Iberian 'Age of Discovery' shipwrecks and dendroprovenance
In-situ timber sampling protocols

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Protocols for *in-situ* timber sampling with a focus on Early Modern 'Iberian' wrecks

1. The 'Age of Discovery'

In an era of unprecedented globalization, it is sometimes difficult to imagine our world without interconnections that circumnavigate the planet. The roots of trade networks and global colonization are of course as old as humans are, but the foundations of truly global mobility were lain in the Age of Discovery, during the 16th to 18th centuries, when Spanish and Portuguese sailing vessels plied the earth's waterways to stretch their empires around the globe. Fueled by trade in spices and slaves, and post-Reconquista (1492) and Battle of Lepanto (1571) religious fervor, the Iberian empires of Spain and Portugal conquered, converted, and controlled territory dispersed across five different continents: North and South America, Europe, Africa, and Asia.

The kings of Spain and Portugal signed treaties that divvied up newly “discovered” (albeit already inhabited) lands between them: the Treaty of Tordesillas (1494) and the Treaty of Zaragoza (1529). The efficacy of these treaties and the demarcations they intimated were often disputed, and the Church frequently intervened. However, the Protestant explorers to the north, namely English and Dutch, like the Muslim Ottomans to the east, disregarded the border allocations altogether, as the Pope had no legitimate control over their seafaring endeavors. As such, much of the European land race was conducted over water. This fact lead to ambitious shipbuilding regimes, swapping of trade secrets, and rapid changes to traditional ship architecture.

This paper aims to highlight some characteristics that are thought to be unique to Iberian ships of this period, and which could make these vessels easier to identify *in situ*. Mostly, it provides archaeological researchers with a set of protocols as to when and why *in situ* timber sampling may be called for, how to go about it, and what do with the samples afterward (for sampling *ex situ*, see Orton 2000, 191-209). In this way, the guidelines are meant to complement and supplement existing guidelines on shipwreck excavation, dendrochronological sampling, and handling waterlogged wood artefacts (see Historic England 2015a [1998], 2015b [2010a], 2015c [2010b]).

1.1. Emergent oceangoing ship types

The origins of Renaissance-period ship design are still under debate by nautical archaeologists and maritime historians. There are three main lines of thought: 1) Mediterranean carvel-built ships spread into the Atlantic in the 15th century, 2) Spanish and Portuguese shipwrights were more influenced by English and Nordic traditions even before the advent of carvel planking, or 3) the geographical location of the Iberian peninsula made it a confluence of ship design and construction practices hailing from both the Mediterranean and the North Seas, along with Arab influences (Loewen 1998; Castro 2008). There are three main types of oceangoing ship in use during this period in Iberia, each with its own set of functions and qualities, although these could and did often overlap. These ships are all hybrid forms, and at the time of writing, the only form attested in the archaeological record is the galleon. The other two *could* be attested at various sites around the world but are confirmed only in iconographical and historical attestations, and it seems that at times, the Iberian *nao* or *nau* was synonymous with the pan-European form of the carrack or caravel (Castro 2008; Flatman 2009).

1.1.1. Galleon

The main function of galleons was in battle. They feature two or three decks; fore and stern castles; three or four masts and a bowsprit using both square (fore, main, and bowsprit) and lateen (mizzen and fourth mast, or 'bonaventure') sails. Probably developing out of Mediterranean galleys, galleons were longer than carracks and *naos*, with a length to breadth proportion of 4:1, which decreased water resistance and increased maneuverability. They featured a square stern which supported the high aft castle and allowed for more deck space and mounted cannons.

1.1.2. *Nao*, *nau*, carrack

Nao (in Spanish) and *nau* (in Portuguese) are generic words for 'ship' but, along with 'carrack' (from Italian *caracca*), they typically refer to one with between two and four decks; fore and stern castles; three masts and a bowsprit bearing square sails, except the mizzenmast with its lateen sail. From iconography, the stern of a carrack can be square or round, and its proportions are typical of Mediterranean round ships at 3:1 length to breadth. These vessels could be enormous in size and had an alleged carrying capacity of 500 to 600 tons, which facilitated long voyages to India or the Americas. Their average burden though was around 100 metric tons, doubling from the 16th to 17th century. Although their primary function was as merchantmen, 16th-century commentators said that a capacity of 400 tons would allow the vessel to be effective both in commerce and war. Fleets of merchantmen were always armed and were requisitioned by the navy when needed.

1.1.3. Caravel

The caravel developed out of an older Mediterranean prototype (compare *carabus* in Latin, καραβος [karavos] in Greek, and قارب [qaarib] in Arabic) and was adapted in 16th c. Iberia to suit the needs of the *armada*. It typically featured four masts with all but the foremast supporting lateen sails. With a length to breadth ratio of 3.5:1, they were lightweight (about 50 tons compared to the 100 tons of a carrack), fast, and readily maneuverable. Because they were adapted to different sailing circumstances on the Mediterranean and Atlantic coasts, and because of the ship type's antiquity and regional evolution, its telltale characteristics, even its favoring of lateen sails, change from place to place and time to time, rendering it perhaps more difficult to identify in the archaeological record. However, it may also be more prevalent, as the caravel is noted in historical sources as the ship of choice from the 15th to 17th centuries, eventually being traded in for the carrack.

1.2. What it means to be 'Iberian'

The idea of an Iberian shipbuilding tradition is a modern descriptor constructed to categorize the origins of wrecked vessels. Those involved in the design and construction of ships during this period would likely not have thought of themselves as Iberian or Atlantic, or their methods as falling into these categories either. However, contemporaneous historical and iconographical accounts assert that all Iberian oceangoing vessels shared a few common characteristics: they were built empirically without architectural plans (at least until the mid-16th century) but based on proportion and scale; and they were skeleton-first (frame-based), carvel-built with planks fixed flush to the frames. More recently, several researchers have compiled a more detailed list of features that are common to the hulls of ships built along the Iberian coast, or elsewhere complying with the 'same tradition' (compiled from Loewen 1998; Castro 2008; Oertling 2001).

1. Oak (*Quercus* sp.) dominates the structural timbers (frames, ceiling, decks, keel, etc.) as well as the treenails, although pine (*Pinus* sp.) may be used in the hull planking. Repairs have been documented as chestnut (*Castanea sativa*), and other broadleaf woods have been noted in small quantities.

2. Oak treenails (25mm diameter) and iron fastenings (10-12mm square section) are both used in the hull, and at each join of a frame and a plank, two of each are used.

3. Timber measures, or 'scantlings', are uniform, even between large and small ships:

◦ floor timbers = 19-20cm square section

◦ futtock square sections decrease from 19-20cm to 14cm at the upper deck

◦ hull planks = 33-38cm wide, 4.5-6cm thick, and max. 10-11m long

◦ deck and wall planks = 17-19cm wide, 3-3.5cm thick, and max. 10-11m long

4. Some first futtocks and floor planks are assembled laterally with dovetail mortise and tenon joints, and these alternate with 'floating futtocks' that are only fastened to the hull planks.

5. The notched keelson swells in size at the main mast step and is buttressed on each side against the bilge clamps (or footwale), and on one or both sides of the keelson, thee is a semi-circular cavity in the wood that held the pump.

6. The outermost ceiling strakes, called *albaolas*, are crenelated and feature small inserted planks.

7. Central frames are predesigned and preassembled.

8. Curved timbers (*couces*) connect the stem and sternpost. These are supported by a curved knee, over which is a y-shaped frame (*pica*) connected to the *couce* by deadwood (*coral*).

9. The transom is flat with a tall, more-or-less vertical sternpost.

While any one of these characteristics could be seen in a vessel of a different origin, when taken together, they are assumed to be diagnostic of pan-Iberian shipbuilding traditions from the 16th to 18th c. This method of identification is not without its issues: namely, that the sample shipwrecks confirming these traits may have been engaged in Iberian trade, but it cannot be confirmed that all of them were built in Iberia, or by Iberians, or even necessarily for Iberians. This is one reason why advancing the methods and analytical potentials of dendroprovenance are so important. If a broad sample of structural timbers could be dated and provenanced, it would make a stronger case for outlining, temporally and spatially, the historical 'place' of the ship.

1.3. Treasure and archaeology

All shipwrecks are treasure troves of information, but few contain actual treasure. With romantic ideas of sunken hordes of gold doubloons and treasure chests of jewels guarded by one-eyed pirate skeletons, Spanish and Portuguese shipwrecks are especially prone to the efforts of those who seek to profit financially, not culturally, from 'excavating' shipwrecks. The practices of modern-day treasure hunters frequently destroy heritage sites just to get to “the rich stuff” (a phrase made famous in Steven Spielberg's 1985 film, *The Goonies*). The shipwreck assemblage is rarely adequately recorded, and excavations are less than systematic, let alone scientific. Artefacts retrieved from the site are sold to collectors for profit, where, far more often than not, they disappear from public access.

Not surprisingly, ship timbers do not usually promise a great deal of profit for treasure hunters, so they are forcefully removed or otherwise ruined in the search for more valuable artefacts. That being said, a large timber was recently found as driftwood on the coast of one of the Hebrides (Scotland), and at the time of writing, it is for sale on Ebay with a starting bid of 750 GBP. The seller describes it as coming from one of Philip II's *armada* galleons wrecked in the storm of 1588. Without context though, this claim cannot be validated, and it is unlikely that any archaeological project or dendrochronology lab would be in a position (financially or ethically) to purchase the timber in order to confirm a date or origin. Whether a timber is destroyed or sold, either way, its scientific potential is greatly compromised in exchange for profit.

Countries that have ratified the 2001 UNESCO convention may prosecute treasure hunters for the theft of global heritage; however, in countries that have not ratified the convention, these individuals and companies may be paid handsomely for their crimes. It is worth noting, however, that the profit is one-sided; in many cases, the costs of judicial proceedings and litigation resulting from contested activities or rights is publicly funded, that is, by the same taxpayers who will no longer have access to heritage items sold into private collections.

2. Timber samples and dendroprovenance

While we often speak of find-spots in archaeology, original provenance is just as important to compiling an understanding of an object's place in history. When discussing dates of objects, there are often two: one for the construction and one for the deposition. Likewise, with highly mobile objects like ships, construction and deposition locations are rarely the same. Knowing both ends of the temporal and spatial spectra of an object helps us to trace what happened between these events, thereby becoming better equipped to answer questions related to mobility, interconnectivity, and resource acquisition and management. While cargo, personal belongings of the crew, and other items related to the ship's everyday functioning can be highly informative, to reveal the circumstances surrounding where a ship originated, it is necessary to examine the wood from which it was built.

In the study of ancient watercraft, wood could be considered the material of most fundamental interest. Textual records since Antiquity describe shipbuilding and mention the trees felled to furnish timbers for new vessels or even new navies. However, the implications of these texts depend on accurate translations of the flora listed, as well as accurate correlations between ancient toponyms and modern geographical features. Both of these tasks are notoriously problematic and are often contested by historians (e.g., Meiggs 1982). Archival information can also occasionally be misleading, as authors had their own agendas when writing, which may skew reality. The same is true for art historical sources. Therefore, archaeological sciences open up a complementary avenue of deriving this information from primary sources.

Wood can survive into the archaeological record in anaerobic environments that repel xylophagic organisms. Underwater, wood may be protected from teredo, gribble, and piddock by lying beneath layers of mud or peat, for example. Large wooden watercraft can also be preserved in intertidal zones or in rivers, frequently those that have been infilled with sediments. Several 'Iberian' ships located around the world have been preserved through these exceptional depositional circumstances. And in the frequent absence of primary source texts like a ship’s manifest, or archival records related to the vessel’s construction, one way to determine its provenance is to consider the actual timbers from which it was fashioned. This approach is called dendroprovenance, and several methods have been developed to achieve it, each with its own set of potentials and limitations.

Determining the provenance of shipwrecks via their timbers is a notoriously tricky issue due to multi-culturalism inherent in the maritime world (cf. Harpster 2013). Cargo is traced to various ports of call, as are crew members and passengers, and even the ones building or designing the ship may be foreign to the dockyard where it was constructed. To make matters even hazier, a ship may have been built at one locale and purchased or commandeered at another, or owned by a person of one ethnicity and operated by another. Therefore, while questions of ship ethnicity may lead only to dead ends, pursuing questions of its provenance can lead to fruitful discussions of resource acquisition, timber trade, timber transport, and the relationships between forestry (and often, deforestation) and shipyard activities, not to mention valuable information about types and qualities of wood and their function and efficacy as a ship timber (Loewen 2001; Loewen & Delhaye 2006).

Timber trade, however, brings up another potential stumbling block in efforts at provenancing a vessel's place of construction via its wood. Even if a ship's timbers can be provenanced to a specific region, that does not necessarily mean that the vessel was built at the nearest shipyard; it only indicates the origin of the wood. In theory, the timber could have been transported to any number of distant shipyards and the vessel constructed there. However, recent provenance studies performed on ship timbers have determined that Northern and Western European shipyards relied most heavily on nearby forests, so the provenance of ship timbers was indicative of the provenance of the ship (Daly 2007, 229, 236-237; Allevato et al. 2009). For Iberia, this trend is supported by historical data from the Basque Country that reserves a coastal frontier of forest for the navy. Even if knowing the origin of a single piece of wood will not rewrite the history of shipbuilding or naval forestry, dendroprovenance techniques can still be used to fill in the gaps of what we do know about the vessel: where it's been and when. In turn, this information can contribute to a better understanding of ancient and historical landscapes and industry. Essentially, a timber sample is not just a piece of soggy old wood; it is unique data that bears a great responsibility for representing the timber, the ship, and the forest whence it came.

2.1. Scientific analyses

Wood origin has been the focus of a number of scientific investigations in recent years, stemming from advances in dendrochronology and wood characterization studies, and realizing the potentials and limitations of each (Eckstein & Wrobel 2007; Bridge 2012). In response, new scientific methods have been developed and old ones adapted to address common historical assumptions and the general lack of accurate information about anthropogenic fluctuations in world forests. These methods were also advanced to better understand alterations in species distribution and the complexities of trade networks. Current lab-based dendroprovenance techniques include DNA studies, dendrochronology, dendroarchaeology, trace element and isotopic analyses, and anatomical/structural markers. Each of these methods is consistently being further developed and improved so that the current range of applications can be expanded temporally and spatially, and to include more wood types in varying conditions. Dendrochronology and dendroarchaeology are the two most cost-effective, but each analytical method comes with its own set of limitations and benefits, so ideally, multiple methods should be pursued for any given sample.

2.1.1. Dendrochronology

While tree-ring signatures are a well-known method for dating archaeological wood, and as indicators or long-term regional climate change, dendrochronology can also be used for wood provenance. The method has been demonstrated numerously in nautical contexts using the Northern European oak master chronology (Haneca & Daly 2014; Domínguez-Delmás et al. 2013; Daly 2007; Nayling & Susperregi 2014; Wazny 2011). However, in regions where no master regional chronology exists yet, such as Iberia, dendrochronology can provide a date (often in conjunction with C14 wiggle matching), and other methods such as dendroarchaeology or anatomical markers are used to suggest a provenance (Domínguez-Delmás et al. 2015). Tree ring databases (e.g., ITRDB) and existing chronologies are systematically being updated and modified, and it is expected that this method will continue to be very important for shipwreck archaeology, providing a date and place, in the future. This is one reason why all samples taken should be submitted to a dendrochronology lab so that they can be incorporated into existing chronologies, thereby strengthening the dataset and increasing its application and accuracy.

However, attempting to create a regional chronology from ship timbers will likely result in more frustration than fact. Established and absolute regional chronologies should already be in existence before comparing tree-ring sequences from ship material, which, as noted above, is often characterized by wood from several different regions, of several different species, in varying levels of preservation, and in many cases, from coppiced woods or plantations which do not reflect regional or temporal variation the same way that forest trees wood (see Guibal & Pomey 2004; Wicha 2005). For best results, tree-ring chronologies should be based on confirmed 'knowns' in the present that extend back into the past via multiple cross-dated historical datasets; not constructed with unknowns.

2.1.2. Dendroarchaeology

Dendroarchaeology relies on confirmed taxa IDs and distribution maps to seek the overlapping growth range of species represented in a given assemblage. This overlapping range is taken as the locale for construction, and the current distribution maps are assumed unchanged from the past. Taxonomists and palynologists may find this method's base assumptions problematic. First inter-genus and -species relationships and subdivisions are not always agreed upon. Second, many trees cannot be identified to the species level based on visible microscopic characteristics alone (see http://www.woodanatomy.ch for a reliable online ID guide). For example, three species of European oak (*Q. robur, Q. petraea, Q. pubescens*) commonly used in shipbuilding cannot be differentiated by wood anatomy, so dendroarchaeology alone would not be able to ID, let alone provenance, these woods. Third, palynology demonstrates that flora distribution fluctuated frequently in the past, as it does now. However, dendroarchaeology can be used to help support other methods: for example, pollen analysis has been used in conjunction with dendroarcaeology to provenance shipwreck timbers and even delimit areas of possible ancient shipyards (Allevato et al. 2009; Muller 2005; Giachi et al. 2003). By itself, dendroarchaeology can also be used to provenance wood securely identified to the species level and dating to relatively recent periods that might better reflect current distribution patterns.

2.1.3. DNA

Genetic fingerprinting has isolated sources for modern tropical timbers to within 300m of where they were felled. This is commonly used to track illegal timber trafficking in tropical regions (e.g., Jiao et al. 2014). However, its archaeological application is debated because the chloroplast DNA signal becomes obfuscated with the material’s degradation, whether old and dry or waterlogged. That being said, archaeological *Populus euphratica* wood from China was amplified with PCR (polymerase chain reaction) and differentiated from others in the genus (Jiao et al. 2015; see also Deguilloux et al. 2004; Dumolin-Lapègue et al. 1999), so the potential for this method's development in archaeology is very promising. From an underwater context, the cpDNA of one oak sample from the *Mary Rose* shipwreck (1510-1545) was successfully extracted (Speirs et al. 2009), promising the potential for provenance data to be derived from aged, waterlogged wood.

2.1.4. Geochemistry

Mass spectrometry (using, e.g., ICP-MS, or an inductively-coupled mass spectrometer) can highlight the chemical or elemental relationship between specific geological environments and the trees that grow on them. Plants leach chemicals from the local bedrock, hydrology, and atmosphere, and measurements of these elemental or isotopic ratios in wood can be used to develop species- and location-specific isotopic or trace element spatial signatures. Primary trace elements examined are Ba, Mn, Cu, Zn, and Pb, and isotopes include $\delta^{18}O$, $\delta^{13}C$, $^{87}Sr/^{86}Sr$. However, because accurate contributor proxies cannot be developed, and a 'map' can never really be complete, these techniques are limited to ruling out pre-existing hypotheses (Pollard 2011, 637), which are usually based on other typologies, iconography, or textual references in contemporaneous literature. For example, strontium isotope ($^{87}Sr/^{86}Sr$) analysis can be applied to archaeological wood to provide either a match or non-match between the archaeological sample and its supposed origin (Graustein & Armstrong 1983; Gosz & Moore 1989; Durand et al. 1999; English et al. 2001; Reynolds et al. 2005). By themselves, matches, even of identical isotopic ratios, cannot absolutely ensure a geographical origin though because the very same ratio could be found in a region that has not been sampled and for which no 'map' or spatial signature exists (Rich et al. 2012, 2015). So while this method offers a unique way to weed out pre-existing origin hypotheses, it must be coupled with other approaches, scientific or historical, to generate new hypotheses (e.g., Rich et al., forthcoming).

2.1.5. Anatomical and structural markers

Wood characterization studies examine the anatomical anomalies and structural chemistry of a sample. These methods can be used to identify common growth habitats. For example, samples from Iberian forests known to have furnished ship timber are sampled, and these are analysed for microscopic and chemical tracers that indicate elevation, slope, soil acidity, hydration, frost, parasitic attacks, fire outbreaks, pollution exposure, etc. Trees from the same growth environment exhibit the same anomalies, so when archaeological wood is compared, it is possible to trace its provenance by matching these anomalies (somewhat similar to dendrochronological and geochemical techniques). FTIR measures molecular bond vibrations (especially of cellulose and lignin), and Py-GC/MS measures molecular compositions (such as carbohydrates, tannins, and resins) (Traoré, Kaal & Coritzas 2016; Khanjian, Schilling & Maish 2012; Łuceijko et al. 2009; Colombini et al. 2007); like other techniques described above, the combined results provide distinct 'signatures' based on species, habitat, and development.

3. Sampling and sub-sampling

While removing pieces of wood from a shipwreck may sound fairly straightforward, it is anything but. Every shipwreck is different, and its unique assemblage, location, condition, and preservation must be taken into account before selecting timbers. Choosing the right timbers to represent the ship and its wreck, and to be of scientific value, is half the battle (Orton 2000). And these decisions will be made, generally, underwater. Once a timber has been sampled and brought to the surface, it cannot be put back again, so recording all samples is part of maintaining the site archive. Furthermore, each scientific analysis has its own set of requirements for a sample, and often, compromises will have to be made to ensure both high quality dendroprovenance results and the integrity of the archaeological site. It is expected that archaeology teams engaged in sampling procedures have sufficient experience and competence to carry out the work. This may involve consulting heritage agencies to recruit new team members experienced with waterlogged wood or wood science to assist or advise on the procedures described here. No less than the cargo or personal items of the crew, ships and their timbers are invaluable components of material culture and should be treated with the same respect as shown to other objects.

As such, it should be emphasized first and foremost that when timbers are selected for potential sampling, they must be adequately recorded before inflicting any damage (ie., cutting or removing) on them. The second point of emphasis is that sample populations are not the same as target populations (Orton 2000, 181); in other words, when trying to understand the larger-scale construction contexts of, e.g., Iberian ships (target population), it is important to remember that the samples taken from a single shipwreck site (sample population) cannot be used to directly account for or explain the target with any precision. They can really only be representative of that shipwreck assemblage; however, these representatives can be projected to expand (or create) datasets of dates, chronologies, scantlings, provenances, tool marks, technological changes, and the myriad other data that can be derived from ship timbers. These in turn can contribute to explaining the target population.

3.1. Selection

Structural timbers, such as planks, beams, and frames, should be targeted for dendroprovenance sampling. These timbers are more likely to be representative of the ship's original architecture, and will therefore be more diagnostic as to the ship type and theoretically, where it was built and when.

There are some timber selection strategies that can be developed with a basic knowledge of wood properties and of period shipbuilding. For example, if deciduous oak is likely to have been used in structural timbers (as is the case for 'Iberian' ships as well as British, Ottoman, Scandinavian, and Dutch vessels of this period), it will be beneficial to take samples from both frames and planks. Deciduous oak (*Quercus* subg. *Quercus*, unlike the shrubbier evergreen (or 'live') oaks also used in shipbuilding) is a ring-porous wood, which means that during spring, it develops large cells that facilitate quick growth, after which cell growth slows with the onset of summer, further diminishing in fall, and ceasing altogether in winter, indicating the terminus of the ring boundary. There are two reasons for archaeologists to regard the growth pattern of deciduous oak as it pertains to shipbuilding. The first reason is that the rings, divided by rays extending outward from the pith, are often visible on exposed transverse ends of timbers, making it possible to identify an oak timber underwater, without removing a sample at all. It can then be estimated whether the oak was slow or fast grown and which dendroprovenance analyses could be conducted on it. The second reason is that the large early-wood cells grown during the spring are vulnerable areas in the wood, where tangential breakage is most likely to occur. For this reason, ship frames often relied on fast-grown oak, which has lived through fewer springs and therefore has fewer weak spots tangentially. On the other hand, planks were better converted from slow-grown oak, as tangential breakage is less relevant in horizontally placed timbers, including the keel and keelson. As a result, longitudinal timbers are more likely to have the >50 annual growth rings required for dendrochronology, while frames may have only 30-60 rings, which is usually insufficient for accurate cross-dating, and thus provenancing.

Ideally, samples would come from both planks and frames, even if frame samples can only be used for other types of analyses that do not require a large number of annual growth rings. The other advantage of sampling a variety of frames is that they will often bear the clearest marks of having been converted from a felled tree; that is, frames are more likely to retain sapwood or even bark edge, which, if possible to date dendrochronologically, will provide the exact year of felling, and sometimes even the season. If there is sapwood data on file for the region where the tree was felled (as is the case for Norther European oaks outside of Iberia), then the missing sapwood rings may be estimated within a few years of the felling date.

For analyses that require large numbers of tree rings, the best planks to sample are those that were converted radially. What this means is that the tree was divided from the center out toward the bark, as in the rays of the sun. The result is not only a stronger length of wood more resistant to warping, but also an ideal surface for the measurement of growth rings, and by extension, growth anomalies that could imply origin. The two short ends of the plank will feature the radius of the transverse section, revealing ring sequences from pith to sapwood. Radially cut planks are also relatively easy to spot underwater, given the right conditions. If the wood surface appears to be composed of straight lines extending the length of the plank, then it is radially cut. If the ends of the timber are still in good condition, a section can be removed from the end of the plank with one cut or from a better preserved or accessible area in the middle with two cuts. Naturally, the more cuts that are made, the more time is spent underwater and the more unstable the assemblage may become, so the selection strategy should consider both of these factors.

3.1.1. Assemblage and preservation

Like any archaeological site, a shipwreck is subject to a great deal of environmental and anthropogenic change. Tidal currents can wash away protective layers of sediment, or deforestation upstream can lead to thick soil dumps in the delta. Major storm systems can create scour marks on the seafloor, and trawlers can leave trails of disturbed seabed that last for miles. These and myriad other environmental factors may have direct impacts on shipwreck assemblages and how they are preserved *in situ*. Of course, invasive archaeological activity on the site will affect it as well. Therefore, non-invasive methods should be used first prior to sampling any timber. Mapping, sketching, taking GPS points, and using methods such as photogrammetry, will help ensure that any sample taken has a recorded provenance in relation to the assemblage. Months and even years after a sampling campaign, questions of archaeological context are certain to arise. Was that plank section removed from the port or starboard side? That frame from the bow or stern? These are questions that should be easily answered through adequate recording.

An assessment of the condition of the shipwreck assemblage will also inform which timbers could provide samples of the greatest scientific value. Badly degraded timbers will likely be of little value outside genus or species identification. Of course, this is an important step toward understanding the ship, but used alone, it is unlikely to provide a reliable provenance. Instead, focusing efforts on timbers in good condition will furnish samples that can be used for multiple analyses. Even so, a timber may appear to be in very good condition, but when sawing, it becomes clear that the interior is more mollusk tunnel than wood. If a massive oak log has never been so easy to cut through, there is a good chance that it is not worth even that much effort. It is better to leave it in place and look elsewhere. If excavation is permitted, or already undertaken, the best chances for finding timbers with the least amount of erosional or xylophagic damage is under the seabed.

Fundamentally, archaeologists should not take more samples than can realistically be processed. Responsibilities for post-excavation analyses, including documentation and storage, should be weighed realistically. Furthermore, taking a timber sample is an irreversible step toward the vessel's eventual disintegration. This too is a big responsibility, and archaeologists need to consider the long-term impacts of their decisions of where to sample and how many to take.

Generally speaking, a good rule of thumb for the best results is to supply analysts with 20-50 samples per vessel, with each sample representing a different timber, and ideally, from a different area of the ship (laterally and longitudinally). From the analyst's perspective, more is always better; however, the economic law of diminishing returns also applies to samples, stating that eventually, more is not better (Orton 2000, 7). Statistically, it is better to have fewer high-quality samples than dozens of low-quality. As a rough, conservative estimate, and in particular for ships built of Iberian timber, only 50% of samples taken will prove useful for dendrochronology, which shares some sample requirements with anatomical and molecular marker analyses. As an example, a wrecked 16th century galleon in Galicia has seen two sampling campaigns, producing 29 and 19 samples respectively of mostly oak (with two of pine in the latter campaign). Of these 48 samples, only 35 could be used for dendrochronology, and even then, the samples could not be cross-dated between themselves or with established chronologies. Therefore, they – and the ship – remain absolutely and relatively undated.

While we must always be mindful of the integrity of the site, if a shipwreck has recently been exposed and its wood is at risk of eminent deterioration (or anthropogenic destruction), it would be wise to concentrate efforts on taking a few extra samples from this site, as there may not be a chance to return to it in the same condition if at all. After the first dive or two on the site, archaeologists should have sufficient information to develop an underwater sampling strategy (see Orton 2000, 179-184).

3.1.2. Sampling underwater

In many cases, shipwreck sampling campaigns will be conducted underwater, in conditions from tropical to tempestuous. Clearly, the safety of the divers is more important than getting that last cross-section. Sawing large timbers underwater requires a great deal of physical exertion, and divers should be prepared to extend their usual air consumption rate by two or three times. There are also associated dangers of using saws, usually rusty ones, underwater, where lacerations can easily occur without the diver even being aware of them. Using a chainsaw underwater can only be done by hard-hat divers on surface supply.

But besides being safe underwater, sampling divers should also find a balance between enthusiasm and being realistic in terms of the number of samples taken. Likewise, sampling unique ship features should also be approached with caution. In the example of a campaign on an 18th century French corvette, on the next to last day of the field season, two divers were using a dredge to remove sand from an area of semi-exposed timbers. Unexpectedly, they exposed the keelson. A sample of the keelson would be nearly unmatched in terms of value for dendroprovenance studies. It is likely to have been formed of a long-lived tree, such as oak or pine, for which reference chronologies are likely to exist. However, when the divers returned to the area to record (photographs, measurements from fixed points, and drawings) before removing a sample, they realized that this very important feature could not be recorded sufficiently in the time they had left to work on the site. On the spot, they made the difficult decision to not destroy the integrity of the timber and instead re-covered it with sand. Making these kinds of judgment calls are difficult enough, but even more so when mental faculties are stunted by the effects of being underwater, even at shallow depths. This too is an unavoidable aspect of working in this unique environment and one that archaeologists should be prepared to face and factor into their diving and sampling strategies.

Divers should also try to collect samples that will be useful for the greatest variety of analyses (see below, 3.3). For example if bark or the soft outer rings, sapwood, are visible, that is a good indicator that this timber would be worth sampling. When possible, a close inspection of the transverse section of a timber will also help the diver decide whether or not the sample would be worthwhile. If the annual growth rings are visible, check to see how narrow they are. Timber adapted from slow-grown trees is likely to provide more information relevant to dendroprovenance than trees that were only a few decades old when felled, as explained above (3.1) and in the example provided below.

If the transverse section is not visible, or not accessible (i.e., the ends are overlain by other wreckage or joined to other timbers, they are buried beneath a great deal of sediment, or the ends are badly degraded), a wedge sample may be removed. In taking a wedge sample, the saw is positioned centrally along the timber but at an angle. After cutting down a few centimeters, the saw is removed and then placed further down the timber and at an opposite angle so that the cuts will join at the bottom, and a wedge-shaped piece of wood can be removed. This acts as a kind of pre-sample, letting the wood specialist see if this timber would be worth spending a whole dive, or even two, to cut a section from.

Because samples are representative of both the ship and the forest where they originated, it is also important to collect a variety of wood and timber types for dendroprovenance: not just planks, but also frames, beams, etc., and not just oak, but also pine, chestnut, or that mysterious reddish-colored timber that might be representative of a repair in some exotic location where oak and pine were unavailable.

There are also those unfortunate cases where the ideal timber is spotted, but it is impossible to sample. This may be due to the presence of iron fittings that cannot be sawn through, or because the saw cannot fit between the desired timber and the one next to it. In many other cases, the timber section is half sawn only to encounter a nail. Sometimes nails can be broken through with a hammer and chisel, and other times, the half-cut sample must be abandoned. In some cases, especially with softwood or timbers from older shipwrecks, the saw may be abandoned altogether. In the case of sampling the pine hull planking from a Late Classical Greek shipwreck off the coast of Cyprus, the desired plank (radially converted with estimated > 80 rings) was situated on the edge of the trench, so the saw was easily used to cut back from the edge toward the opposite side of the trench and the rest of the hull. However, there reached a point when to go further back with the saw would mean damaging the plank next to the one being sampled. In this case, the saw was set aside and a putty knife put to work in its stead. The wood was soft enough that the putty knife cut through without having to be hammered. The sample was removed with a trowel rather like lifting a large piece of cake from a plate. It was then wrapped in burlap and secured with ropes in a pre-prepared crate, and gently toted the 45 m back up to the surface.

In another scenario, due to the limitations of time and more challenging conditions underwater, only three samples of oak framing elements from a 16th century supposed carrack were able to be removed. These samples contained pith and sapwood, and they were very well preserved within the clay seabed.

This all bodes well for dendrochronology, but for reasons stated above regarding construction with oak frames, the ring counts were insufficient for cross-dating. Furthermore, because the trees were young (between 24 and 45 years old), their annual growth rings represent 'juvenile growth': that is, like human adolescents, trees also experience growth spurts and stunts that may be irrespective of the factors, such as nutrition, hydration, health, and environmental conditions, that dictate to a large degree the growth patterns of adult trees. In other words, erratic juvenile rings are often unusable for dendrochronology as well as for anatomical and molecular marker analyses that are equally dependent on the indicators of relationships between growth and environment. So again, a greater number of samples from a variety of ship timbers helps to maximize the potential for several dendroprovenance techniques to be applied to a shipwreck assemblage.

3.1.3. Sampling on land

Shipwrecks are not necessarily underwater. And ancient ships are not always wrecked. In many cases, nautical archaeologists don't even have to get wet to do their job, although they may get pretty muddy. Two examples are provided here: one, the Newport Ship, is a vessel that had been abandoned in mid-repair on the banks of a river in Wales and eventually silted over, and the other, the Belinho shipwreck, is a disarticulated vessel whose timbers have washed ashore in Portugal after storms in the Atlantic. While the general guidelines of timber selection are the same underwater and on land, recovering and sampling ship timbers in rescue- or development-led projects comes with a few of its own caveats leading to possibilities for different recording and sampling strategies.

One of the main differences between sampling campaigns on land and those underwater is time. With the possibility of longer working days spent in the direct company of the timbers themselves instead of dealing with the logistics of how to get to them, recording and sampling processes can be expedited and made much more thorough, comparatively speaking. The other major difference is the tools at one's disposal, namely increment borers.

The Newport Ship was excavated from the mud timber by timber, with each one being recorded and conserved before reintroduced to the reconstructed vessel. Each of the 2000 timbers was cleaned and placed in a shallow tank to keep it waterlogged, and then each was recorded using a FaroArm and Rhino 3D software (Jones 2013). Painstaking recording of individual timbers allowed the vessel to be digitally reconstructed while at the same time capturing the patterns of cut marks, fastening, and details of conversion necessary to track what kinds of forests these timbers came from. Once the structural timbers were recorded, some were selected to sample for dendrochronological dating and provenance. The samples were selected based on the number of rings and the presence of sapwood or even bark edge, as was present on the keel. The majority of the samples were taken from the outer perimeter of vessel, which revealed wood from slower grown trees than those found in the inner sections. Fifty planks or strakes (13%) from port and starboard sides and 39 framing timbers (15%) from around the outer perimeter of the ship were sampled. These planks produced the samples that came to compose the vessel's chronology through ring-width means, which were then used to cross-date the ship timbers against regional chronologies. For some timbers, a wedge sample of sapwood and outermost heartwood rings was taken first, followed by a core sample to add the inner heartwood rings to the sequence. Each sample combined via the overlapping rings to represent the full timber and the tree from which it was derived (Nayling & Suspijna 2014).

Following the example of the Newport Ship project, sampling timbers washed ashore from the Belinho shipwreck combined an ambitious agenda of digital recording techniques and sampling for six different dendroprovenance methods. Given the space on land to undertake such a study, timber characterization was a primary aim in order to develop a relationship between the construction of the ship and the source forests that provided its timbers. Some seventy timbers were recorded using digital photography, FaroArm or laser scanning, and those that met the criteria for dendrochronology (>50 rings) were sampled with the other dendroprovenance analyses in mind as well. Frames were sampled by removing a section, and frames were sampled using an increment borer.

Using an increment borer on the timbers is preferable to cutting a cross-section, particularly in cases such as the above where each timber was to be conserved for restoration (in full or part) of the ship. An increment borer, which cannot be used underwater where leverage is limited to nonexistent, removes only a thin (ca. 4.3-5.15 mm) cylindrical section of wood, so the damage to sampled timbers can be better minimized on land. An isotopic borer (12 mm) can also be used which produces a sample thick enough that it can be subsampled for other analyses.

3.2. Post-excavation processing

As with the removal of any cultural object from an archaeological site, taking timber samples from a shipwreck means dealing with artefacts. Waterlogged wood makes for an extremely fragile artefact. Samples should always be handled with utmost care because if they are broken, glue will do nothing to resolve the problem. Storage facilities should be fully equipped to retain the wood while it awaits its destination. And of course, in the meantime, *ex situ* as much as *in situ*, these artefacts must be fully cleaned and recorded before being passed on to wood science laboratories, where, depending on the analysis, the samples may be destroyed. Fortunately, there are many options available today for recording, and the storage needs of waterlogged wood for short periods of times can be adapted to numerous field situations. (The reader is also invited to refer to Historic England 2010 for further information).

3.2.1. Cleaning

Before detailed recording can begin, the sample should be thoroughly cleaned. It may seem that wood coming from underwater would already be clean, but this is rarely the case. As mentioned above, wood is best preserved beneath sediment, so remaining clay and mud will be brought to the surface along with the sample. Gently rubbing the soiled surface while softly rinsing with water will usually remove even clayey sediment patches. Often, sediments are most forcefully lodged within the cavities created by wood-boring organisms. Gently spraying with fresh or salt water will flush out the soil; however, those cavities may be hosting biogenic fillers as well as geogenic ones.

Wood-boring molluscs like piddock and teredo will frequently still be in the wood when it is surfaced. It is important to dispose of these animals while cleaning and before storage because if they are left inside, they will die, resulting in an unbearable odour that also attracts sea scavengers such as gulls. Besides flushing them out with water, forceps or pincers may be helpful to reach into the bore-hole and pluck them out. Quickly removing the sealife from the sample will also help prevent biological contamination and further damage to the wood (see below).

After it is clean, whichever methods are chosen for documenting the sample *ex-situ*, it should remain moist. This can be challenging when working in hot, dry climates where water can evaporate from wood in seconds. Keeping the sample misted or splashed with fresh or salt water will keep it hydrated and preserved during documentation processes.

3.2.2. Visual recording

The first option for recording a timber sample visually is by drawing it. Although a pencil and paper may seem an archaic practice compared to digital techniques (see below), this method has the advantage of enabling the archaeologist to take the time to examine the details from multiple angles. This method involves close observation that may bring to the surface such features as tool marks, unusual planes, or joints, which could go unnoticed during hasty photographic recording. In many cases, the sample will not need to be drawn archaeologically, but a rough sketch to illustrate conversion method, notable features, and the transverse section (with growth rings and rays), will be a helpful and expedient way to 'get to know' the object and its potentials for dendroprovenance, as well as to provide other information about the ship's construction.

The ways in which to create digital visual records of artefacts are constantly expanding, while the options for doing so are becoming more cost-effective and more user friendly. With a digital camera, which nearly everyone has these days, and certainly all archaeological projects, samples can be photographed with a scale to capture each side, the growth rate of the original tree (transverse section), and any other features that exhibit information about the timber or tree from which it came, and which it now represents.

For particularly unique samples that feature tool marks or an unusual conversion or joining method, archaeologists may wish to take digital recording to the next level. Two frequently used options, both of which can be conducted in the field, are photogrammetry and RTI (reflectance transformation imaging). Photogrammetry can be used to create photomosaics or 3D images, while RTI is used to record subtle surface variations, such as tool marks, inscriptions, or makers' marks.

Photogrammetry involves taking a multitude of overlapping photos of the object from all possible angles, but holding the distance between camera and object constant. The images are then processed with specialized software (e.g., Agisoft) that transforms the pixel-based digital images into point clouds. If dense enough, these point clouds then produce a 3-D image of the object. This file can be uploaded to an online host, such as Sketchfab, or can even be sent to a 3D printer. Photogrammetry is also increasingly being used underwater to record objects *in-situ* and even to document phases of shipwreck excavations (e.g., Demesticha, Skarlatos & Neophytou 2014). Other commonly used 3D timber recording methods include 3D laser scanning and FaroArm Contact 3D Digitiser (Jones 2013).

RTI requires slightly more equipment but is still possible to conduct in most field situations. The high-res digital camera is mounted on a tripod in a dark room with a reflective object, such as a billiard ball, between the camera and the artefact being recorded. The camera and billiard ball remain stationary, while the flash goes off at various distances and angles from the artefact. The photographic files are then processed by computer software (RTI processing and viewing freeware is available from http://culturalheritageimaging.org) that overlaps the images into a single .rti file. The viewer can than change the lighting on the object to literally highlight the surface that reveals the most information. Besides its many archaeological and historical applications, this technique is also used by the FBI to capture notes written on pieces of paper that were torn away: the message imprinted on the sheet below is invisible to the naked eye, but RTI can make these faint marks readable again.

3.2.3. Text-based description

Text-based descriptions are also needed for each sample in order to record qualitative and quantitative information about the object. Height, width, thickness, and if possible, weight, should be documented. Written descriptions of the sample's unusual features will complement the visual records and also add substance to the project archive. The condition of the wood should also be described, noting the level of damage (either on a scale or in descriptive terms), and its cause.

Of utmost importance, and something that cannot easily be relayed visually, is the archaeological context from where the sample originated. While the sample's context was recorded in situ before its removal, that information will be important to have on hand in numerous places. Furthermore, the context can also be important for the laboratory analyst who should be given copies of all descriptive forms along with the samples. Taking note of sediment type, depth, original versus inflicted damage, size, and other factors will help clear up any discrepancies further down the road.

3.2.4. Storage

In most cases, the location of the fieldwork and the location of the lab(s) conducting analyses will not be the same. A plan for storing samples during this period between surfacing, recording, and wood science should already be in place before the field season begins.

In general, waterlogged wood should be kept wet, cool, and out of direct sunlight. Ideally then, temporary storage in a refrigerator would be a clever solution, especially in warm climates. However, this is not always possible, so other solutions could include keeping well-cleaned samples in large plastic containers filled with water (fresh or sea). These containers can be kept in a garage, below decks, or any other place where they are cool and out of direct sunlight. Retaining water may need to be replaced every few days depending on ambient temperature so that the storage environment creates the fewest possibilities for rot or other biogenic damage to occur. As detailed below, biogenic contamination of samples can impede the results of several different dendroprovenance methods.

Ideally, analysts will be prepared to receive samples within only a few days of their removal from the site. When packing samples to mail or deliver to a laboratory for analysis, as much water as possible should be removed before wrapping the sample loosely in bubble wrap, foam, or other cushioning material. Samples should be kept like this for as short a time as possible, and still handled with great care.

3.2.5. Database management

Developing an effective database for recording archaeological fieldwork is an important part of every archaeological research project. When the project involves diving, *in-situ* recording, and sampling, the amount of records can quickly pile up. Databases not only help manage these records, but they can lay the essential groundwork for GIS- or web-based dissemination strategies. However, the database and the data itself must be structured correctly to be effective tools for researchers both inside and outside the project. And because database structures can quickly become complex and change 'as-needed', it is recommended that data is first entered into a spreadsheet, and then transferred into the database when the structure is finalized.

Data is organized by codes that indicate the type of data being referenced. This is usually a string of numbers and letters (units) that are organized from most broad to most specific, and which reference other elements in the database. For example, let's say we want the database to record the characteristics of a timber sample from the shipwrecked galleon at Ribadeo, Spain. The first unit within the code for this timber sample might start with the site code. This is an arbitrary configuration of numbers and letters, but the configuration must remain consistent, and it helps if it is obvious. For this site, we choose RIB01 – the first three letters of the location or name of the vessel when it sank, and a numerical code indicating order. The numerical order will become important if more than one vessel is discovered at the same site, as frequently occurs.

The second unit would reference the artefact within the site; in this case, the artefact would be the timber. So for example, the first timber labeled and recorded *in situ* might be labeled 001W, with the 'W' indicated the material type: wood. The fifteenth timber would be 015W, and so forth. However, other artefacts may be recorded and other types of samples removed from the site. The qualitative letter marker should always be placed at the end of the unit so that each numerical code is unique (i.e., there would never be wood, metal and ceramic artefacts with the same numerical code (W001, M001, C001); instead, each number is unique, and the letter simply serves to qualify the material. In this way, should the qualifier ever need to change, this can easily be done without disrupting the numerical order and introducing possible errors into the database. Now we have a string of RIB01-001W.

The third unit references the sample taken from this artefact. In our example, let us presume that there were three samples removed from the same timber. These could be identified as 01S, 02S, and 03S, where 'S' is for sample. This gives us a string of RIB01-001W-01S and so on.

Finally, as described below, if and when these samples are divided further, they can be assigned 01SS, where 'SS' is for sub-sample. This gives us a final string of RIB01-001W-01S-01SS, continuing numerically indefinitely. Naturally, this system can be adapted to the needs and aims of the project, as long as the ID codes are unique, representative, and searchable.

3.3. Sub-sampling

It is likely that a single sample removed from a shipwreck will be sent to several different laboratories for different purposes. This is called sub-sampling. Each analysis listed above and below has different criteria to achieve the most reliable, accurate results: the size of the sample, from where in the tree it was converted, age of the sample, condition, etc. The following section describes ideal samples for each analysis as well as the minimum criteria for analysts. This information was provided by scientific analysts at European research institutions engaged in dendroprovenance, specifically of timber samples from Iberian shipwrecks of the 16^{th} - 18^{th} centuries. However, like much of the practical information presented here, these general criteria may also be applied to other archaeological contexts.

3.3.1. Dendrochronology

For dendrochronological measurements, contamination is not such a threat to accurate results. The primary requirements for a dendrochronology sample have to do with the orientation and the number and type of rings. A sample should include a minimum of 50 annual growth rings (but over 80 is preferred), and would ideally also include the pith and the outermost sapwood rings or even the bark edge. Samples that represent slow-grown trees will provide the most amout of information. Complete cross-sections are ideal, because even if the timber has been damaged by wood-boring organisms (especially gribble, piddock, and shipworm) or is otherwise damaged, accurate ring sequences can often still be constructed. Waterlogged samples should be kept wet, as drying will lead to distortion in the rings. The pith provides the first growth year of the tree, while the bark provides the last; even if the bark or bark edge is not retained though, the felling date of the tree can sometimes be reconstructed with sufficient sapwood rings. Clearly, in an underwater context, this ideal is not often met, so any transverse section with 50 or more rings is worth submitting for analysis. While coring along the radius of the stem is common on land, increment borers cannot be used underwater, so whole cross-sections must be taken, or end sections of radially-sawn planks (see above, 3.1). However, because the analysis is not destructive to the sample, it can be reused for another analyses, such as anatomical and structural studies. (For more information on dendrochronological dating, see Historic England 1998).

3.3.2. Dendroarchaeology

Samples for dendroarchaeology are the same as they would be for species identification, so no great size or particular part of the tree is needed. The sample should represent at least a few fully visible annual growth rings, and should also include tangential and radial sections, so a cohesive bit of wood a couple cubic centimeters would be enough to suffice in most cases. These samples could easily be taken from remnants of other analyses, such as dendrochronology, anatomy, DNA, or radiocarbon. In the vast majority of cases, species identification will be performed prior to any of the analyses discussed here, but it never hurts to seek multiple opinions, especially with such a low-cost method which offers a quick turnaround time.

3.3.1. DNA

Submitting wood samples for DNA analysis is different from collecting DNA for forensic evidence or for the human genome project, although contamination is a serious issue in each. A wood sample may come from any part of the converted tree; however, it must be large enough that contaminated areas can be removed and still leave something over for the analysis, which requires at least enough wood to fill three 2mL reaction tubes. In underwater contexts, wood is likely to be contaminated with mollusk shells from wood-boring organisms and a whole host of sealife; regardless, anyone handling the sample should use sterile Latex gloves and avoid further contamination through bodily fluids (sweat, oil, blood, saliva, etc.). Storage of wet or waterlogged samples is also problematic, as they cannot be held in paper (the usual recommendation), and sterile plastic containers quickly become breeding grounds for bacteria and fungi. In this case, samples are best kept refrigerated in an open container in fresh, clean water before handing over to the laboratory.

3.3.4. Geochemistry

At the time of writing, geochemical methods require samples suitable for measurement with a mass spectrometer, and individual samples do not have to be more than a gram or two. However, when delivering a sample for these purposes, contamination factors into the minimum size needed, as does the need to run multiple destructive analyses on the same sample to ensure measurement and instrument consistency. Therefore, ideal samples will be at least 5 cubic centimeters (or 50 grams of a dry sample), so that contaminated areas, such as teredo galleries lined with calcite, can be removed and that sample divided up still further to run repeat measurements. The sample may be from any woody part of tree: sapwood, heartwood, branch, bark, or even twigs. It should be stored dry or refrigerated in clean water and a sterile plastic container. The turnaround time can take weeks.

3.3.5. Anatomical and structural markers

Microscopic analysis of a wood sample for distinct anatomical markers is not destructive, and turnaround time can be quite fast, taking only a few days. The sample should include at least 40 growth rings, preferably from the stem of the source tree. This sample can be reused for and from dendrochronological investigations, and it could be reused for structural analyses or radiocarbon. The great the sample size and number, the more representative the investigations can be of the entire tree.

On the other hand, FTIR (Fourier transform infrared) spectroscopy and Py-GC/MS (pyrolosis-gas chromatography/mass spectrometry) are destructive analyses, but samples can be reused from dendrochronology or wood anatomy. Preferably, two samples per timber should be provided (again for instrument and measurement accuracy), and these should have minimal damage (scars, infestations, breakage, etc.). Ideally, the sample should be a core or transverse section that retains the pith and bark, or at least sapwood. The turnaround time is similar to other spectrometer-dependent analyses, with roughly four weeks needed.

3.3.6. Radiocarbon (C14)

While not a useful isotope for provenance, like C13, this analysis is included here briefly because it is one of the most common analyses undertaken on archaeological wood. Furthermore, because the archaeologist will likely sub-sample the initial shipwreck sample, it may be helpful to know what is needed to sub-sample for radiocarbon dating. Timber samples needed for C14 analysis can be of only a few grams, but the samples should be representative of the cutting date of the tree. For this reason, samples should ideally be taken from the outermost sapwood rings. This is because timbers cut from long-lived, slow-grown trees will often include hundreds of rings, each of which would provide a different date; a sample of the pith of such a tree would produce a date centuries older than the construction of the ship. Wood taken for radiocarbon testing should be handled with latex gloves to avoid contamination, and samples should be kept apart in sterile plastic bags or boxes. 33

4. Legal considerations

Today, heritage is political. As a result, legal considerations for archaeological work underwater differ greatly depending on federal (or in some cases state, provincial, or civil) jurisdiction in the area where the work is to be undertaken. The following information is based on legislative regulations in the United Kingdom at the time of writing. Despite the fact that the UK has not yet ratified the 2001 UNESCO convention on the protection of underwater cultural heritage, its national regulations for permissions, documentation, qualifications, and reporting archaeological work (and even more so for archaeological work underwater) are strict and complicated compared to the regulations of many European and other industrialized nations. The reader is encouraged to seek out current standards as they apply to their proposed place of work, even if work is to be done in the UK, as legislation regarding heritage frequently changes. It is the archaeologist's responsibility to be fully aware of all legislative concerns before pursuing work on an archaeological site. Awareness of restrictions and permissions should be raised far in advance as applications can take weeks or months to be processed, and some licenses may be accompanied with fees. While the paperwork and fees may be a hassle, noncompliance would undoubtedly result in litigation and fines amounting to a great deal more paperwork and fees, not to mention a damaged reputation that could have far-reaching implications.

4.1. Heritage and environmental organizations

Under the UK's National Heritage Act of 1983, Historic England (formerly English Heritage, or the Historic Buildings and Monuments Commission of England) was established as a non-departmental public body sponsored by the Department of Culture, Media and Sport. Among other responsibilities, it supervises activities that impact cultural heritage, including archaeological excavation on land and under water. In order to conduct archaeological research on a designated underwater site, Historic England requires a permit for either survey or excavation, which is granted to a licensee free of cost. The licensee furnishes a complete project plan (including risk assessment; see below, 4.2.2; Historic England 2015d [2006]) for activities on the site, how artefacts will be dealt with, and how the results will be disseminated. If a permit is granted, it is valid until 30 November, after which the license must be renewed to continue work on the site. Regardless of whether or not the permit is to be renewed, Historic England also requires a licensee report by 30 November detailing the work that was done on the site, by whom and when, the status of any artefacts or samples removed from the site, analyses being undertaken, the condition of the site and its level of vulnerability, the results of the work, how it will be disseminated, and a prospectus for future work (see Historic England 2015c [2010b] and below, 4.4.).

In regards to underwater archaeology, Historic England also works closely with the Marine Management Organisation (MMO), another non-departmental public body, which was established as a result of the Marine and Coastal Access Act of 2009. As one of its remits, MMO monitors activities that impact the seabed through deposition or removal of material and includes activities such as drilling, dredging, and even burials at sea. Their current policy in regards to underwater archaeology is dependent upon whether or not power tools will be involved in excavation. If only survey work is being done, or if sediment can be removed by hand-fanning, troweling, or shoveling, then no permit is required. If an airlift or dredge, or a chainsaw (for example), is to be used, then a marine license is required and should be produced when applying for an excavation permit from Historic England. In most cases, licenses for underwater excavations are eligible to use MMO's fast-track system, which has a fixed fee of 175 GBP.

4.2. Approved Code of Practice (ACoP) for Scientific and Archaeological Diving Projects

The UK Health and Safety Executive (HSE) is another non-departmental public body, which emerged after the Health and Safety at Work etc. Act of 1974. HSE has generated guidelines for many different types of work conditions, and within the category of work that involves diving (SCUBA or surface supply), there are five categories: commercial offshore, commercial inland/inshore, media, recreational, and scientific or archaeological. The ACoP for scientific and archaeological dive operations using SCUBA outlines a set of procedures, including a chain of command, that should be followed to ensure that underwater fieldwork is in compliance with the law (Health and Safety Executive 2014 [1998]). While the reader is strongly advised to seek out the analogous set of legal guidelines relating to health and safety at work for her/his own locale, this section will paraphrase the ACoP's position on dive planning and risk assessment.

4.2.1. Diving Project Plan

Different from the general project plan required by some heritage protection agencies, such as Historic England (see above, 4.1), the diving project plan lays out the details of diving operations, while minimizing the details of the archaeological background, significance of the work, and any top-side procedures such as recording, conservation, or dissemination. The diving project plan should break down specific underwater operations and explain how they will be achieved and how they will be supervised. In open water situations, the supervisor will not be diving and instead must maintain a two-way communication (through voice or lifelines) with the divers conducting the operation. Therefore, in the diving project plan, either the contractor or the supervisor must explain how each operation will be safely supervised by no more than one person on the surface. Each member of the diving team should have access to the plan before operations begin, and any changes to operations should be updated in the plan. The plan and its accompanying risk assessments should be ready at hand at all times while underwater work is being conducted.

4.2.2. Risk Assessments

An integral part of the diving project plan are the site- and date-specific risk assessments and emergency safety procedures. For the general project plan (see above, 4.1), the risk assessment will be site-specific. However, for the diving project plan, this will need to be updated daily for each site where work is to be done underwater. The daily and site risk assessments should evaluate all possible risks to those involved in boat and dive operations. Therefore, circumstances of weather, visibility, depth, breathing gases, decompression, currents, air temperature, water temperature, entanglement risks, slipping onboard, etc. should all be evaluated and rated. For the site risk assessment, these may be somewhat general, as weather conditions, for example, are subject to change, while visibility, currents, and entanglement on the site can be averaged or surmised. However, the daily risk assessment will be more specific to the present conditions of the atmosphere, the support vessel, equipment, etc. Each risk assessment must also demonstrate ways in which risks are being mitigated, such as briefing divers on hazards, ensuring that divers are wearing exposure suits appropriate to water and weather conditions, etc.

Finally, emergency contact information must be kept up to date and in a readily accessible location. This document should include contacts (telephone, address, and radio if applicable) for coast guard, nearest decompression chambers, local doctors and hospitals, police, and any other relevant sources for emergency assistance.

4.3. Receiver of Wreck

The Receiver of Wreck (RoW) is a government official who addresses the treatment of wreck and salvage operations as delimited by the Merchant Shipping Act of 1995. Besides the UK, Canada and Ireland also have a receiver of wreck, and other countries may have similar posts or agencies that interpret federal or local salvage laws on behalf of finders and owners.

Under UK law, 'wreck' can be considered:

Flotsam: floating goods lost from a perished ship that can be recovered on the surface of the water

Jetsam: goods cast overboard from a ship in danger of sinking without the intent of later recovery

Derelict: property (goods or the entire vessel) abandoned at sea without the intent of later recovery

Lagan: goods cast overboard in a manner such that the owner could retrieve them at a later time

Any items falling into these categories, regardless of size or significance, and landed in the UK must be reported to the RoW, even if the finder and owner are the same entity. The fine for not reporting items is up to 2500 GBP. In the UK, reported items may not be removed from the country for one year, nor may they be destroyed or sold. During this one-year period, the RoW may conduct an investigation into the ownership of the wreck, and the owner may step forward at this time to present a title of ownership to the RoW. Unclaimed wreck is handed over to the Crown after one year, unless the find was made outside UK territory, in which case the unclaimed wreck is handed over to the finder as salvage. For more information, see https://www.gov.uk/report-wreck-material or JNAPC 2007.

4.4. Follow-up reports and archiving

Archiving is necessary because it allows primary information to become available for public consultation, and therefore, open to alternative interpretations. This is the case for archaeological data, including any scientific or otherwise quantitative results to come out of archaeological fieldwork. Licensee reports submitted to Historic England (see above, 4.1) are archived in the Historic England Archive. Other pieces of archive deposited with HE are available to view free of cost, or for a fee to download from the organization's website or to receive a print copy. Other kinds of follow-up reports may be required from funding organizations. In all cases, the outline of the final report should include a project background, objectives, methods, results, prospectus for future work, and bibliography;

however, each entity requesting a report will have its own requirements, and in many cases, a template may be provided or requested to make sure that all reporting standards are met. Licensee reports are incorporated in the local Historic Environment Records (HERs) where the archaeological work is being done. Keeping HERs up to date ensures that local authorities are aware of the heritage that may be at risk by development.

Researchers working outside the UK should check with that country's respective heritage agency to learn about the standard procedures for archiving data and their requirements. To assist in this task, the Archaeology Data Service (ADS) in the UK and Digital Antiquity in the US have collaborated to provide a set of general guidelines for ensuring the archival quality of digital documents produced during archaeological fieldwork (Niven & Pierce-McManamon 2007).

Archiving standards for archaeology have been compiled elsewhere as well (Brown 2011 [2007]; ARCHES 2007-2013) to include non-digital records, such as licenses, maps, logbooks, drawings, plans, film and slide photographs, etc. For underwater archaeology, dive logs are also an essential part of the archive.

When dealing with samples, the sample itself as well as the results of analyses undertaken will also become part of the site archive. Therefore, there will need to be an arrangement with a appropriate archiving and/or conservation facility for how and where the samples will be stored after analysis, assuming non-destructive methods are used or there are remaining materials after destructive analyses are conducted.

For the results of scientific analyses that may be conducted for dendroprovenance (see above, 2.1, 3.3), there are international databanks available for tree-ring studies and most recently, some stable isotope analyses. The most commonly used databank for dendrochronology is the International Tree-Ring Data Bank (ITRDB) which is hosted by the US National Oceanic and Atmospheric Administration (NOAA). All tree-ring data and metadata may be stored here free of charge and is likewise available for free to researchers worldwide. Recently, efforts have been undertaken to include isotope data, particularly carbon-13 and oxygen-18, in the metadata of tree-rings. TRiDaS is an independent database and represents another option for the deposition of standardized tree-ring data and metadata that can be read universally (Brewer & Jansma 2015). Besides tree-rings, there are also several genome databanks, the most inclusive being GenBank, which represents a vast open access repository for DNA sequences of all types of organisms, including plants. GenBank and the related databank Genome are both maintained by the US National Center for Biotechnology Information (NCBI).

5. Ethical considerations

Aside from the far-reaching legalities involved with shipwreck archaeology (see section 4), which are dependent on local legislation, ethical considerations apply more universally. They may not be governed by laws, and noncompliance may not be punishable with fines, but abiding by the set of guidelines presented below will help to ensure that the irreplaceable heritage that shipwrecks represent is treated with the respect that it deserves. While the sale of antiquities is discussed above (1.3), this section will discuss issues of in-situ preservation, maintaining site 'authenticity', archaeology as a destructive science, and the importance of dissemination (especially open-access) in maritime archaeology.

5.1. UNESCO and in-situ *preservation*

The 2001 UNESCO Convention for the Protection of Underwater Cultural Heritage recommends in-situ preservation as first recourse. The reason for discouraging unnecessary surfacing of cultural heritage results from three main lines of thought:

- Laboratory treatment of water-logged elements may be expensive and time consuming, while always a risk of deterioration of material remains.
- Museum buildings often lack room and conditions to accommodate large size wooden or metallic objects recovered from wrecks or submerged ruins.
- The authenticity of a site, its context and its integrity cannot be guaranteed when objects are recovered from it. The special significance of heritage as testimony of an historic event as well as the attraction of the underwater environment can best be preserved by opting for in situ conservation.

However, the Convention acknowledges that leaving heritage assets in-situ is not always the best course of action (or non-action, as the case may be). Recovery of artifacts or even entire vessels can be justified if doing so would make a “significant contribution to protection or knowledge or enhancement of underwater cultural heritage” (unesco.org). What constitutes a “significant contribution” is subjective, but the following three scenarios are provided:

- the underwater cultural heritage remains are threatened by any natural or human factors (i.e., urban and port developments, pillage, environmental conditions, etc.);
- scientific research can get results that contribute significantly to the knowledge of the history of humanity;
- study, research, and dissemination enhance the awareness and consideration of a region towards the protection of its underwater cultural heritage.

The second scenario applies most directly to any archaeological campaign with a focus on in-situ timber sampling for provenance. However, in many cases, two or even all three scenarios could apply to intended investigations on a shipwreck. As mentioned above (3.1.1), the seafloor is a dynamic place, and in areas subject to intense anthro-, geo-, or biogenic changes, wooden ship remains are frequently at greater risk for loss or irreparable damage. Additionally, because 'Iberian' shipwrecks are found all over the world, a shipwreck excavation or sampling campaign could be a rare chance to raise awareness of submerged heritage in places that may not have major public museums, like the Vasa or the Mary Rose, devoted to maritime heritage (see 5.3). Before removing any material from a site, these factors – complex and subjective though they may be – should be taken into consideration and applied to the site under discussion. Each is unique, and therefore, each must be considered in light of its own circumstances above and below the waves.

5.2. Destruction or displacement?

As stated above (5.1), UNESCO's third reason for encouraging *in-situ* preservation claims that, “The authenticity of a site, its context and its integrity cannot be guaranteed when objects are recovered from it.” With the removal of wood samples from a shipwreck, or other artefacts of the assemblage, the site is changed permanently. While most archaeologists readily admit that ours is a destructive science, alternatively, we can think about sampling procedures less as destruction, and more as displacement (Lucas 2001). All intrusive fieldwork, whether ethnography, biology, geology, or archaeology, results in destroying the very things we are trying to understand. This sentiment of loss that accompanies the paradox of fieldwork stems from a basic understanding of the process as one of the disturbance of authenticity, integrity, or 'purity'. If we can reroute that thinking to understand this change of context as a productive rather than reductive one, then we can also see artefacts as objects existing in phases of context. As an object experiences displacement from one context, it experiences placement in another, so that archaeological practice becomes a creative act as much as a destructive one.

However, this line of thinking becomes slightly more complicated with wood samples. Particularly for those archaeological samples submitted to destructive analytical processes, such as mass spectrometry, traditional thought would claim that the processes of taking and analysing samples destroys both context and artefact. If that were completely true though, then the researcher would be left with nothing, and we know from practice that this is not the case. The artefact's context is altered, and rather than the object experiencing annihilation, its physical matter is likewise converted into quantifiable data, which is then subject to interpretation – again, creating new contexts (and new meanings) through various acts of displacement. This is perhaps a helpful way of thinking about sampling procedures: that is, while we have clear obligations for maintaining the primary source data, the processes of obtaining these data are not fundamentally inauthentic or impure.

5.3. Dissemination

Regardless of whether or not one prefers to think of archaeology, and archaeological sampling in particular, as destruction or displacement (or in another way altogether), disseminating our research questions, methods, and results is imperative. Other scientists as well as the general public share professional and personal interests in what archaeologists do. This is no less the case with shipwrecks, which are a subject of popular fascination the world round. However, underwater archaeology poses a great challenge to effective dissemination, especially to the public.

The nature of underwater archaeology is closed off to most people. Even sport divers have limited access to underwater sites, due to depth or other physical conditions, or due to the licensing requirements for protected sites. The most commonly visited shipwrecks are the ones that have been brought to the surface (Vasa, Mary Rose). Other vessels, such as the Newport Ship or Khufu's Solar Barge, were never wrecked per se but have been made available to the public through the opening of their own museum. This of course, is not possible in all cases: there may be limited funds available for such enterprises, or the level of preservation of the vessel may preclude its being lifted.

There are some effective examples of *in-situ* preservation in combination with public dissemination.

Shipwrecks in Lake Michigan rest in water clear enough that tourists can see the wrecks from glass-bottomed tour boats. Of course, this experience of a site is somewhat fleeting, and furthermore, it only works for shallow sites in clear water; deeper wreck sites or those in murky waters would remain unavailable. Dive trails are another good example of how the UNESCO convention can be followed while opening up heritage to the diving public. For example, a dive trail off the coast of Galicia (Spain) includes shipwrecks divable on SCUBA that range from galleons to submarines. The Spanish Plate Fleet wrecked along the Florida Keys in 1733 present another case for how Iberian vessels comprising a single wrecking event have been presented to diving communities concerned with heritage, instructed to "take only photos and leave only bubbles." However, the vast majority of people, even those with a vested interest in maritime heritage, do not dive. Modern technology can provide a way to combine in-situ preservation with dissemination to the public, diving or not.

3D models can be made through photogrammetry (for photogrammetry as a way to record sites, see above, 3.2.2), which can then be uploaded onto online platforms accessible by everyone with internet. The advantage of a 3D model, as opposed to a photomosaic, is that the audience has a greater chance to interact with the site. Viewers can 'swim' around features such as canons, concretions, and combustion engines, exploring even fine details for themselves.

A next technological step toward allowing viewers a 'dry dive' on the site is through augmented reality. These web-based software applications can give the effect of 'being' underwater, thereby giving audience members a more realistic experience of interacting with underwater heritage. All these methods champion the so-called "primacy of vision," so more democratic methods of dissemination could seek to appeal to other senses beyond only sight to develop a multi-sensory experience.

Involving local press and filmmakers can result in documentaries of the research on a site, which are highly attractive to the public. Documentaries can be uploaded to YouTube or other video hosting websites, and links can be made through social media, departmental or site web pages, or the project blog.

Although somewhat time-consuming, blogging can also be an effective way to engage the public and peers with ongoing project research. Interdisciplinary efforts will not go unnoticed, and blogs can highlight site work that extends beyond archaeology to include historical archive research, experimental components, visual recording, software engineering, specialist analyses, conservation efforts, and ecological awareness to name a few. One example of an interdisciplinary approach to an online blog can be found at forseadiscovery.wordpress.com.

Although perhaps not the most exciting method of dissemination, complete archiving is another important way of ensuring that work on a site, any materials lifted, results of analyses, and conclusions are made available to peers and the public, and that this primary source information is available for perpetuity as well. For further information, see above, 4.4.

Options for disseminating even underwater archaeology are only limited by the creativity of the researchers involved. Even with limited time and budgets, there are innumerable innovative ways to bring shipwrecks to the surface, so to speak, in order to foster a greater sense of appreciation for the fleets beneath the seas.

6. Conclusions

6.1. Future of scientific and nautical archaeologies

As demonstrated in the above text, nautical archaeology involving a strategic timber sampling campaign for dendroprovenance (or dating) can create several different avenues for combining shipwreck archaeology and archaeological sciences. With new methods for determining wood provenance being developed all the time, and established ones working steadily towards greater accuracy and precision, the future of dendroprovenance is bright. Likewise, nautical archaeology has also seen great advances in technology in recent years, including the use of acoustic and photographic mapping techniques, ROVs, and even specialized aquanaut suits for excavating deepwater wrecks. Underwater drones or other robotics-based engineering could be the next major technological advance applied to underwater archaeology. And countless other innovations are on the way, some of which we can't even imagine yet. This is truly an exciting time for archaeologists and for archaeology.

Training more underwater archaeologists in scientific specializations, and wood scientists in doing archaeology underwater, will help ensure that communications between the multiple brackets of archaeology remain open and productive (Jones 2004). This is not to say that specialist status is easy to come by, but having an idea of what it takes to extract and amplify DNA from piece of wood, or what it takes it to remove that piece of wood from the underwater environment, will lend perspective and foster mutual understanding of work environments and the amount of effort that goes into getting results. This can only result in greater cooperation and communication.

6.2. Importance of inter- and multi-disciplinary collaboration

Along these same lines, going beyond archaeology is increasingly important to gaining a more robust understanding of the past, and by extension, the present and future. Inter- and multi-disciplinary collaboration is essential to maximizing the informational potential of a site. While often used interchangeably, these two terms have subtle but important differences in meaning. Interdisciplinary refers to collaborations that involve several disciplinary approaches to create a unified story. Multi-discplinary collaborations involve several disciplinary approaches to create a variety of stories about the same subject. Both approaches can be used within the same project. By examining the same subject from as many different angles as possible, it becomes possible to reach a consensus. And even if a consensus is never reached, say for example, on the provenance of a certain shipwreck, the differences in results and conclusions incite the kind of debate that stimulates still further research, which in turn, refines the methods available for use and even the questions able to be asked.

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