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From Forests to the Sea, from the Sea to the Laboratory: the Timbers of the Frigate Santa Maria Magdalena (18th Century)

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Abstract

The case study of the 18th-century Spanish frigate Santa Maria Magdalena constitutes one of the opportunities given to the ForSEAdiscovery (“Forest resources for Iberian Empires: Ecology and Globalization in the Age of Discovery” - Marie Curie Actions Initial Training Network) project team to approach the subject of shipbuilding and timber supply in the Iberian Empires of the early modern age. This was to be achieved in an interdisciplinary way through the combination of three different disciplines: history, through the research of written sources; archaeology, through the collection and study of the material evidence of ships; and, wood science, though the analysis of timber samples from archaeological sites and old living trees.

Keywords

18th century, Spain, interdisciplinarity, archives, timber

Introduction

Driven by the increased demands on seafaring defense, the Spanish Crown launched the Santa María Magdalena frigate from the Esteiro shipyard of Ferrol (Galicia, north-west Spain) in 1773. In 1810, the ship was wrecked at the Bay of Viveiro (Figure 1), in the context of the Spanish War of Independence (1808–1814). In June 2015, the ForSEAdiscovery project team organised an underwater timber sampling campaign on this shipwreck site. Through various wood provenance studies (i.e. dendrochronology, inorganic and organic chemistry), combined with historical research in national archives and international sources such as the Sound Toll Registers, the frigate’s timbers promise to shed light on late 18th-century Spanish naval construction, forestry practices, and timber supply in relation to shipbuilding in northern Spain. As a highly interdisciplinary project, ForSEAdiscovery integrates research fields in the humanities and life sciences. This paper presents the joint efforts of historians, archaeologists and wood scientists to determine: 1) what kinds of trees were used to construct which parts of the Santa Maria Magdalena; 2) their provenance; 3) the timber trade networks and state management involved in supplying wood to the Ferrol shipyard; and, 4) best-practice methodologies to reach these conclusions.

Historical background

In the early 1770s, King Charles III (1759–1788) was developing the policy of shipbuilding initiated by his predecessors as part as the so-called Bourbon Reforms. These consisted of a programme of economic and administrative restructuring in which a new conception of a centralised Navy took a prominent role, as the key factor of the maintenance of a vast and spreading colonial Empire. In this context, the arsenals at Cartagena, Cadiz, Ferrol and Havana became the centres of the state-controlled shipbuilding industry (Merino Navarro 1981).

On 1 August 1772, a Royal Order announced a programme of construction of three urcas afragadadas, and one frigate to be carried out by the Esteiro shipyard (arsenal of Ferrol), and this is when the story of La Magdalena begins (AGS, SMA, 349, 1 August 1772). According to payment orders of salaries to the
shipwrights, its construction began in September and continued for the next ten months (AGS, TMC, 4207: 16 October 1772; AGS, TMC, 4207: 17 November 1772; AGS, TMC, 4207: 16 December, 1772; AGS, TMC, 4208: 22 January 1773; AGS, TMC, 4208: 20 February 1773; AGS, TMC, 4208: 18 March 1773; AGS, TMC, 4208: 20 April 1773; AGS, TMC, 4208: 20 May 1773; AGS, TMC, 4208: 21 June 1773; AGS, TMC, 4208: 24 July 1773; AGS, TMC, Marina, 4208: 28 August 1773). The official launch took place in Ferrol on 7 July 1773, and the document of its announcement described the vessel as a 26 to 34 gun frigate, 145 feet long (AGS, SMA, 350: 7 July 1773).

After 37 years serving the Spanish Navy in Atlantic waters, the Santa María Magdalena sunk in Viveiro bay (Lugo province, Galicia, Spain), along with the bergantín Palomo, in the context of the Spanish War of Independence (1808–1814). In November 1810, these Spanish vessels took part in an Anglo-Spanish squadron which fought against the French occupation of Santoña (Santander, Spain). On the night of 2 November, after being hit by a severe storm, the Magdalena, Palomo and a few other vessels had to evacuate Santoña and took shelter in Viveiro. The damage inflicted by the storm such as the loss of the anchors, determined the fatal outcome: the Magdalena collided with the English frigate Narcissus and later crashed against the Reef of Castelos and sunk soon after, taking the lives of 20 members of the crew (Fernandez Duro 1867: 220–25; Filliat 1976: 313).

History: timber supply in Ferrol (1771–1773)

The historical research aimed to obtain information about the construction process and main features of the Magdalena, as well as the model of timber supply in Ferrol during the late 18th century.

The archival research was mostly centred on the Spanish sources of the Navy administration corresponding to the section of the Navy Ministry (SMA) and state accounts of the court of auditors (Tribunal Mayor de Cuentas, TMC) from the Archivo General de Simancas (AGS), in Valladolid, Spain. In order to further investigate the subject of timber import from northern Europe, the research involved cross-reference with the Danish database of the Sound Toll Registers Online (STRO, last viewed 31 March 2017), which records the passages of merchant vessels and their products, from Baltic ports to their destinations, through the Danish Sound (Gøbel 2010).

Besides the information regarding the shipbuilding process and main features of the frigate, the researched sources did not contain any further data specifically related to the Magdalena, namely the timber used in its construction. Therefore, the team decided to work...
with historical documents dated from 1771 to 1773 about all the aspects of timber supply to the Ferrol Department in order to identify the whole context of timber acquisition. These documents cover the period of construction (1772–1773) and the previous years, in which some of the timber used in the Magdalena might have arrived.

Thus, the sources from AGS allowed the identification of three major regions of wood supply: northern Spain, northern Europe, and the Caribbean. Each of these major regions provided specific species and types of ship elements, and that is related, not only to the inherent qualities of the different woods, but also to the economic and technological strategies behind this model of supply.

**Timber from northern Spain**

The volume calculations indicate northern Spain as the main area of provenance of the timber used in Ferrol by the time of the Magdalena construction, corresponding to 73% (sum of 17,020 m³, during the years 1771 to 1773) of the total supply (23,418 m³) (Figure 2-A). Such preponderance is expressed, as well, in the diversity of species, from oak to ash (Figure 2-B) and, especially, in the diversity of the typologies of ship pieces (Table 1). However, the quantification of pieces by units shows that northern Spanish timber is not used for the majority of the pieces. This place is occupied by northern Europe with pine planking, masts and spars. In terms of units, northern Spanish timber corresponds to 35% in a total of 19,781 pieces out of 56,005 (Figure 2-B, Table 1). This discrepancy between volume and quantity is explained by the nature of the ship elements. In fact, northern Spanish timber was, by far, the preferred choice when it came to the structure of the hull, reinforcements and other elements below the waterline, which correspond to very sizeable elements when compared to planks, the most abundant type of piece (Table 1).

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2 except in the case of the data from TMC and STRO that was used in the cross-reference of northern European timber trade, which was extended to 1770.
3 this quantification involved 58 documents from the following sections and subsections: Secretaría de Marina, sub-section arsenales (units 347, 349, 350), sub-section asientos (unit 621), sub-section (unit 788); Tribunal Mayor de Cuentas, sub-section marina, Ferrol (units 4207, 4208); the documents exclusively used for the accounts are not mentioned at the final references to avoid having an exhaustive list; the quantitative data provided by the Spanish sources was unevenly presented in units and volume (cubic cubits); in order to calculate the volume of units, we searched for its approximate measurements within the pie de burgos measuring system, according to piece typologies (Gautier 1769; Fernandez de Landa 1784); the volume of Nordic pine pieces was calculated according to the measurements of the masts, spars and planks listed in the information about timber needs for 1772 and 1773 (AGS, SMA, 621: 15 November 1771; AGS, SMA, 621: 15 September 1772); for the calculation in cubic metres: Marien y Aróspide 1789: 28; Aranda y Antón 1999: 107; all these calculations are merely indicative.

Oak (Quercus) grew in northern Spain’s forests in special abundance, and this was the primary timber for those kinds of ship elements (Aranda y Antón 1990; 1999: 23–24), contributing to this region’s tradition as a strong Peninsular centre of shipbuilding at least since the 16th century (Goodman 1997). Proximity to timber sources was an obvious criterion of choice since it not only facilitated transport (costs and infrastructures) but also allowed the close control of trees by the naval engineers and shipwrights in order to assess quantities and quality in terms of material, shape and size (Aranda y Antón 1999: 15–16; Wing 2015: 178–87). The multiplicity and specificity of typologies of the structural elements of the hull and other pieces to be placed below the waterline, the measurements of which varied according to the size, scantling, typology and shipbuilding technique can be seen in the treatises, wood regulations (Gautier 1769; Fernandez de Landa 1784) as well as reports of shipwrights and engineers boards. These required closer supervision than the pine planks, deals, masts and spars used in the upper works, which were mass-produced and purchased from the Baltic region in varied but rather standardised measurements for multiple purposes (Gallagher 2016).

Following the proximity criterion, Asturias’s forests appear as the main region of supply, followed (in this order) by Cantabria, the Basque Country and Navarra. There was also a significant group of endogenous timber pieces with undetermined origin, which was constituted by spare timber from Guarnizo shipyard (Figure 2-B). Each of these regions had a contractor who operated the felling, carving and transport of timber by land and final delivery by boat: Andres Garcia Quiñones, António Francisco Quiñones and Juan Gonzalez Pola, for Asturias; Francisco Caetano Iglesias, for Cantabria; Real Compañía Guipuzcoana de Caracas for Guipuzcoa and Navarra. Oak, the predominant timber with 14,091 units, could be found from Asturias to Navarra and was, once again, mostly used for planking (4,218 units) followed by framing elements such as futtocks and beams, uncategorised pieces and then a great variety of types (Table 1). Beech (Fagus sylvatica) had a similar regional distribution and was used for planking, beams and also came in as raw timber. Holm oak (Quercus ilex) was identified as coming from Cantabria but for the most part its origin is not specified. It was used for axles of gun carriages and other non-identified applications. Black poplar (Populus nigra), walnut (Juglans regia),
Alder (*Alnus glutinosa*) and ash (*Fraxinus excelsior*) came from Asturias and were sporadically delivered in small quantities. Except in the case of walnut planking, these types of timber arrived as unprocessed timber. Pyrenean pine has a low representation within the overall northern Spanish timber accounts, corresponding to only 2% (402 m³). This supply is the result of technical experiments with the aim of reducing dependency from northern Europe imported pine (AGS, SMA, 349: 20 November 1771; AGS, SMA, 349: 25 July 1772; AGS, SMA, 349: 23 September 1772; AGS, SMA, 349: 14 November 1772) (Figure 2-B, Table 1).

The data indicates the secondary role of timber import through the Baltic trading networks, as these constitute 23% in terms of volume (total of 5,394 m³ along the 1771–1773 period), even if, in terms of unit quantities, northern European timber corresponds to 64%, with 34,550 pieces (Figure 2). This material is exclusively made up of pine, consisting of planking, the largest group of pieces in 34,338 units8, 45 main masts, and 167 minor masts and spars9 (Table 1), revealing the import

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8 excluding 32 from the Pyrenees.
9 excluding 27 from the Pyrenees.
### Table 1: Number of pieces per species and type, Ferrol—1771-1773 (AGS, SMA, 347, 349, 350, 621, 788; AGS, TMC, 4207, 4208).

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<th>beech (F.G.)</th>
<th>holm oak (O.I.)</th>
<th>cedro (C.O.)</th>
<th>guyacán (G.)</th>
<th>tropical (und.)</th>
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<th>walnut tree (J.R.)</th>
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<td>3317</td>
<td>1866</td>
<td>653</td>
<td>526</td>
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131
of highly specialised products. In a time of economical protectionism, the Maritime Departments would limit the acquisition of exogenous raw material to timber that could not be found in the Iberian Peninsula in abundance with the proper sizes, and that was strictly necessary for building vital and substantial parts of the vessels. That was the case of the pine species from northern Europe such as *Pinus sylvestris*, which exhibited long, wide and straight trunks making it especially suited for masts, spars and planks (Aranda y Antón 1999: 23).

This mass-produced timber served the European market (Astrom 1988) and Spain became a substantial importer, purchasing this material increasingly from the 1740s (Gallagher 2016; Reichert 2016). Spanish agents took part in the timber trade networks through supply contracts with the Navy, the so-called Asientos. By the time of the *Magdalena*’s construction, Pedro Chone, a Bilbao resident, was the provider of masts, spars and planking for the three Maritime Departments of Cartagena, Cadiz and Ferrol (AGS, SMA, 788, 2 January 1772). Aided by representatives in Spain, the contractor operated from the Baltic ports of Saint Petersburg, Riga and Danzig, negotiating with the local suppliers and coordinating the shipments through Dutch captains and merchant vessels such as urcas and galeotas (AGS, SMA, 621: 1 September 1772; AGS, SMA, 621: 29 May 1773; AGS, SMA, 621: 20 August 1773; AGS, SMA, 788, 2 January 1772). As the stocks seem to be constantly running out of pine, the Navy from time to time sought for alternative suppliers when the contractor was not able to fulfill orders in time (AGS, SMA, 350: 15 May, 1773; AGS, SMA, 621: 16 November 1771; AGS, SMA, 621: 20 May 1773).

According to STRO there were 35 passages containing timber destined for Ferrol via the Danish sound between the years 1770 and 1773. Only seven of these can be matched to records in the TMC. Possible reasons for this are that the timber may have been redirected or re-exported to another port, or that the wood was purchased by someone other than the Navy. After all, timber was also needed for general carpentry, private construction, and private shipbuilding. Indeed, six of the unmatched passages contained timber that was designated for shipbuilding, such as masts and spars, or accompanying products such as hemp or sailcloth.

Of the matched records, all were carried by Dutch captains, representing Ameland, Amsterdam, Hoorn, and Warns as homeports. Three of these passages originated from Danzig, and four from Riga. Products brought from Danzig were fir deal (fyre dehler), thick planks (bohler), and unspecified wood products (travahre). Products brought from Riga were boat-hook shafts (baadshagestager), balks (bierl), ordinary deals (gemeene dehler or ord. dehler), masts (master), spars (spirrer or raar), and planks (planker). Only two shipments matched closely with the products and numbers given in both the TMC and STR.

These discrepancies make it difficult to conclude how much Baltic timber noted in the STR was destined for the Spanish Navy. Out of 50 payment orders in the TMC for the department of Ferrol concerning the acquisition of timber within Europe between the years of 1770 and 1773, only six could be confirmed to concern timber that came directly from the Danish Sound (representing seven STR records). Only two other shipments were re-exported via Amsterdam, and, thus, are not reflected in the STR. This suggests that the majority of the Navy’s trade with the Baltic was direct by this time, rather than passing through a ‘middle person’ port such as Amsterdam.

An important aspect which the Sound Toll Register corroborates is that the imported timber was never oak, or any of those pieces necessary for the framing elements of the hull. Instead, they mostly consisted of spars for rigging and various sizes of pine planking, which were used in the final construction steps of a ship, such as upper hull planking, deck planking, and sacrificial outer planking.

The Caribbean supply corresponds to only 3% of the total volume with 104m³ and 1674 pieces (Figure 2). This timber had its origins in Cuba and Mexico, and its supply was locally operated by shipbuilding contractors of the arsenal of Havana, and then the Navy and Crown colonial officers would transfer part of this material to Spain, through the ships of the *Carrera de Indias*, among other goods in its cargoes, such as sugar, which was the possible reason for the low volume of each shipment. Cadiz was the destination port of this route from 1717 and worked as a redistribution hub, by sending material to Ferrol, as well as Cartagena (AGS, SMA, 347: 6 February 1771). Sometimes, the transport was made by charted private ships, which would deliver the material directly to Ferrol (AGS, SMA, 347: 4 May 1771; AGS, SMA, 347: 24 August 1771).

The tropical timbers such as guayacán (*Guaiacum*), cedro real (*Cedrela odorata*), chicharrón (*Terminalia eriostachya*) and sabicú (*Lysiloma latisiliqua*) are very hard, dense and resistant types of material, particularly suited...
for the crafting of structural pieces and those, which are subject to aggressive elements, such as constant friction and exposure to corrosion by shipworms such as *Teredo navalis* (Aranda y Antón 1992: 7–31; Aranda y Antón 1999: 27). Thus, the lists of deliveries contain cedrela futtocks, stringers, wales and anchor stocks of undetermined tropical species, keels made of cedrela and chicharrón/sabicú, cedrela top timbers, guayacán logs for further carving, chicharrón/sabicú and cedrela keelsons, among other typologies, and a vast group of undetermined typology of guayacán pieces (Table 1).

Some 1771 and 1773 documents may contain the explanation for such small deliveries, as they mention that the Spanish arsenal’s stocks were already well supplied with guayacán (AGS, SMA, 347: 19 July 1771) due to the constant shipments and low use of this material and, therefore, new shipments should be suspended (AGS, SMA, 350: 4 June 1773; AGS, SMA, 350: 10 July 1773).

**Archaeology: sampling the *Santa María Magdalena* timber assemblage**

The remains of a vessel constitute the ultimate evidence of how ships were built (Steffy 1994). As mentioned above, the frigate *Magdalena* was built in the shipyards of Ferrol and sailed for about 37 years in the service of the Spanish Navy. During that time, the vessel benefited from repairs and adjustments that made her unique in many ways. *La Magdalena*’s unique features are a testimony to a specific moment in naval history in which several countries were at war and were in direct competition for the expansion of their overseas power.

Also at this time, shipbuilding technology was shifting into the experimental. Shipwrights and shipbuilders were developing and testing building techniques using wood species other than oak and pine, which had been the woods of choice for hundreds of years. According to Enrique García-Torralba Perez (2011: 257, 258), the *Magdalena* was part of an experiment and, therefore, built following specific procedures. Under the same geometric plans, four vessels were constructed in the shipyards of Cartagena and Ferrol: *Magdalena*, *Margarida*, *Marta* and *Clara*. Despite sharing the same drawings and architecture, different wood species were employed allowing shipbuilders from the Spanish Royal Navy to identify and analyse each prototype and use the most reliable as a model to replicate. In order to better understand the decisions made in the forest and in the shipyard prior to the construction of the *Magdalena*, the ForSEAdiscovery dive team undertook an archaeological campaign in Viveiro, Galicia.

Over the course of seven days in June 2015, the ForSEAdiscovery dive team removed 22 wood samples from the hull remains of the *Magdalena* at the bottom of the Viveiro Bay (Figure 3-A) in order to elucidate the circumstances of her construction—how she was built, with what kinds of wood, and from where that wood originated. In cases like the *Magdalena*, historical sources can be highly suggestive of where shipbuilders procured their timber, but taking timber samples from shipwrecks has several advantages over relying solely on the historical sources, even in well-documented cases like the timber supply for the arsenal of Ferrol:

1. Providing wood scientists with samples for further study is the only way to develop scientific methods of dendroprovenance so that they can be used in cases without historical documentation;
2. The scientific method allows for ‘proofs’ of provenance that frequently challenge so-called reasonable assumptions as well as historical documents made in error;
3. Timber sampling campaigns permit an individual study of elements used in shipbuilding, such as wood types, scantlings, joinery and fixings used, as well as gathering the extent of the remains and their level of preservation and risk.

One of the outcomes of the ForSEAdiscovery project has been to generate a set of protocols for the removal of wood samples from historic shipwrecks, and the fieldwork done at the *Magdalena* has been instrumental in this development. The sampling protocol defined that the impact on the remains of the vessel should be minimal. Therefore, it was only after mapping, sketching, positioning and using other non-invasive recording methods that timbers were finally sampled. To gain the highest volume of provenance data while creating the least amount of damage to the shipwreck, certain timbers were targeted for sampling while others remained untouched. Elements likely to represent the original structure of the vessel, such as planks, beams, and frames, were preferred to minor elements which were frequently replaced and/or which would be unlikely to contain sufficient or reliable data for provenance.

In general, archaeological evidence of Iberian ships (Castro 2008; Oertling 2001) demonstrates a common practice of utilising the parent tree’s growth pattern for the required timber shape. This technique, alone, promises to help gain a better understanding of the relationship between Iberian shipbuilding and forest management. For one, it demonstrates that shipbuilders were well aware of the properties of the wood they selected, and that this knowledge at the disposal of the shipbuilder led to the creation of more reliable vessels (although this is not to say that this knowledge was always actually put to use). For example, fast-grown deciduous oak was frequently used for vertical elements like frames, while slower-grown oak could be used for
Figure 3. Sampling the *Magdalena* timber assemblage:
A) 2015 underwater archaeology campaign.
B) Sample of pine ceiling planking.
horizontal elements. Because oak is ring-porous, each ring represents a potential breaking point, so the more rings a tree and its derivative timber has, the more vulnerable it is to splitting with vertical pressure, as would be experienced by frames and stanchions (cf. Rich et al., this volume). Horizontal elements on the other hand do not experience the same kind of pressure against the cross-section. Therefore, to provide samples to wood scientists reliant on high numbers of annual growth rings (e.g., dendrochronology), planks were targeted over frames, the latter of which tended to represent the parent tree well but were often only a couple decades old when felled. Figure 3 is a sample of ceiling planking that was converted from a slow-grown pine tree and preserves 146 annual growth rings, which made it an ideal candidate for wood provenance analyses. Another factor in its suitability for our study is that even after 200 years underwater, this wood sample is very well preserved with very few boreholes introduced by Teredo navalis and other xylophagic organisms that would increase the difficulty of taking accurate measurements of tree-ring widths or of chemical composition.

Each of the 21 samples taken from the Magdalena was treated as an artefact. They were cleaned, measured, photographed, drawn, and entered into the ForSEAdiscovery database before being stored in fresh clean water and delivered to their destination—the wood science lab. The recording of each sample was performed with a tablet and stylus to produce detailed record sheets to hand over to the wood analysts along with the samples themselves, which are often destroyed over the course of analysis. These primary records are also retained in the database for studying the scantlings, tool marks, and joinery methods of sampled ship components, as well as the conditions of the wood when it was sampled, which may be useful for future conservation and site formation process analyses.

Wood science: aiming to establish the provenance of the wood

Once the shipwreck samples arrived at the laboratory of dendrochronology of the University of Santiago de Compostela (Spain) a selection was made, setting aside the best preserved samples (i.e. showing the fewest galleries caused by Teredo navalis) to divide them into subsamples that would be used for organic and inorganic geochemical studies of wood composition and characterisation. The main aim of the wood science team of the ForSEAdiscovery project is to develop reference methodologies and datasets to enable us to establish the provenance of Iberian ship timbers. These comprise tree-ring-based datasets (ring-width, earlywood, latewood, vessel and latewood density chronologies), stable strontium isotopic data, and data about the organic composition of different wood species in different areas. All these datasets have been developed for pine (Pinus nigra and P. sylvestris) and oak species (Quercus robur, Q. petraea, Q. faginea and Q. pyrenaica) in key areas of the Iberian Peninsula that supplied timber for shipbuilding during the early modern period (Domínguez-Delmás et al. in prep.). The techniques used for organic and inorganic wood characterisation have been conducted in a smaller group of samples of the trees used for dendrochronology and wood anatomy. Once the reference datasets have been concluded, it has been possible to cross-check the shipwreck timbers with them in order to try and identify the origin of the wood. In this work we present results of the dendrochronological analyses and preliminary data from infrared spectroscopy on the Magdalena shipwreck samples, researches carried out at the University of Santiago de Compostela (USC, Spain).

Dendrochronology: determining timber date and provenance through tree-rings

Samples from 21 different timber elements of the Magdalena shipwreck were sent to the laboratory of dendrochronology of the Department of Botany at the USC.

A preliminary inspection was carried out to determine the suitability of the samples for dendrochronological dating. Such samples should contain a sufficient number of tree-rings to allow for sound statistical results (e.g. 80 to 100 tree-rings). Exceptionally, timbers with as few as 30 tree-rings could be researched to attempt cross-dating with other samples from the same structure and, thus, all timbers with more than 30 tree-rings were analysed in this study. The transverse surface of the samples was cleaned with razor blades from the inner- to the outermost ring to perform a ring count and register the presence of pith and sapwood. This preliminary inspection also served to identify samples corresponding to the group of deciduous oaks (Quercus subg. Quercus) and chestnut timbers (Castanea sativa), as both present large early wood vessels placed in a ring-porous disposition although the deciduous oaks show large multiseriate medullary rays that distinguish them from the chestnut. These characteristics make them distinguishable by the naked eye. The identification of other species was attempted through observation with an Olympus BX40 microscope of wood anatomical features on thin slices of the radial and tangential section of the wood and using the identification key proposed by García Esteban et al. (2003). Ring-width acquisition was done with a TimeTable measuring device (University of Vienna) coupled with PAST5 software (SCIEM).
Table 2: Species identification and tree-ring analysis. 1) Quercus subg. Quercus; 2) Pinus sylvestris/nigra; 3) Castanea sativa; 4) conifer (unidentified); pith: present (+1)/absent (-); bark edge (WK): present (+)/absent (-)/estimated; MRW: mean ring width (cm); σ: standard deviation (cm).

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<th>Pith</th>
<th>Sapwood</th>
<th>Bark Edge</th>
<th>MRW</th>
<th>σ</th>
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<td>-</td>
<td>-</td>
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<td>0.51</td>
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<td>47</td>
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<td>-</td>
<td>-</td>
<td>Severely damaged by Teredo navalis</td>
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<td>3 MAG00015</td>
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<td>+</td>
<td>0</td>
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<td>-</td>
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<tr>
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<td>8</td>
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<td>1 MAG00013</td>
<td>28</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Not suitable dendro</td>
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Wood identification and dendrochronological results

Fifteen samples were identified as deciduous oak (*Quercus* subg. *Quercus*), five as conifers (four of which are *Pinus sylvestris*/*nigra*), and one as chestnut (*Castanea sativa*) (Table 2). The oak samples MAG01-001W-01S, MAG01-005W-01S and MAG01-020W-01S, as well as the chestnut sample MAG01-004W-01S were discarded for tree-ring analysis, as they contained fewer than 30 tree-rings (Table 2).

Cross-dating with oak and pine reference chronologies from Spain, central and northern Europe resulted in the absolute dating of three samples: MAG01-018W-01S (dated after 1667 C.E.), MAG01-019W-01S (after 1716 C.E.), and MAG01-021W-01S (after 1702 C.E.) with chronologies of *Q. petraea* of the north of Spain, being a *Q. petraea* composite chronology (made with seventeen trees from Cantabria and two trees from Asturias, QUPE19MC, Domínguez-Delmás unpublished) the one providing the best statistical results (Figure 4). The provenance of these timbers is, therefore, some forests in the north of Spain (regions of Asturias, Cantabria or Basque Country), but the dendrochronological results do not allow to pinpoint an exact location. The absence of sapwood in the samples hampers estimating the felling date of the trees, hence, the dates can only be given as terminus post quem (dates after which the timber was cut). The tree-ring series of those samples have been averaged into the object mean curve MAG3MC that spans the period 1590–1716. The rest of the samples did not produce statistically sound results between them.

Geochemical fingerprinting of *Magdalena* shipwreck: relevance of the initial FTIR results

Wood is a complex polymeric material composed by polysaccharides and lignins. These lignocellulosic macromolecules are responsible for most of the physical and chemical properties that result on differences between wood types (Hedges 1989). The variety of wood types is not only associated with the taxonomies and the environmental factors of the growing location but also to decay factors associated with the storage environment, particularly for archaeological woods (Fritts 1976; Hedges 1989). The characterisation of the molecular structure of wood chemistry allows detailed understanding of wood properties. Although considerable studies have been done using diverse types of techniques, much more effort is still needed for us to fully understand the preservation of the chemical composition of archaeological wood (Pandey 1999).

Fourier transform infrared spectroscopy (FTIR) is a widely used vibrational technique for wood analysis (Colom and Carillo 2005; Traoré *et al.* 2016). Unlike conventional chemical analysis, it has the advantage of time efficiency and does not require sample destruction (an important aspect when analysing archaeological artefacts). It has been used to differentiate between soft- and hardwood, showing that softwood lignin is essentially composed of guaiacyl moieties, whereas hardwood lignin is composed of guaiacyl and syringyl moieties (Colom and Carillo 2005; Evans 1991). FTIR has been more often used to evaluate archaeological wood in order to choose the appropriate conservation method. It is a useful technique for studying chemical changes that have occurred during the decay process undergone on ancient wooden artefacts. In this work we applied FTIR to some wood fragments from *Magdalena* shipwreck timbers in an attempt to evaluate the potential of this technique for allowing the identification of the provenance of waterlogged samples.

Four *Pinus* sp. (MAG02, MAG03, MAG15 and MAG16) and two *Quercus* sp. (MAG10 and MAG21) fragments were analysed by FTIR. The samples were oven-dried for two weeks at 30°C, and then the surfaces were cut in order to visualize tree-rings. Measurements were recorded on consecutive individual rings, from the outer part (recent rings) to the inner part (older rings) of each fragment. The FTIR-ART equipment used was an Agilent Cary 630 FTIR Spectrometer equipped with a single-reflection diamond crystal. The spectra were collected in the absorbance range from 4000 to 400 cm⁻¹ over 100 scans per sample, at a resolution of 4cm⁻¹. To get a first impression on the collected data, average and standard deviation spectra were calculated on the relative absorbance spectra. Average spectra reflect the dominant spectral bands, whereas the standard deviation indicates which are the largest relative variations (Traoré *et al.* 2016). For the purpose of this study, the samples were grouped according to the wood specie.

Figure 4 represents FTIR spectra of the two type of wood. The average spectra showed several peaks at identical bands for the two types of wood but according to the relative peak intensity there were differences. Very high peaks with lower intensity for oak woods were recorded at a band near 1030cm⁻¹, which is attributed to C-O stretching in primary alcohol in cellulose (Popescu *et al.* 2007). Moderate absorption peaks were recorded near region assigned to symmetric CH₂ valence vibration at bands 2925 and 2860cm⁻¹ (Schwanninger *et al.* 2004). Several lower peaks were presented at region for bands absorption associated to aromatic molecular structures vibrations with lower intensity for pine woods at 1590 cm⁻¹ and lower intensity for oak sample at 1690, 1510 and 1260cm⁻¹ (Colom and Carillo 2005). The standard deviation spectra showed higher variability in pine wood than in oak wood. The largest variabilities in
Figure 4. A) Magdalena oak samples dating. Tree-ring series averaged into mean curve MAG3MC, which dates against a Quercus petraea composite chronology (QUPE19MC). Legend: TBP: Student’s t adapted according to Baillie and Pilcher (1973); asterisks represent signification GL level (***, p<0.001); GL: percentage of parallel variation as defined by Eckstein and Bauch (1969), and indicated by the shaded background; CC: correlation coefficient; OL: overlap between the series; X-axis: calendar years. B) Average (a) and standard deviation (b) spectra obtained by FTIR.
pine wood were highlighted at bands near 2925, 2860, 1690 and 1030 cm⁻¹. These bands are due to absorption respectively C-H stretch, carbonyl bond vibration in carboxylic structure and C-O bond vibrations; these bands are main peaks for terpenoid compounds (Faix and Böttcher 1992, Schwanninger et al. 2004). The highest variability in oak woods was presented at band near 1120 cm⁻¹ a related typical syringil unit C-H bond vibrations (Popescu et al. 2007).

Conclusions

Despite the lack of data specifically related to the wood used in the construction of the Magdalena, written sources provide exhaustive information about the overall supply to the arsenal of Ferrol. These allow the characterisation of the context within which the frigate was constructed and, therefore, give relevant clues for the archaeologists and wood scientists about the species, provenance and application of timber in the crafting of different ship elements. In fact, the results of the analysis of the historical documents indicate the high probability that the remaining framing elements of the hull and other elements placed below the waterline contain a preponderance of northern Spanish timber, particularly oak, followed by the other less represented endogenous species, as well as a minor usage of tropical timber. On the other hand, aside from sacrificial planking, any northern European pine timber that might have been used in the ship’s construction was most likely applied in the upper works and, thus, has been destroyed through erosional and biodegradational processes over time on the archaeological wreck site. The documentary evidence about the use of Pyrenean pine is a significant factor for the identification of the provenance of the extant pine elements.

To supplement the historical data and to provide a scientific basis for the relationship between forestry and shipbuilding practices in 18th-century Ferrol, an underwater archaeology campaign was enacted. A primary aim of the campaign was to remove wood samples from La Magdalena’s remaining hull timbers for dendro-provenance. In accordance with the protocols for in-situ ship timber sampling (currently in development), specific timbers were targeted based on the likelihood that they would be able to provide sufficient provenance data to justify their removal from the shipwreck assemblage. Qualifying factors included the timbers’ function within the ship (i.e., original structural elements such as planks, frames, beams, etc.) and their condition (i.e., lowest levels of biogenic degradation). Timbers were fully recorded before sampling, and the 22 samples retrieved were treated as artefacts and equally recorded in great detail; these primary records are held in the ForSEAdiscovery database for further research into Iberian shipbuilding methods. The wood samples were then dispersed to partner laboratories for dendro-provenance.

Carrying out an appropriate sampling protocol is crucial for the success of dendrochronology. In the case of La Magdalena shipwreck, eleven out of the 21 samples retrieved presented almost 80 rings or more, and three of them could be absolutely dated with a provenance in the regions of Asturias, Cantabria or Basque Country in the north of Spain. This provenance is consistent with the information found in the historical archives about the origin of some of the wood supplying the Ferrol shipyard when La Magdalena was built. The lack of internal matches between more oak samples could indicate that the wood was sourced from different areas, which is also consistent with the archival information.

The preliminary results from the application of FTIR to La Magdalena shipwreck show the potential of using this technique to study waterlogged woods. The use of the average and standard deviation spectra enables us to obtain details about the chemistry of shipwreck timbers. From these results we can conclude that the combination of FTIR with powerful statistic methods is promising and may allow the identification of organic markers for the distinction between species and provenance of wood from shipwrecks.

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Online resources: