting it off). One is acoustic: the node quietens the reed by narrowing its bore at the exit. The other is visual: the node makes it easier for players to reliably distinguish which reed is which throughout a 'yoke's' lifetime. Unlike a mark or binding, it does not rub off, fall off, or fade away. We now have compelling answers to all of our questions: retaining the node is a musically effective and labour-saving solution to the balance problem created by putting perfectly equal reeds into pipes of differing pitches, a solution well worth transmitting to students. As with all investigations by practical experiment, however, other solutions are possible and we should remain curious until these findings have been tested by other teams of investigators who see the world differently, and who have the resources to design an experiment that is more rigorous. The most serious limitation to this investigation is the lack of consistent data logging over time, with reeds wandering between instruments and players. The problem of chaotic, inconsistent record keeping with no professional support, training, or leadership in research methodology is a limitation for which we present a low-cost way forward below.

> βέλτιστα μὲν οὖν εἶναι τῶν μεσογονατίων πρὸς τὴν ζευγοποιΐαν ὅλου τοῦ καλάμου τὰ μέσα·
>
> They say that the best internodia for reed-making [*zeugopoiḯa*] come from the middle of the entire cane;

This statement accords with our own experience, finding that the best reeds tend to come from between the third and fifth internodes on shorter stems, or the fourth and seventh internodes on longer stems. Theophrastus then adds:

> μαλακώτατα δὲ ἴσχειν ζεύγη τὰ πρὸς τοὺς βλαστούς, σκληρότατα δὲ τὰ πρὸς τῇ ῥίζῃ·
>
> Those close to the blossom produce the softest reed-pairs [*zeúgē*], those near the roots make the hardest.

[19] Stelios Psaroudakēs (2008; 2020) proposes a 6L-Rule, which we would revise to a 7L-Rule: Longer sections of bone belong to the Longer pipe, which is held in the Left hand, has fingerholes Lower in pitch, has a Left thumbhole displacement, and uses a slightly Louder reed with a Larger internal diameter at the exit.

This is incontestably true: the cortex is invariably harder and thicker in the lower sections, becoming softer and thinner nearer the top. We would add that there is considerable variation between culms, even those growing from the same section of rhizome. The hardness of the first internode on one culm could, for example, match that of the fourth internode on its neighbour.

4 Straw reeds

While doublepipes with internal diameters of 7.5–10 mm, which were played in the Classical and Graeco-Roman periods, certainly used cane reeds made from stems of a matching diameter, other types of materials may have been utilised for the production of reeds for more slender instruments.[20] In the late 19th century, multiple discoveries of pipes in Egyptian tombs, often still equipped with reeds, led scholars to believe that the material generally used for smaller reeds had been straw.[21] In his 1889 catalogue of unearthed Egyptian pipes, Victor Loret reports three straw specimens – two fragments of finished mouthpieces, and one stem presumably stored by the player as raw material for making new reeds – all of which may still survive today (Table 1).[22] A fourth reed, apparently unknown to Loret, is perhaps the only surviving item of a collection of about ten Egyptian reeds held at the Museum of Musical Instruments in Brussels, the materials of which had been identified as cane and straw (Figure 9).[23] As no recent palaeobotanical studies have been conducted on any of these finds, the identification of the material as straw calls for verification, and without any seed-bearing spikes or panicles, it may be impossible to narrow down the species.

Since modern cereals, both domesticated and wild, differ greatly from their ancestors, selecting straw stems whose characteristics match the few fragments preserved in museums presents difficulties. Botanical taxonomies are fluid and may confer a specious tidiness on organic evolution that is not scientifically warranted, especially when chronological and geographical views are widened. In our harvesting experience, looking for suitable culms in the same stands, year after year, it is clear that environmental conditions are critical – nutrients, water, warmth, and sunlight at key growth stages. It appears that we are not hunting down a genetic mutation, or another variety or subspecies, because straw of sufficient diameter is much easier to find in some years than others. However, the cumulative effects of genetic mutations, cross-fertilization, changing climate, and human interference calls for an approach that resists singular solutions. We have conducted our experiments using *Avena sterilis* because it is convenient (growing all around Marco Sciascia's home), plausible (the progenitor of domesticated oat crops, indigenous to Southwest Asia), appears

20 On reed and reed-seat diameters in the Graeco-Roman period, see Wysłucha and Hagel 2023: 383.

21 Baines 1968: 199: "Among the fifty-odd cane pipes found in Egyptian tombs – nearly all of them double-pipe components with three or four holes – many had fragments of straw-like matter adhering to one end, thought to be remains of reeds." Cf. Chappell 1974: 261.

22 Loret 1889: 197–206. The list was updated in a later study: Loret 1913: 17–20. It was incorporated in English into Kathleen Schlesinger's list of extant aulos pipes, see Schlesinger 1939: 419–56. Schlesinger built straw reeds for her facsimiles of Egyptian pipes.

23 Cf. Baines 1968: 193.

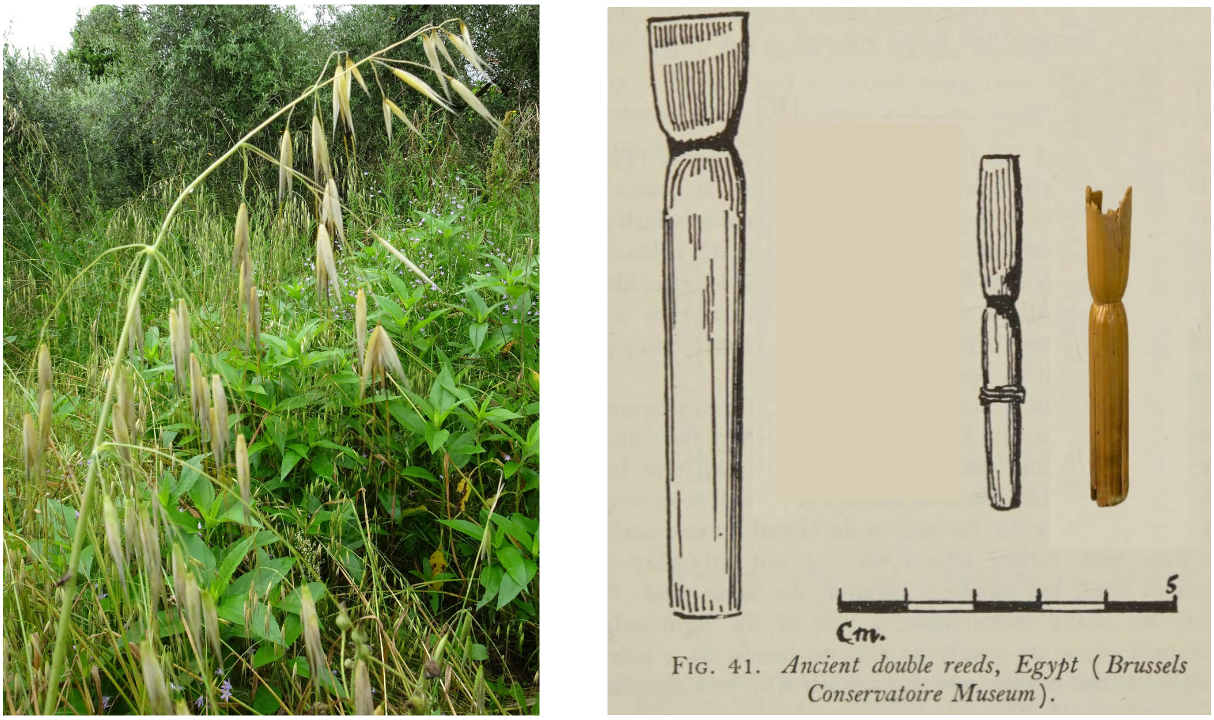


Figure 9: Left: *Avena sterilis* in Orte, Italy © M. Sciascia. Right: drawings of two reeds in the Brussels Museum of Musical Instruments (Baines 1968: 193) and a photo of the only surviving reed, inventory no. 3397. © MIM - Musical Instruments Museum.

museum	inventory number	Loret's 1913 cat. no.	dimensions
Turin, Museo Egizio	11 according to Loret; currently?	20	Diameter: 5 mm
London, British Museum	No number according to Loret; currently EA38166 and EA38168?[24]	33/35	Diameter: 4 mm Length: 31.9 mm
Leiden, Rijksmuseum van Oudheden	I. 476 according to Loret; currently 220?[25]	17	
Brussels, Musiekinstrumentenmuseum	3397 (not mentioned in Loret)		[Diameter: 6mm Length: 53mm][26]

Table 1: Potentially surviving straw reeds in European museums.

[24] It is possible that the find survives with inventory numbers EA38166 and EA38168. Cf. https://www.britishmuseum.org/collection/object/Y_EA38166 [Accessed 23 November 2024].

[25] Schlesinger describes this item in the following way (1911, s.v. Mouthpiece): "A case excavated in Egypt was found to contain two pipes, and in addition five pieces of reed without bore or holes, and three pieces of straw suitable for making double-reed mouthpieces." This description matches a group of finds currently catalogued with inventory number 220.

[26] Dimensions estimated from the drawing reproduced in Figure 9 (far right).

Figure 10: 'Theophrastian yokes' made of *Avena sterilis* harvested in Orte, Italy, June 2023, with internodes of two giant culms (200 cm tall and 7–9 mm wide at the internodal midpoints), harvested a year later in the same location. Clockwise from centre: Reed caps made from birchwood tongue depressors. Five 'yokes' made from internodes of ⌀ 5–9 mm, one uncut, one unsqueezed. Six internodes cured in the shade, cut from a giant culm harvested when slightly green (17 June 2024), 7–8 mm in diameter at the midpoints. Six internodes cured in their leaf-sheaths in full sun for 6 hours (37°C), cut from a giant culm harvested when golden (8 July 2024), 8–9 mm in diameter at the midpoints. Seventeen uncut 'yokes' for 'Lady Maket' pipes, ⌀ 5 mm: six of internal waist ⌀ 2.7 mm (tied with white thread); five of ⌀ 2.3 mm (tied with brown thread); six ⌀ 2.0 mm (tied with black thread). © B. Brown.

to match what we have so far seen of the fragments in museums, and is supported by a literary tradition that we can trace back to Vergil.[27] More rigorous scrutiny of the archaeological evidence and experimentation with other species, circling back and forth between experiments and evidence, re-examining the museum fragments with more experienced eyes, is desirable but beyond the scope of this study.

We have found it best to harvest oat straw just before it turns completely golden, which in central Italy is in the second half of June. Like *Phragmites*, *Avena sterilis* culms have multiple nodes protected by leaf-sheaths, normally seven.[28] Straw of sufficient diameter for Egyptian doublepipes (5–8 mm) and Graeco-Roman auloi (7–9 mm) comes from stems that reach a height of 180–200 cm. This is unusual for any of *Avena*'s thirty accepted species.[29] Rather than curing harvested straw in direct sunlight, which makes it brittle, we have found it better to let the culms dry out more gently, in the shade and in their leaf-sheaths. This keeps it more pliant and, as with *Phragmites*, protects the walls of the internodes from dirt and damage. The results of our experiments show that *Avena sterilis* is a good candidate for making reeds for a wide variety of instruments (Figure 10). Compared

[27] *Avena* is the pipe of Vergil's bucolic, famously featuring in the opening verses of his first Eclogue.

[28] A video of ours (Brown 2024) shows culms of exceptional length and girth being processed, and the resulting reeds being played.

[29] Kew 2024, *Avena*.

Figure 11: Making 'Theophrastian yokes' in straw – tying a waist around a knitting needle of ⌀ 2.0 mm, using coloured thread to record different internal waist diameters. Cambridge, 19 May 2024. © B. Brown.

to *Arundo* and *Phragmites*, *Avena* 'yokes' are quick and easy to make, become playable in a fraction of the time, and as far as we can tell last just as long. The significant factors determining the life expectancy of a reed, in our experience, are care on the part of the reed owner (avoiding accidents and mould) and selection on the part of the reed maker (in the field and in the workshop).

The reeds we make for reconstructions of ancient Egyptian pipes, including the so-called Lady Maket pipes found in El Lahun, Egypt (now held in the Museum of Musical Instruments in Berlin), have provided an opportunity for iterative research (Figure 10, Figure 11, and Figure 12). Our current use of oat straw is provisional, building up expertise before a closer examination of original straw reed fragments, which we intend to accomplish by eye and electron microscopy, not just in one museum but by comparing fragments in Turin, Brussels, Berlin, Leiden, and London. The next step is to observe more closely the characteristics we are trying to match, and to assess the degree of diversity in antiquity. For now, all we can report is that *Avena sterilis* works, and the larger culms growing in central Italy have sufficient diameter and strength to produce compelling results not only in narrow-bore Egyptian doublepipes (such as the 'Maket' pipe) but in wider-bore Graeco-Roman doublepipes (such as the 'Louvre' *aulos*). As with *Phragmites*, we have verified experimentally that a pair of *Avena* reeds manufactured from a single internode, squeezed before cutting,

Figure 12: Reconstruction of the ‘Lady Maket’ doublepipe with an instrument case. © M. Sciascia.

greatly reduces the difficulty of getting the 3-hole and 4-hole pipes to sound well together and tends to encourage this balance to endure, rather than diverge over time. One early mistake we made was to scrape away the shiny epidermis at the tips of the blades. These scraped reeds did not last and lacked the reliability of those that preserve straw’s water-repellent outer skin. We also learned that the ‘onion’ above the waist should be as rotund as possible, not flattened, otherwise the spring in the blades can be insufficient to re-open the tips, particularly when tonguing (a technique for which there is no positive evidence in antiquity but was eminently possible).

5 Data Logging for Reed Research

Troubled by the spectre of beliefs setting in without scientific support, we started logging data more systematically in 2023. We are in the process of developing a system that we hope reed makers and players of every level will find easy and attractive to use, with a strong perpetuity plan so that a multi-lifetime, multi-regional, multi-perspective evidence base could be available to future researchers. One of the main issues with this sort of data collection is accuracy. Rather than recalling details weeks after the event, or storing information on scraps of paper that can become detached from bundles, we are currently using a Google sheet that enables collaborators in different regions to log information immediately, in the field and on the road. For example, capturing data for *Phragmites* harvested by the students we were training in Matera, Italy (Figure 13).

Figure 13: Bundles of *Phragmites australis*, harvested October 2023, labelled with locations of four harvest sites around Matera, Italy. Photographed 20 March 2024 after overwintering in the open air. © B. Brown.

An open-access catalogue records the location (places marked in our database are provided with GPS coordinates and a link that directs to Google Maps) and date the reed material was harvested; notes on curing, manufacturing, and parenting; and for *Phragmites* (not straw), the internodal section it was made from, recorded via the colour of the waist binding (see Table 2). Our aim is to make it easy for any reed maker to be systematic, contributing observations to a dataset that has an increased chance of being of scientific value down the line.

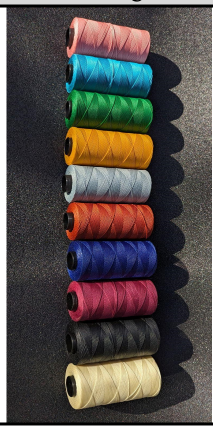
ancient colour	internode	waist binding thread
rose	10	
sky blue	9	
grass green	8	
gold	7	
silver	6	
cinnabar	5	
Ishtar Gate	4	
violet hematite	3	
bitumen	2	
whitewash	1	

Table 2: Colour system designed to foster public participation in longitudinal research, learning which internodes players prefer because the relevant information is enduringly visible in the reed's waist binding (see Figures 8 and 14).

In order for players to log observations throughout the lifetime of their reeds, there need to be unique IDs on every reed that remain legible for years. We found permanent ink wears off quickly, so switched to a laser engraver and initially burned IDs onto twenty-eight 'Theophrastian yokes' (twenty-three in *Phragmites*, four in *Avena*, and one in *Arundo*) and thirty singletons (twenty-one in *Phragmites*, eight in *Avena*, and one in *Arundo*): a total of eighty-six reeds for ancient pipes of every kind (Figure 14).

The use of Google sheets enables us to gather collective experience in this extremely niche sphere by increasing the number of investigators. This is our chosen starting point because it is an accessible platform that is robust and cheap to maintain, removing barriers for players who are not trained researchers to participate by logging observations and reed-treating procedures. Our ambition is to foster a multi-perspective, community-driven dataset that propels research forwards by systematically following hundreds of reeds, harvested in numerous locations, from their gathering to the end of their playable lives. We are still in the early stages of testing and development and would welcome feedback on how to refine the Lotos Lab data-logging system. We en-

Figure 14: Eighty-six reeds, laser-engraved with the unique IDs AAAA to AACF in January 2023. Pairs that make up 'Theophrastian yokes' have the same ID. In each 'yoke', the root-end reed and the blossom-end reed are distinguished by coloured thread: brown/red for the left/low pipe, blue/green for the right/high pipe. © B. Brown.

Figure 15: Forty-three 'Louvre yokes' and twenty-one 'Ur yokes' made by Marco Sciascia in September 2024, using *Phragmites australis* harvested in Benevento, September 2023, with waist bindings in colours that identify the internode (see Table 2) and birchwood reed caps; not yet laser engraved with unique IDs. © M. Sciascia.

courage players to record and share their experience with us by email or by using the forms at www.lotos-lab.com.

6 Conclusions

We hope to have demonstrated in this article the virtue of close collaboration between Classical philologists and aulos players in understanding Theophrastus' passage on reed-making. This not only brought us closer to identifying the cane species he describes, but also solved a technical problem of manufacturing reeds that produce a balanced sound from the left-hand and right-hand pipes through what we call 'Theophrastian yokes'. Our experiments with harvesting and processing *Arundo*, *Phragmites*, and *Avena* have begun to shed light on at least some aspects of ancient reed-making procedures, and bring us a step further in our quest of developing reconstructions of ancient instruments that follow available sources as faithfully as possible. Experiments are an important part of our work as they help us to fill in all the gaps where ancient testimonies are silent or insufficient. For this reason, our research will always have to rely on experimentation and collaboration, constituting a journey of trial, error, and teamwork, engaging with those who have different sensitivities and ideas.

Acknowledgements

We are tremendously grateful to colleagues of all hues who have gone through the discomfort of interaction between cocoons of expertise, forging out of the authors' obsessions, drafts, and diversions this end result. We could not have achieved this on our own. We particularly thank Kamila Wysłucha for innumerable suggestions; and for final-stage polishing, Michael Carroll and Sarah Burgin. For imperfections that remain, we accept sole responsibility. For aspects that prove solid starting points, credit is due not only to those named but a host of patrons and supporters who have encouraged our activities in multiple ways. We thank you all.

Video Example

1: A green culm of *Phragmites australis* with stems of secondary growth, one on either side of the tenth internode, compared to *Arundo donax* with multiple stems of secondary growth from many nodes, both growing beside the river Gravina di Matera, Italy, 21 February 2024. © B. Brown 2024: https://youtu.be/Jx4cfneSxEc

Bibliography

Baines, A. (1968). *Woodwind instruments and their history.* London: Faber & Faber.

Bellia, A. (2015). The virtual reconstruction of an ancient musical instrument: The aulos of Selinus. *Digital Heritage* 1, 55–8. https://doi.org/10.1109/DigitalHeritage.2015.7413833.

Barker, A. (1984). *Greek musical writing.* Vol. 1*: The musician and his art*. Cambridge: Cambridge University Press.

Becker, H. (1966). *Zur Entwicklungsgeschichte der antiken und mittelalterlichen Rohrblattinstrumente*. Hamburg: Musikverlag H. Sikorski.

Brown, B. (2019). Phragmites australis vs Arundo donax. *The Workshop of Dionysus*, 16 September 2019. http://doublepipes.info/phragmites-vs-arundo [Accessed: 4 October 2024].

Brown, B. (2024). *Oat straw reeds for Louvre aulos.* https://www.youtube.com/watch?v=VlJ5YwxYb8k [Accessed: 15 November 2024].

Brown, B. and D'Angour, A. (2018). Euripides Orestes Chorus, *EMAP Resources for Euterpe* 1. Fileset, figshare. https://doi.org/10.6084/m9.figshare.6885089.

Chappell, W. (1874). *The history of music (art and science).* Vol. 1: *From the earliest records to the fall of the Roman Empire*. London: Chappell & Co. and Simpkin & Marshall.

Curtis, J. (1914). The double flutes*. The Journal of Hellenic Studies* 34, 89–105.

Govaerts, R., Nic Lughadha, E., Black, N., Turner, R. and Paton, A. (2021). The world checklist of vascular plants. A continuously updated resource for exploring global plant diversity. *Scientific Data* 8, 215. https://doi.org/10.1038/s41597-021-00997-6.

Hardion, L., Verlaque, R., Baumel, A., Juin, M. and Vila, B. (2012). Revised systematics of Mediterranean Arundo (Poaceae) based on AFLP fingerprints and morphology. *Taxon* 61: 1217–26.

Hagel, S. (2010). Understanding the aulos Berlin Egyptian Museum 12461/12462. In: R. Eichmann, E. Hickmann and L.-Ch. Koch (eds), *Studien zur Musikarchäologie (Orient-Archäologie)* 7 (25), Rahden: Marie Leidorf, 67–87.

Hagel, S. (2014). Better understanding the Louvre aulos. *Studien zur Musikarchäologie (Orient-Archäologie)* 9 (33), Rahden: Marie Leidorf, 131–42.

Hagel, S. (2021a). Assessing unknown parameters of instrument finds by writing software. *Archeologia e Calcolatori* 32, 403–21. https://doi.org/10.19282/ac.32.1.2021.22.

Hagel, S. (2021b). Understanding early auloi: Instruments from Paestum, Pydna and elsewhere. In: G. Zuchtriegel and A. Meriani (eds), *La tomba del Tuffatore: rito, arte e poesia a Paestum e nel Mediterraneo d'epoca tardo-arcaica*. Pisa: Edizioni ETS, 421–59.

Hansen, D.L. et al. (2007). Clone-specific differences in Phragmites australis: Effects of ploidy level and geographic origin. *Aquatic Botany* 86.3, 269–79. https://doi.org/10.1016/j.aquabot.2006.11.005.

Hardion, L. et al. (2014). Origin of the invasive Arundo donax (Poaceae): a trans-Asian expedition in herbaria. *Annals of Botany* 114.3, 455–62. https://doi.org/10.1093/aob/mcu143.

Hort, A.F. (ed.) (1916). *Theophrastus. Enquiry into Plants*, Vol. 1: Books 1–5. Translated by Arthur F. Hort. Cambridge, MA: Harvard University Press.

Kew, Royal Botanic Gardens (2024). *Plants of the World Online.* Entries under the family Poaceae:
Arundo: https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:30012630-2;
Avena sterilis: https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:391787-1;
Phragmites australis: https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:30337627-2
[Accessed: 28 September 2024].

Lambertini, C. et al. (2012). Exploring the borders of European Phragmites within a cosmopolitan genus, *AoB PLANTS* 2012. https://doi.org/10.1093/aobpla/pls020.

Loret, V. (1889). Les Flûtes égyptiennes antiques. *Journal asiatique* 8.14, 197–237.

Loret, V. (1913). Egypte. In: A. Lavignac (ed.), *Encyclopédie de la musique et dictionnaire du conservatoire*, Vol. 1, Paris: C. Delagrave, 1–34.

Psaroudakēs, S. (1994). *Tragoidia: towards a description of Lexis and Melopoiia.* Vol. II, (Unpublished doctoral thesis. University of Reading). Available at: https://www.academia.edu/37083943/_1994_Auletikos_kalamos_pdf [Accessed: 8 August 2023].

Psaroudakēs, S. (2008). The auloi of Pydna. In: A.A. Both, R. Eichmann, E. Hickmann and L.-Ch. Koch (eds), *Studien zur Musikarchäologie (Orient-Archäologie)* 6 (22), Rahden: Marie Leidorf, 197–216.

Psaroudakēs, S. (2020). Lyre and aulos from an Athenian Classical grave in the area of the so-called 'Eriai' Gates and the Dipylon (grave 48, 470–50 BC). *Greek and Roman Musical Studies* 8.1, 11–44. https://doi.org/10.1163/22129758-12341360.

Reichlin-Moser, P.J. and Reichlin-Moser, B. (2015). *The Elgin aulos*. Basel: Atelier für Geigenbau. Available at: https://reichlin-moser.ch.

Schlesinger, K. (1911). Mouthpiece. In: H. Chisholm (ed.), *Encyclopædia Britannica*. Available at: https://en.wikisource.org/wiki/1911_Encyclop%C3%A6dia_Britannica/Mouthpiece. [Accessed: 8 August 2023].

Schlesinger, K. (1939). *The Greek aulos. A study of its mechanism and of its relation to the modal system of ancient Greek music. Followed by a survey of the Greek harmoniai in survival or rebirth in folk-music.* London: Methuen.

Shtein, I., Baruchim, P. and Lev-Yadun, S. (2021). Division of labour among culms in the clonal reed *Arundo donax* (Poaceae) is underlain by their pre-determined hydraulic structure. *Botanical Journal of the Linnean Society* 195.3, 348–56. https://doi.org/10.1093/botlinnean/boaa062.

Steinmann, C. (2021). *Nachklänge. Instrumente der griechischen Klassik und Ihre Musik. Materialien und Zeugnisse von Homer bis heute*. Basel/Berlin: Schwabe.

Sturtevant, R., Fusaro, A., Conard, W., Iott, S., Wishahm, L. and Van Zeghbroeck, J. (2024). *Phragmites australis australis* (Cav.) Trin. ex Steud.: U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. Available at: https://nas.er.usgs.gov/queries/greatlakes/FactSheet.aspx?Species_ID=2937 [Revised: 19 January 2024; Accessed: 2 October 2024].

Terzēs, C., and Hagel, S. (2022). Two Auloi from Megara. *Greek and Roman Musical Studies* 10.1, 15–77. https://doi.org/10.1163/22129758-bja10040.

Tutin, T.G. et al. (eds) (1980). *Flora europea* 5. Cambridge: Cambridge University Press.

Wang, Q., Wu, J.-Y., Teng, W.-J. and Liu, Y.-P. (2006). Effects of planting methods and overwintering protection on growth of Arundo donax. *Forest Research* 19.6, 813-15.

Wysłucha, K. and Hagel, S. (2023). The mouthpiece of the aulos revisited. *Greek and Roman Musical Studies* 11.2, 362–407. https://doi.org/10.1163/22129758-bja10062.