Chapter 9
The Timbers of the Frigate *Santa María Magdalena* (Eighteenth Century): A Spanish Warship in History and Archaeology

Ana Rita Trindade, Marta Domínguez-Delmás, Mohamed Traoré, Nathan Gallagher, Sara A. Rich, and Miguel Martins

Abstract The case study of the eighteenth-century Spanish frigate *Santa Maria Magdalena* constitutes one of the opportunities given to the ForSEAdiscovery project team to approach the subject of shipbuilding and timber supply in the Iberian Empires of the early modern age, in an interdisciplinary way, through the combination of efforts 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, through the analysis of timber samples from archaeological sites and old living trees.

A. R. Trindade (✉)
Instituto de Historia, Consejo Superior de Investigaciones Científicas (CSIC), Madrid, Spain
e-mail: ana.rita.rodrigues@cchs.csic.es

M. Domínguez-Delmás
University of Amsterdam (UA), Amsterdam, The Netherlands

M. Traoré
Ecole Nationale d'Ingénieurs Abderhamane Baba Touré, Bamako, Mali

N. Gallagher
Indianapolis, IN, USA

S. A. Rich
Coastal Carolina University Conway, SC, USA

M. Martins
Universidade Nova de Lisboa (UNL), Lisbon, Portugal

A. Crespo Solana et al. (eds.), *Heritage and the Sea*,
https://doi.org/10.1007/978-3-030-86464-4_9

Fig. 9.1 Location of the *Magdalena* shipwreck site in Viveiro Bay

1 Introduction

Driven by the increased demands on seafaring defense, the Spanish Crown launched the S*anta Maria Magdalena* frigate from the Esteiro shipyard of Ferrol (Galicia, northwest of Spain) in 1773. In 1810, the ship wrecked at the bay of Viveiro (Fig. 9.1), in the context of the Spanish War of Independence (1808–1814). In June 2015, the ForSEAdiscovery project organized 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 have the potential to shed light on late eighteenth-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.[1]

[1] This chapter constitutes a revised and enhanced version of Trindade et al. 2020.

2 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 program of economical and administrative restructuring in which a new conception of a centralized Navy took a prominent role, as the key factor of the maintenance of a vast colonial empire. In this context, the arsenals of Cartagena, Cadiz, Ferrol, and Havana became the centers of the state-controlled shipbuilding industry (Merino Navarro 1981).

On August 1, 1772, a Royal Order announced a program of construction of three *urcas afragatadas,* and one frigate to be carried out by the Esteiro shipyard (Arsenal of Ferrol), and this is the begining of the story of *La Magdalena*.[2] According to payment orders of salaries to the shipwrights, its construction began in September and lasted for the next 10 months.[3] The official launch took place in Ferrol on July 7, 1773, and the document of its announcement described the vessel as a 26–34 gun frigate, 145 feet long.[4] After 37 years of serving the Spanish Navy in Atlantic waters, the *Santa Maria Magdalena* sunk in the 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 November 2, 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 damages inflicted by the storm, such as the loss of the anchors, determined the fatal outcome: the *Magdalena* collided with the English frigate *Narcissus*, crashed against the Reef of Castelos and sunk soon after, taking the lives of 20 members of the crew (Fernández Duro 1867; Gambón Fillat 1976).

2.1 History: Timber Supply in Ferrol (1771–1773)

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 eighteenth century.

Archival research was mostly centered on the Spanish sources of the Navy administration corresponding to the section of the Navy Secretary (*Secretaría de*

[2] Archivo General de Simancas (AGS), Secretaría de Marina (SMA) 349, August 1, 1772.

[3] AGS, Tribunal Mayor de Cuentas (TMC), 4207: October 16, 1772; AGS,TMC, 4207: November 17, 1772; AGS,TMC, 4207: December, 16, 1772; AGS,TMC, 4208: January 22, 1773; AGS,TMC, 4208: February 20, 1773; AGS,TMC, 4208: March 18, 1773; AGS,TMC, 4208: April 20, 1773; AGS,TMC, 4208: May 20, 1773; AGS,TMC, 4208: June 21, 1773; AGS,TMC, 4208: July 24, 1773; AGS,TMC, Marina, 4208: August 20, 1773

[4] AGS, SMA, 350: July 7, 1773

Marina - SMA) and state accounts of the court of auditors (*Tribunal Mayor de Cuentas,* TMC) from the Archivo General de Simancas (AGS), in Valladolid, Spain.[5] 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 with the *Magdalena*, such as the timber used in its construction. Therefore, the team decided to work with historical documents dated from 1771 to 1773[6] 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, during 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 natural habitats of the trees, but also to the economic and technological strategies behind this model of supply.

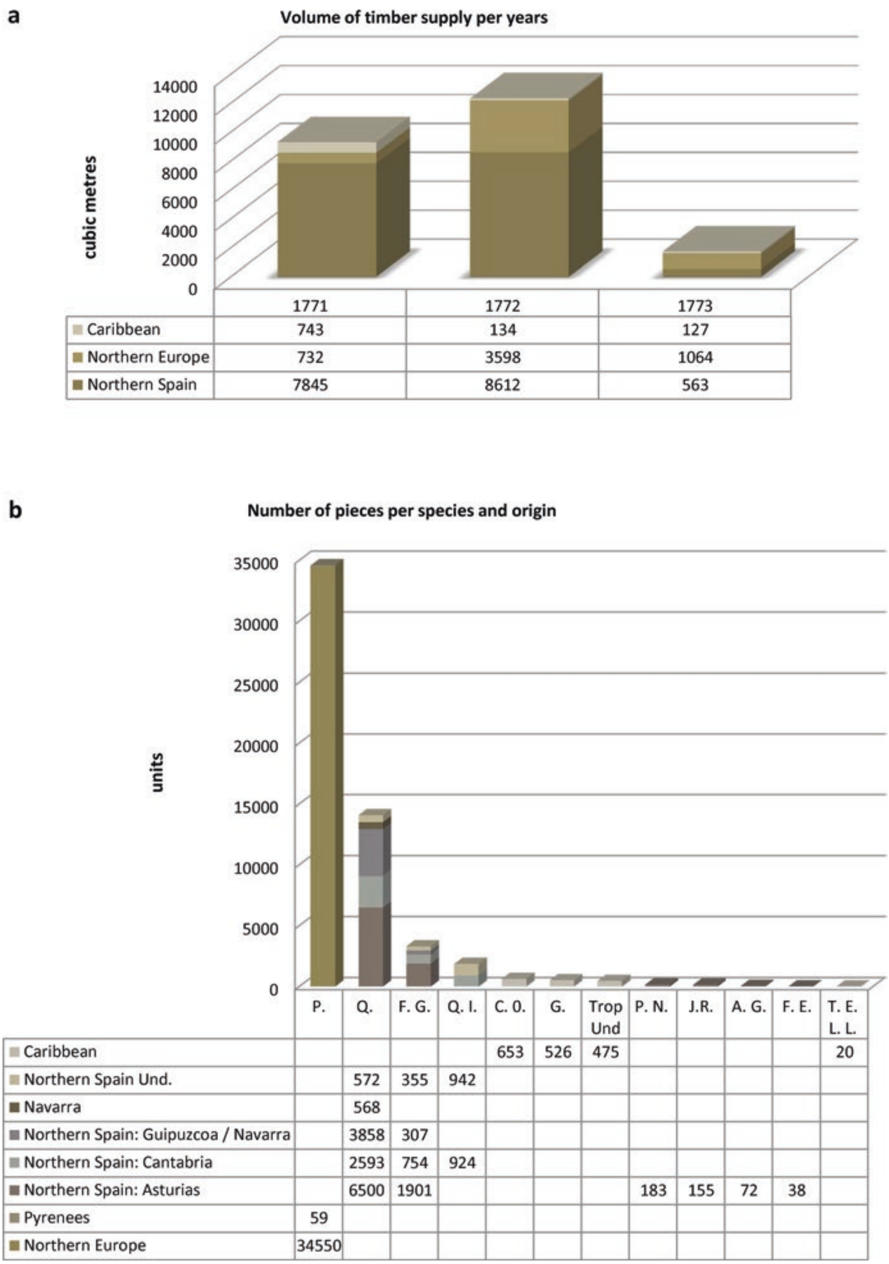
2.2 Northern Spanish Timber

The quantification of northern Spanish timber supply involved the examination of 58 documents from the following archive sections and subsections: *Secretaría de Marina,* subsection *Arsenales* (units 347, 349, 350), subsection *Asientos* (unit 621), subsection (unit 788); *Tribunal Mayor de Cuentas,* subsection *Marina,* Ferrol (units 4207, 4208). The quantitative data provided by the Spanish sources was unevenly presented in units and volume (*codos cubicos* - cubic cubits); in order to calculate the volume of timber elements, we searched for their approximate measurements in *codos*, within the *Pie de Burgos* measuring system, according to the piece typologies of presented by Francico Gautier in 1769[7] and Romero Fernandez de Landa (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 informs of timber needs for 1772 and 1773.The volume calculations (Marien y Arróspide 1789; Aranda y

[5] *Secretaría de Marina,* sub-section *Arsenales* (units 347, 349, 350), sub-section *Asientos* (unit 621), sub-section *Registros* (unit 788); *Tribunal Mayor de Cuentas,* subs-section *Marina,* Ferrol (units 4207, 4208), in a total of 97 documents.

[6] Sound Toll Registers Online, viewed March 31, 2017, http://www.soundtoll.nl/index.php/en/over-het-project/str-online. Except in the case of the data from TMC and STRO that was used in the cross reference of Northern Europe timber trade, which was extended to 1770.

[7] Gautier, F. 1769. *Reglamento de maderas de Roble necesarias para fabricar un Navio de 70 Cañones*. Mss. San Lorenzo, November 11, 1769; AGS, MPD, 41, 033bis. Ubicación Anterior: SMA, 0034215



	1771	1772	1773
Caribbean	743	134	127
Northern Europe	732	3598	1064
Northern Spain	7845	8612	563

	P.	Q.	F. G.	Q. I.	C. 0.	G.	Trop Und	P. N.	J.R.	A. G.	F. E.	T. E. L. L.
Caribbean					653	526	475					20
Northern Spain Und.		572	355	942								
Navarra		568										
Northern Spain: Guipuzcoa / Navarra		3858	307									
Northern Spain: Cantabria		2593	754	924								
Northern Spain: Asturias		6500	1901					183	155	72	38	
Pyrenees	59											
Northern Europe	34550											

Fig. 9.2 Volume and number of pieces by origin, Ferrol 1771–1173 (AGS, SMA, 347, 349, 350, 621, 788; AGS, TMC, 4207,4208)

Table 9.1 Number of timber pieces per species and type, Ferrol 1771–1773. (AGS, SMA, 347, 349, 350, 621, 788; AGS, TMC, 4207,4208)

species / type of piece	pine (P.)	oak (Q.)	beech (F.G.)	holm oak (Q.I.)	cedrela (C.O.)	guayacán (G.)	tropical (und.)	black popplar (P.N.)	walnut tree (J.R)	alder (A.G.)	ash tree (F.E.)	chicharrón (T.E.)/sabicú (L.L.)
planking	34370	4218	2436						16			
futtocks		3859			602							
undetermined		1058		924		502		97	5	72	3	
unprocessed timber		582	686			24		86	134		35	
beams		1278	195									
axis for guncarriages				942								
knees		562										
wales		486					68					
waterways		367										
stringers							333					
floor timbers		327										
pegs		306										
masts and spars	194											
ledges		190										
top timbers		150			31							
stanchions		137										
keels		30			14		26					14
counter timbers		65										
pieces for hawseholes		55										
innerstern posts		49										
main masts	45											
cruchers		45										
shelf beam		40										

sheer bitt		38										
keelson		26			6							6
anchor stocks							35					
stern knees		32										
buttocks		25										
sternposts		20										
masts steps		19										
riders		19										
v-frames		17										
chocks		16										
bill step and the for emast partner		16										
spritsail yards		16										
fashion pieces		14										
stern panel timbers		9										
bitts		4					5					
tillers		2					6					
stern dead woods		6										
sternsons		2										
cathead		2										
bulwarks		2										
stern timbers		2					2					
TOTAL	34609	14091	3317	1866	653	526	475	183	155	72	38	20

Antón 1990)[8] indicate Northern Spain as the main area of provenance of the timber used in Ferrol at the time of the *Magdalena's* construction, corresponding to 73% (sum of 17,020 m^3, during the years 1771–1773) of the total supply (23,418 m^3) (Fig. 9.2a). Such preponderance is expressed, as well, in the diversity of species, from oak to ash (Fig. 9.2b) and, especially, in the diversity of the typologies of ship pieces (Table 9.1). However, the quantification of pieces per units does not reflect the majority of Northern Spain timber, as this place is occupied by Northern European pine planking, masts, and spars. In terms of units, Northern Spain timber corresponds to 35%, in a total of 19,781 pieces out of 56,005 (Fig. 9.2b and Table 9.1). This discrepancy between volume and quantity is explained by the nature of the ship elements. In fact, Northern Spain timber was, by far, the preferred choice when it came to the structure of the hull and other elements below the waterline, which correspond to very voluminous elements, when compared to planks, the most abundant type of piece (Table 9.1).

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), contributing to this region's tradition as a strong peninsular center of shipbuilding, at least since the sixteenth century (Goodman 1997). Proximity to timber sources was an obvious criterion of choice, since it not only facilitated transport (costs and infrastructures), but 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 1990; Wing 2015). 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[9](Fernandez de Landa 1784),[10] 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 massively produced and purchased from the Baltic region in varied, but rather standardized 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,[11] and Navarra. There was also a significant group of endogenous timber pieces with undetermined origin, which was constituted by spare timber from Guarnizo shipyard (Fig. 9.2b). 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

[8] AGS, SMA, 621: November 15, 1771; AGS, SMA, 621: September 15, 1772; all these calculations are merely indicative.

[9] *Reglamentos de Maderas*

[10] Gautier, F. 1769. *Reglamento de maderas de Roble necesarias para fabricar un Navio de 70 Cañones*. Mss. San Lorenzo, 11 November 1769; AGS, MPD, 41, 033bis. Ubicación Anterior: SMA, 00342.

[11] sources of this group of timber are unclear about the specific provenance and just refer to the contractor, who was operating in both regions.

Francisco Quiñones, and Juan Gonzalez Pola, for Asturias; Francisco Caetano Iglesias, for Cantabria; *Real Compañia Guipuzcoana de Caracas* for Guipuzcoa and Navarra.[12] Oak, the predominant timber with 14,091 units, could be found from Asturias to Navarra and was, once again, mostly used for planking (4218 units), followed by framing elements, such as futtocks and beams, uncategorized pieces, and then a great variety of types (Table 9.1).[13] 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 its largest portion does not have any specific mention regarding the origin. It was used for axles of gun carriages and other unidentified 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 Spain timber accounts, corresponding to only 2% (402 m^3). This supply is the result of technical experiments with the purpose of reducing dependency from Northern Europe imported pine[14] (Fig. 9.2b and Table 9.1).

The data indicates the secondary role of timber import through the Baltic trading networks, as these constitute 23% in terms of volume (total of 5394 m^3 along the 1771–1773 period), even if, in terms of unit quantities, Northern Europe timber corresponds to 64%, with 34,550 pieces (Fig. 9.2). This material is exclusively made out of pine, consisting of planking, the largest group of pieces, in 34,338 units,[15] 45 main masts, and 167 minor masts and spars[16] (Table 9.1), revealing the importation of highly specialized 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 which was strictly necessary to build vital and substantial parts of the vessels. That was the case of the pine species from Northern Europe, such as *Pinus sylvestris* which had long, wide and straight trunks, which made them especially suited for masts, spars, and planks (Aranda y Antón 1999).

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,

[12] references are the same used in the counting of northern Spain timber

[13] in order to facilitate the statistic study, the piece typologies were aggregated within main functional groups, in order to avoid an exhaustive list (ex.: first and second futtocks count together just as futtocks)

[14] AGS, SMA, 349: November 20, 1771; AGS, SMA, 349: July 25, 1772; AGS, SMA, 349: September 23, 1772; AGS, SMA, 349: November 14, 1772

[15] excluding 32 from the Pyrenees

[16] excluding 27 from the Pyrenees

Cadiz, and Ferrol.[17] 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.*[18] As the stocks seemed to be constantly running out of pine, the Navy sporadically sought alternative suppliers when the contractor was not able to fulfill the necessities in due time.[19]

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[20] can be matched to records in the TMC.[21] 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 (*fyrredehler*), thick planks (*bohler*), and unspecified wood products (*trævahre*). Products brought from Riga were boat-hook shafts (*baadshagestager),* balks (*bielker*), ordinary deals (*gemeenedehler* or *ord. dehler*), masts (*master*), spars (*spirrer* or *raaer*), 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 "middleman" 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

[17] AGS, SMA, 788, January 2, 1772

[18] AGS, SMA, 621: September 1, 1772; AGS, SMA, 621: May 29, 1773; AGS, SMA, 621: August 20, 1773; AGS, SMA, 788: January 2, 1772

[19] AGS, SMA, 350: May, 15, 1773; AGS, SMA, 621: November 16, 1771; AGS, SMA, 621: May 20, 1773.

[20] Sound Toll Registers Online viewed March 31, 2017: STR270070, September 5, 1770; STR257963, September 23, 1770; STR256454, October, 24, 1770; STR301893, August, 2, 1771; STR260730, August 2, 1771; ST260841, August 3, 1771; STR269696, September 14, 1772

[21] matches between the TMC an STR were found by looking for the captain, year, port of origin, port of destination and then at the transported products; the captain and the year are the most reliable elements for cross-referencing, since the products were categorized differently in the STR and the TMC, and sometimes show completely different numbers.

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 1004 m^3 and 1674 pieces (Fig. 9.2). 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 possible due the low volume of each shipment. Cadiz was the destination port of this route since 1717 and worked as redistribution hub, by sending material to Ferrol, as well as Cartagena.[22] Sometimes, the transport was made by charted private ships, which would deliver the material directly to Ferrol.[23]

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; Aranda y Antón 1999). Thus, the lists of deliveries contain cedrela futtocks, stringers, wales, and anchor strocks of undetermined tropical species, keels made of cedrela and chicharrón /sabicú, cederela top timbers, guayacán logs for further carving, chicharrón/ sabicú, and cedrela keelsons, among other typologies, and a vast group of undetermined typologies of guayacán pieces (Table 9.1).

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[24] due to the constant shipments and low use of this material and, therefore, new shipments should be suspended.[25]

3 Archaeology: Sampling the *Santa Maria Magdalena* Timber Assemblage

The remains of a vessel constitute the ultimate evidence of how ships were built (Steffy 2012). 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

[22] AGS, SMA, 347: February 6, 1771

[23] AGS, SMA, 347: May 4, 1771; AGS, SMA, 347: August 24, 1771

[24] AGS, SMA, 347: July 19, 1771

[25] AGS, SMA, 350: June 4, 1773; AGS, SMA, 350: July 10, 1773

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 (García–Torralba Pérez 2011), the *Magdalena* was part of a test 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 Navy to identify and analyze 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 (Fig. 9.3a) in order to elucidate the circumstances of her construction – how she was built, with what kinds of wood, and respective provenance. 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 to relying solely on the historical sources, even in well-documented cases like the timber supply for the arsenal of Ferrol. (1) Providing samples to wood scientists 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 is 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 as reduced as possible. Therefore, it was only after mapping, sketching, positioning, and using other noninvasive recording methods were timbers finally sampled. To gain the most amount 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 (Oertling 2001; Castro 2008) demonstrates a common practice of utilizing the parent tree's growth pattern for the required timber shape. This technique alone promises to help gain a better

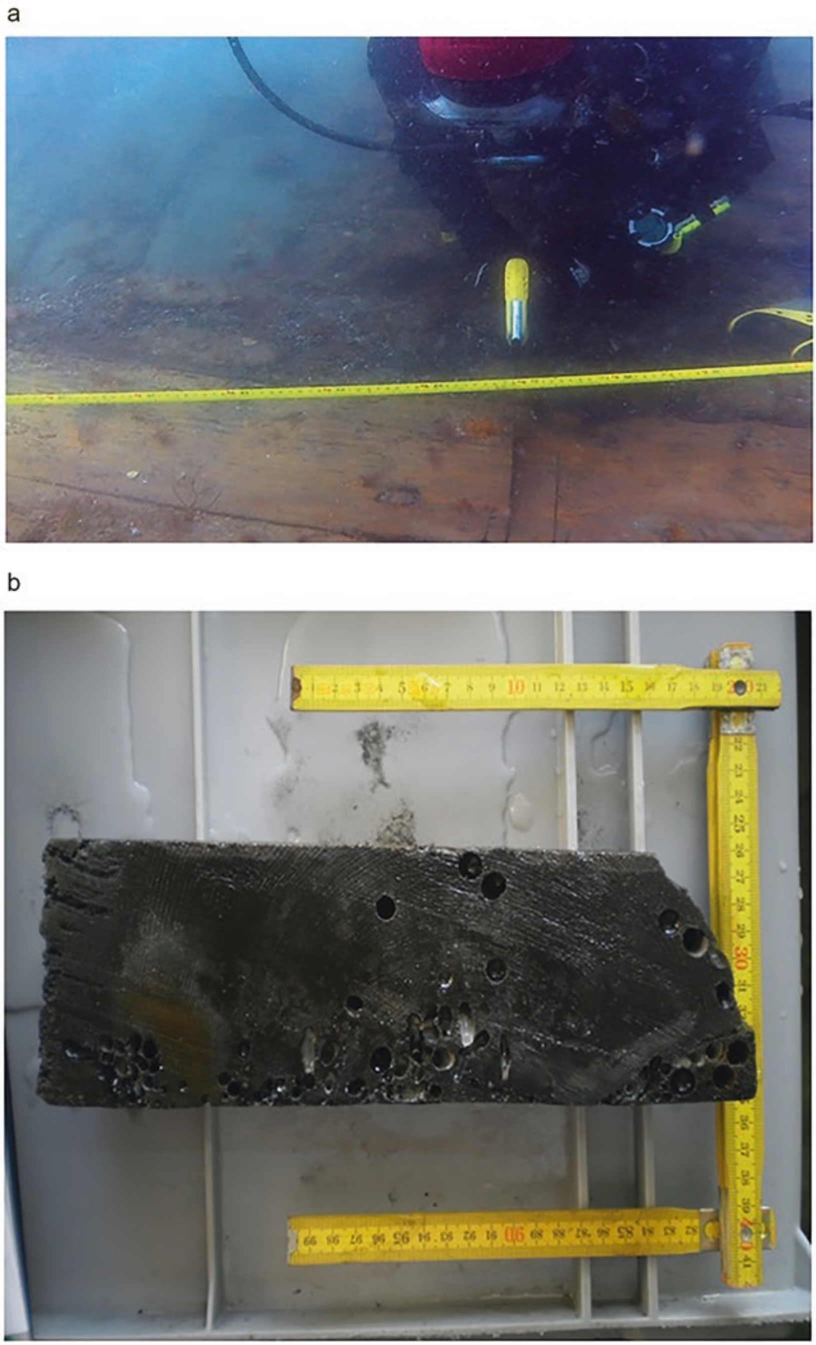


Fig. 9.3 Sampling the *Magdalena* timber assemblage: (**a**) 2015 underwater archaeology campaign, (**b**) Sample of pine ceiling planking

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 to create 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 horizontal elements. Because oak is ring-porous, each ring represents a potential breaking point, so the more rings a tree and its derivative timber have, the more vulnerable it is to splitting with vertical pressure, as would be experienced by frames and stanchions (Rich et al. 2020). 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 9.3b 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 bore holes 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 artifact. 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.

4 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 least number of galleries caused by *Teredo navalis*) to divide them into subsamples that would be used for organic and inorganic geochemical studies of wood composition and characterization. The main aim of the wood science team of the ForSEAdiscovery project is to develop reference methodologies and datasets to enable establishing the provenance of Iberian ship timbers. These comprise tree ring-based datasets (ring width, early-wood, 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. 2020). The techniques used for organic and inorganic wood characterization 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, research carried out at the University of Santiago de Compostela (USC, Spain).

4.1 Dendrochronology: Finding Out the Date and Provenance of the Wood 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., 80–100 tree rings). Exceptionally, timbers with as little 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 analyzed 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 earlywood vessels placed in a ring-porous disposition, although the deciduous oaks show large multi-seriate 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 (2003). Ring width acquisition was done with a timetable measuring device (University of Vienna) coupled with PAST5 software (SCIEM).

Table 9.2 Results of species identification and tree ring analysis. Species: 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)

Sample number	Type of timber element	Species	Dendro code	N rings	Pith	Sapwood	Bark Edge	MRW	σ
MAG01-001W-02S	Frame at bow	1	MAG00011	47	–	0	–	0.68	0.24
MAG01-001W-03S	Frame at bow	1	MAG00012	82	–	0	–	1.43	0.49
MAG01-002W-01S	Ceiling plank at stern	2	MAG00020	100	+	0	–	2.14	1.34
MAG01-003W-01S	Ceiling plankat stern	2	MAG00030	146	–	66	–	1.28	0.36
MAG01-006W-01S	Frame at stern	2	MAG00041	35	+	0	–	2.90	0.78
MAG01-007W-01S	Frame at bow	1	MAG00050	216	–	28	WK?	0.67	0.41
MAG01-008W-01S	Frame at bow	1	MAG00061	67	–	0	–	1.56	0.82
MAG01-009W-01S	Frame at bow	1	MAG00070	49	+	0	–	2.33	0.71
MAG01-010W-01S	Frame at bow	1	MAG00080	144	+	0	–	1.16	0.46
MAG01-011W-01S	Frame at bow	1	MAG00090	78	–	0	–	1.63	0.65
MAG01-012W-01S	Frame at bow	1	MAG00100	49	–	6	–	2.65	0.87
MAG01-013W-01S	Frame at bow	1	MAG00110	125	–	38	–	0.88	0.50

MAG01-014W-01S	Framing element from bow	1	MAG00120	51	–	–	–	1.69	0.72
MAG01-015W-01S	Hull plank from bow	4	MAG00130	32	+	–	–	3.64	1.06
MAG01-016W-01S	Sacrificial hull planking		MAG00141	100	+	–	–	1.66	1.20
MAG01-017W-01S	Wedge sample of frame at stern	1	MAG00151	65	–	–	–	2.18	0.82
MAG01-018W-01S	Frame section	1	MAG00160	78	+	–	–	1.91	0.83
MAG01-019W-01S	Frame section	1	MAG00170	119	–	–	–	1.24	0.51
MAG01-021W-01S	Chiseled block samples from outer hull planking	1	MAG00180	79	–	–	–	1.04	0.19
MAG01-001W-01S	Frame at bow	1	–	Unknown	–	0	–	Severely damaged by *Teredonavalis*	
MAG01-004W-01S	Stringer at stern	3	–	20	+	0	–	Not suitable dendro	
MAG01-005W-01S	Wedge sample from oak frame at stern	1	–	8	–	0	–	Not suitable dendro	
MAG01-020W-01S	Frame section	1	–	28	+	0	–	Not suitable dendro	

4.1.1 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 9.2). 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 less than 30 tree rings (Table 9.2).

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 17 trees from Cantabria and 2 trees from Asturias, QUPE19MC) the one providing the best statistical results (Fig. 9.4). 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 hamper estimating the felling date of the trees, hence the dates can only be presented as *terminus post quem* (dates after which the tree 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 nor with the reference chronologies, therefore their date and provenance remain uncertain (see also Chapter 1, Vol. 2 where the dendrochronological research on *Magdalena* is considered in the broader context of similar research on other Iberian vessels).

4.2 Geochemical Fingerprinting of Magdalena Shipwreck: Relevance of the Initial FTIR Results

Wood is a complex polymeric material composed by polysaccharides and lignin. 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 to 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 characterization of the molecular structure of wood chemistry allows detailed understanding of wood properties. Although considerable studies have been done using diverse types of techniques, still much more effort needs to be done to get an understanding on 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 Carrillo 2005; Traoré et al. 2016). Contrary to conventional chemical analysis, it has the advantage to be time efficient and does

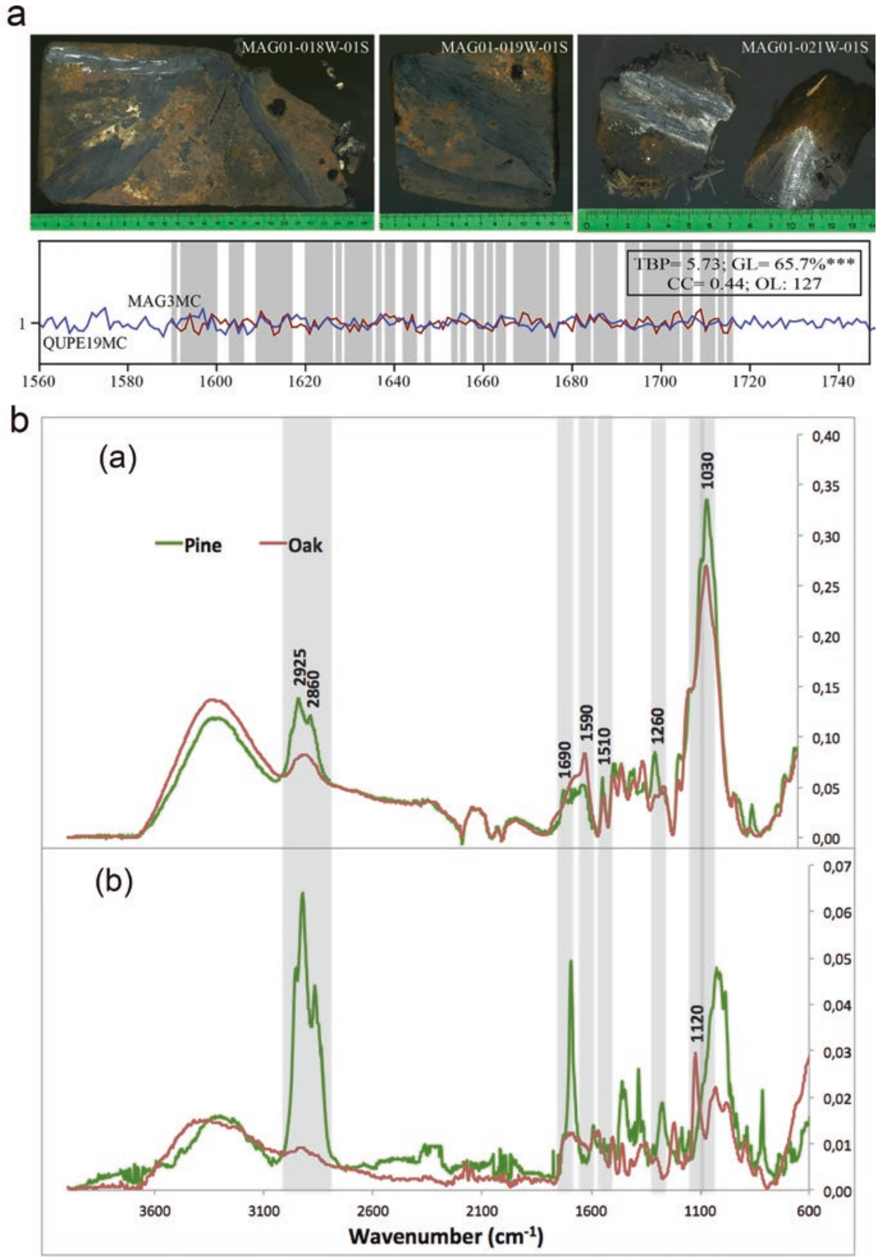


Fig. 9.4 (**a**) Oak samples from the *Magdalena* shipwreck dated by dendrochronology. Their tree ring series has been averaged into the mean curve MAG3MC, which dates against a *Quercus petraea* composite chronology (QUPE19MC). TBP: Student's *t*-value adapted according to Baillie and Pilcher (1973); asterisks represent the signification level of GL (***, $p < 0.001$); 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

not require sample destruction (an important aspect when analyzing archaeological artifacts). It has been used to differentiate between soft and hardwood, showing that softwood lignin is essentially composed by guaiacyl moieties, whereas hardwood lignin is composed by guaiacyl and syringyl moieties (Evans 1991; Colom and Carrillo 2005). FTIR has been more often used to evaluate archaeological wood in order to choose the appropriate conservation method. It is a useful technique to study chemical changes occurred during decay process undergone on ancient wooden artifacts. In this work, we applied FTIR on some wood fragments from *Magdalena* shipwreck timbers, in an attempt to evaluate the potential of this technique to allow the identification of the provenance of water-logged samples.

Four *Pinus* sp. (MAG02, MAG03, MAG15 and MAG16) and two *Quercus* sp. (MAG10 and MAG21) fragments were analyzed 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 performed 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 4 cm^{-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 9.4 represents FTIR spectra of the two types 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 band near 1030 cm^{-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 CH_2 valence vibration at bands 2925 and 2860 cm^{-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 1260 cm^{-1} (Colom and Carrillo 2005). The standard deviation spectra showed higher variability in pine wood than in oak wood. The largest variabilities in 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 syringyl unit C-H bond vibrations (Popescu et al. 2007).

5 Conclusions

Despite the lack of data specifically related with 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 characterization 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 of the remaining framing elements of the hull and other elements placed below the waterline of containing a majority 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 Europe 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 in the archaeological wreck site. The documental 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 eighteenth-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 (Rich et al. 2018), specific timbers were targeted based 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 artifacts 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 dendroprovenance.

Carrying out an appropriate sampling protocol is crucial for the success of dendrochronology. In the case of *La Magdalena* shipwreck, 11 out of the 21 samples retrieved presented almost 80 rings or more, and 3 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 part 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 water-logged woods. The use of the average and standard deviation spectra enables us to determine details about the chemistry of shipwreck timbers. From these results we can conclude that the combination of FTIR with powerful statistical methods is promising and may allow the identification of organic markers for the distinction between species and provenance of wood from shipwrecks.

Acknowledgments We are grateful to Dr. Ana Crespo Solana and Professor Nigel Nayling for the motivation and support for this work. This research was carried out within the ForSEAdiscovery project—*Forest Resources for Iberian Empires: Ecology and Globalization in the Age of Discovery*—funded by the EU Marie Curie Actions Initial Training Networks (PITN-GA-2013-607545).

References

Aranda y Antón G de (1999) La carpintería y la industria naval en el siglo XVIII. Instituto de Historia Naval, Madrid

Aranda y Antón G de (1990) Los bosques flotantes: historia de un roble del siglo XVIII. ICONA, Madrid

Astrom, SE (1988) From tar to timber. Studies in Northeast European Foest Exploitation and Foreign Trade (1660–1860). Comentationes Humanarum Litterarum 85. Societas Scientiarum Fennicap, Helsinki

Baillie MGL, Pilcher JR (1973) A simple cross-dating program for tree-ring research. Tree-Ring Bulletin 33:7–14

Castro F (2008) In search of unique Iberian ship design concepts. Hist Archaeol 42:63–87

Colom X, Carrillo F (2005) Comparative study of wood samples of the northern area of catalonia by FTIR. J Wood Chem Technol 25:1–11. https://doi.org/10.1081/WCT-200058231

De Aranda y Antón G (1992) Las Maderas de América en la Arquitectura Naval del Siglo XVIII. Rev Hist Nav 38:7–31

Domínguez-Delmás M, Rich S, Traoré M et al (2020) Tree-ring chronologies, stable strontium isotopes and biochemical compounds: towards reference datasets to provenance Iberian shipwreck timbers. J Archaeol Sci Rep 34:102640. https://doi.org/10.1016/j.jasrep.2020.102640

Eckstein D, Bauch J (1969) Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. Forstwissenschaftliches Centralblatt 88: 230–250

Evans PA (1991) Differentiating "hard" from "soft" woods using Fourier transform infrared and Fourier transform spectroscopy. Spectrochim Acta Part A Mol Spectrosc 47:1441–1447. https://doi.org/10.1016/0584-8539(91)80235-B

Faix O, Böttcher JH (1992) The influence of particle size and concentration in transmission and diffuse reflectance spectroscopy of wood. Holz als Roh- und Werkst 50:221–226. https://doi.org/10.1007/BF02650312

Fernandez de Landa JR (1784) Reglamento de Maderas Necesarias para la Fabrica de los Baxeles del Rey. Don Joaquín Ibarra, Impresor de Cámara de S.M., Madrid

Fernández Duro C (1867) Naufragios de la Armada Española: relación histórica formada con presencia de los documentos oficiales que existen en el Archivo del Ministerio de Marina. Establecimiento Tipográfico de Estrada, Díaz y López, Madrid

Fritts HC (1976) Tree rings and climate. Acdemic Press, London/New York/San Francisco

Gallagher N (2016) A methodology for estimating the volume of Baltic timber to Spain using the Sound Toll Registers: 1670–1806. Int J Marit Hist 28:752–773. https://doi.org/10.1177/0843871416661682

Gambón Fillat P (1976) Fragata Magdalena. Rev Gen Mar 191:313–318

García-Torralba Pérez E (2011) Las fragatas de vela de la armada española 1600–1850 (su evolución técnica)

García Esteban L (2003) La madera y su anatomía: anomalías y defectos, estructura microscópica de coníferas y frondosas, identificación de maderas, descripción de especies y pared celular. Fundación Conde del Valle de Salazar: Mundi-Prensa, Madrid

García Esteban L (2003) La madera y su anatomía: anomalías y defectos, estructura microscópica de coníferas y frondosas, identificación de maderas,descripción de especies y pared celular. Fundación Conde del Valle de Salazar: Mundi-Prensa, Madrid

Gøbel E (2010) The Sound Toll Registers online project, 1497–1857. Int J Marit Hist 22:305–324. https://doi.org/10.1177/084387141002200213

Goodman DC (1997) Spanish naval power, 1589–1665: reconstruction and defeat. Cambridge University Press, Cambridge

Hedges J (1989) The chemistry of archaeological wood. In: Rowell R (ed) Archaeological wood: advances in chemistry. American Chemical Society, Washington, DC, pp 114–140

Marien y Arróspide TA de (1789) Tratado general de monedas, pesas, medidas y cambios de todas las naciones reducidas a las que se usan en España por Don Tomas Antonio Marien y Arrospide. En Madrid en la imprenta de D. Benito Cano año de MDCCLXXXIX

Merino Navarro JP (1981) La Armada española en el siglo XVIII. Fundación Universitaria Española, Madrid

Oertling T (2001) The concept of the atlantic vessel. In: Alves F (ed) Proceedings of the International Symposium on Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition. Instituto Português Archaeologia; Centro Nacional de Arqueologia Náutica e Subaquática, Academia de Marinha Lisboa, Lisbon, pp 233–240

Pandey KK (1999) A study of chemical structure of soft and hardwood and wood polymers by FTIR spectroscopy. J Appl Polym Sci 71:1969–1975. https://doi.org/10.1002/(SICI)1097-4628(19990321)71:12<1969::AID-APP6>3.0.CO;2-D

Popescu C-M, Popescu M-C, Singurel G et al (2007) Spectral characterization of eucalyptus wood. Appl Spectrosc 61:1168–1177

Reichert R (2016) El comercio directo de maderas para la construcción naval Española y de otros bienes provenientes de la región del Baltico sur :1700-1783. Hispania 252: 129–157. https://doi.org/10.3989/hispania.2016.005

Rich S, Crespo Solana A, Momber G, Nayling N (2018) Shipwrecks and provenance in-situ timber sampling protocols with a focus on wrecks of the Iberian shipbuilding tradition. Oxford Archaeopress Publishing, Oxford

Rich S, Momber G, Nayling N (2020) Maritime archaeological timber sampling: methods and results from the silty Solent. In: Rodrigues JA, Traviglia A (eds) Shared Heritage: Proceedings of the Sixth International Congress for Underwater Archaeology. IKUWA 6. Archaeopress Archaeology; Western Australian Maritime Museum, Oxford; Fremantle, Western Australia, pp 143–152

Schwanninger M, Rodrigues JC, Pereira H, Hinterstoisser B (2004) Effects of short-time vibratory ball milling on the shape of FT-IR spectra of wood and cellulose. Vib Spectrosc 36:23–40. https://doi.org/10.1016/j.vibspec.2004.02.003

Steffy JR (2012) Wooden Shipbuilding and the interpretation of shipwrecks. Texas A & M; Rachal Foundation Nautical Archaeology, Texas

Traoré M, Kaal J, Martínez Cortizas A (2016) Application of FTIR spectroscopy to the characterization of archeological wood. Spectrochim Acta - Part A Mol Biomol Spectrosc 153:63–70. https://doi.org/10.1016/j.saa.2015.07.108

Trindade AR, Domínguez-Delmás M, Traoré M, Gallagher N, Rich S, Martins AM (2020) From forests to the sea, from the sea to the laboratory: the timbers of the frigate Santa María Magdalena (18th century). In: Rodrigues JA, Traviglia A (eds) Shared Heritage: Proceedings of the Sixth International Congress for Underwater Archaeology. IKUWA 6. Archaeopress Archaeology; Western Australian Maritime Museum, Oxford; Fremantle, Western Australia, pp 127–142

Wing JT (2015) Roots of empire: forests and state power in early modern Spain, c. 1500–1750. Brill Academic Pub, Leiden; Boston