Chapter 1
Dendroarchaeology of Shipwrecks in the Iberian Peninsula: 10 Years of Research and Advances

Marta Domínguez-Delmás, Sara A. Rich, and Nigel Nayling

Abstract In the Iberian Peninsula, tree-ring research on shipwrecks started in the 2000s by the authors with the aims of identifying shipwrecks as Atlantic–Iberian-built vessels, studying the organization of timber supply, and refining our understanding of the development of shipbuilding along the Iberian–Atlantic coast during the Early Modern Period. This article compiles the results and observations gathered in the period 2009–2019 through dendrochronological analysis of 23 shipwreck assemblages found in the Iberian Peninsula and elsewhere. Only three of these shipwrecks (*Triunfante*, *Magdalena*, and *Bayonnaise*) had been previously identified and had a known ship history, including date and location of construction. The rest (Barceloneta I, Newport, Ribadeo, San Sebastián, Matagrana, Punta Restelos, Arade 1, Ria de Aveiro F and G, Barreiros, Belinho 1, Delta I, II, and III, Cee 1 and 2, Yarmouth Roads, Emmanuel Point II and III, and Highbourne Cay) had less precise dating based on historical information, construction features, archaeological context/artifacts, and/or radiocarbon dates. Our results demonstrate an almost-exclusive use of deciduous oak (*Quercus* subg. *Quercus*) in structural hull elements until the mid-eighteenth century and suggest a transition from differentiated selection of trees based on growth rates in the fifteenth century toward an indifferent selection in subsequent centuries due to technological advances. Our findings are discussed in the context of shipbuilding and seafaring in the Early Modern Period.

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1 Introduction

Dendrochronology is widely used in the North of Europe to establish the date and provenance of timbers from ship finds subjected to archaeological study. The development of extensive reference tree-ring datasets of different species in most of Europe often allows the successful dating of timber structures, including ship assemblages from Roman times (Čufar et al. 2014; Jansma et al. 2014), the Viking era (Bonde and Crumlin-Pedersen 1990; Crumlin-Pedersen and Olsen 2002; Nordeide et al. 2020), as well as from the Late Medieval, Early Modern, and Modern Period (Daly 2007; Daly and Nymoen 2008; Dobbs and Bridge 2009; Domínguez-Delmás et al. 2013; Haneca and Daly 2014; Nayling and Susperregi 2014; Läänelaid et al. 2019; Lorentzen et al. 2020). Dendrochronological research on shipwrecks and maritime sites in the Americas has also taken off in recent years (Martin-Benito et al. 2014; Creasman et al. 2015). Once the date is established, further inferences can be made about the construction period of the ship and the timber supply area, and woodworking techniques and forest management practices can be placed in an exact chronological period (Rich et al. 2018a; Domínguez-Delmás et al. 2019). In the Iberian Peninsula, tree-ring research on shipwrecks has taken great strides in the past 10 years. This chapter presents the observations and results obtained through dendrochronological research of timbers from shipwrecks found in the Iberian Peninsula, as well as Iberian shipwrecks found elsewhere (the Mediterranean and the Caribbean), predominantly in the period of 2009–2019. These shipwrecks were researched to find out whether they were built in the Iberian Peninsula and, if so, to refine our understanding of the development of shipbuilding along the Iberian–Atlantic coast during the Early Modern Period. Specific objectives were gaining knowledge about (i) their chronology, (ii) the provenance of the wood, and (iii) the procurement of timber for shipbuilding (selection of species and growth rates for particular elements in the ship). In the following, we compile the results of this research, presenting the results of each individual shipwreck, and make inferences, when possible, about the organization of the wood supply.[1] We then reflect on the lessons learned in these 10 years and discuss the results in the context of shipbuilding and seafaring in the Early Modern Period.

[1] Given the length of this chapter, we decided to present a synthesis of dendrochronological results of each shipwreck, and refer the interested reader for detailed results (e.g., graphs and statistics of internal cross-matches between samples of the same shipwreck) to the reports that have been uploaded into Zenodo or other repositories, where they are openly available.

2 Background to Dendroarchaeology of Shipwrecks in the Iberian Peninsula

In the Iberian Peninsula, dendroarchaeological studies started in the 1980s with the research of timbers from historic buildings (Richter and Eckstein 1986). Until the first decade of the twenty-first century, investigations were mostly restricted to the study of historic buildings in the northeast, center, and south of Spain (Domínguez-Delmás et al. 2015 and references therein). To initiate tree-ring studies on cultural heritage outside these regions, the project *Filling in the blanks in European dendrochronology: building a multidisciplinary research network to assess Iberian wooden cultural heritage worldwide* (also known as Iberian Heritage Project, henceforth IHP) was launched in 2009. A network of foresters, historians, nautical archaeologists, and dendrochronologists was assembled to identify old-growth forests, historic buildings with timber-framed roofs, art pieces, and shipwreck assemblages in Spain and Portugal that could be subjected to dendrochronological research (Domínguez-Delmás 2015). Through this network, the opportunity arose to examine and sample diverse groups of timbers from archaeological structures and shipwrecks at the Catalonian Centre for Underwater Archaeology (CASC) in Girona (Spain), at the Centre of Underwater Archaeology (CAS) in Cadiz (Spain), and at the former *Divisão de Arqueologia Náutica e Subaquática, Instituto de Gestão do PatrimónioArquitectónico e Arqueológico* (DANS/IGESPAR) in Lisbon (Portugal). The assemblages studied at those underwater archaeology centres between 2009 and 2011 became, together with the Newport Medieval Ship (excavated in Wales between 2002 and 2003 and identified as a Basque Country-built merchant vessel; (Nayling and Jones 2014), the first Iberian ships/wrecks being subjected to dendrochronological inquiry.

Part of the network built during the IHP subsequently launched the ForSEAdiscovery project (*Forest Resources for Iberian Empires: Ecology and Globalization in the Age of Discovery*; henceforth FSD), which ran from 2014 to 2018. This project recruited 18 fellows as researchers, who were divided into three work packages (History, Nautical archaeology, and Wood provenancing) to examine the timber supply for Iberian Empires during the Early Modern Period (Nayling and Crespo Solana 2016; Crespo Solana et al. 2018; Crespo Solana 2019). Within the FSD, we targeted Iberian shipwrecks along Atlantic–Iberian coasts, the south of England and the Caribbean, aiming to determine their exact chronology and to understand the organization of the timber supply for shipbuilding (including the selection of trees (old/young, fast/slow-grown) and species for different timber elements, forest management practices to increase timber production, timber imports, etc.).

3 Sampling Strategy and Dendrochronological Methods

Between 2009 and 2019, a total of 23 shipwrecks were inspected and sampled for dendrochronological research (Fig. 1.1; Table 1.1). In addition to these wrecks, the Newport Ship has been included in this chapter to contribute to the discussion of fifteenth-century ships. The identifications of the *Triunfante*, *Magdalena*, and *Bayonnaise* were known and well documented. The former two were both built in the Spanish royal shipyard of Esteiro (Ferrol, NW Spain) and launched in 1756 and 1773, respectively. The *Bayonnaise* was a French corvette built in Bayonne (W France) in 1794. The rest of the shipwrecks targeted have been relatively dated to different times of the Early Modern Period (fifteenth to eighteenth centuries) based on historical information, construction features, archaeological context, and/or radiocarbon dating.

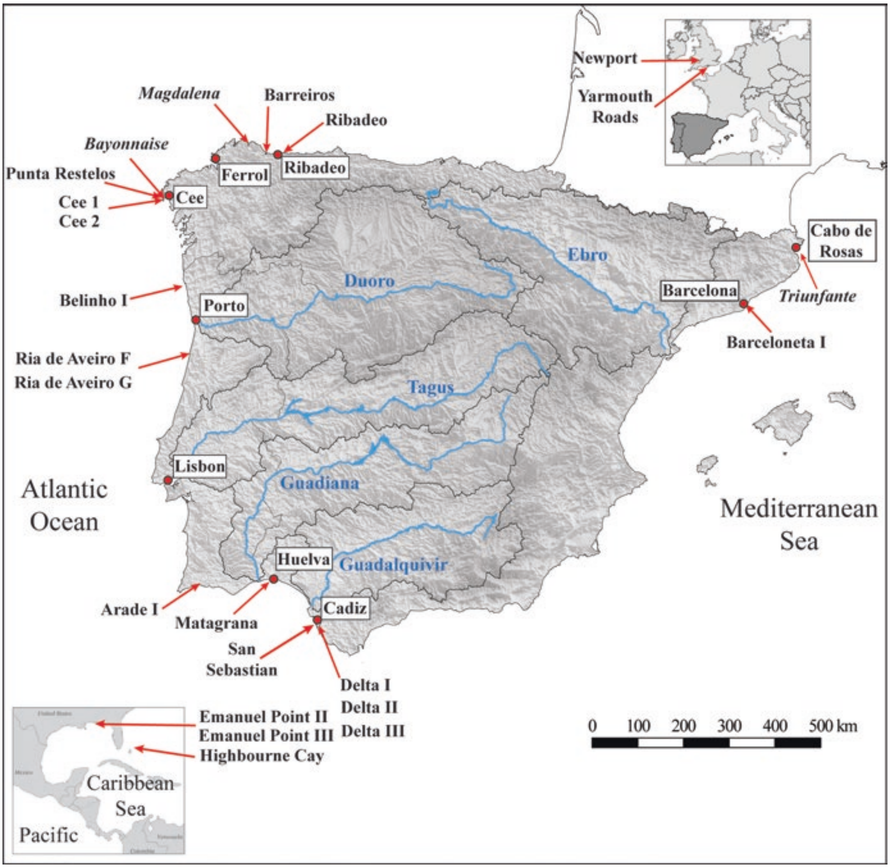

Fig. 1.1 Shipwrecks studied in the period 2009–2019 within the IHP and the FSD projects, plus the Newport Ship, indicating the location where they were found. Some cities and geographical features are indicated for additional geographical reference

Table 1.1 Number of samples collected on each shipwreck, presented with their corresponding identification of wood species when known

Shipwreck	Chronology	*Quercus* subg. *Quercus*	*Pinus sylvestris/ nigra*	*Picea abies/ Larix decidua*	*Abies alba*	Conifer	*Fagus sylvatica*	*Castanea sativa*	Tropical	Others	Total
Barceloneta I	c. 1410?	14									14
Newport	c.1450	110					1				111
Barreiros	Fifteenth century?	4								1	5
Ría de Aveiro G	Fifteenth century?	2									2
Ría de Aveiro F	Fifteenth–eighteenth century	1						1	9		11
Highbourne cay	c. 1520	16									16
Emanuel point II	c. 1550s	31									31
Emanuel point III	c. 1550s	4									4
Yarmouth roads	Mid-sixteenth century	17									17
Belinho 1	16th–eighteenth century?	12				2			1		15
Delta II	Mid-sixteenth century	35				3	2		4	5	49
Arade 1	c. 1583	24						2			26
Punta Restelos	c. 1590s	7									7
Ribadeo	c. 1590s	36	2	3	2	1	1	2		1	48
Delta I	Seventeenth century	22	3				1				26
Delta III	Seventeenth century	6	1				2				9
Matagrana	17th–eighteenth century	2									2
Triunfante	1754/56		6								6
Magdalena	1778	17	4			1					22
San Sebastian	Eighteenth century?	2									2
Bayonnaise	Eighteenth century	10									10
Cee 1	Late nineteenth century	5				1					6
Cee 2	?	3									3
		380	16	3	2	8	7	5	14	7	442

Some of those samples were collected for wood identification only, or to have an idea of the growth rate of the tree furnishing the timber. Therefore, the total number does not represent the number of samples selected for dendrochronological research

Given the objectives of the research, which included the characterization of trees used during the Early Modern Period for shipbuilding, the sampling strategy avoided bias toward timbers suitable for dendrochronological dating (i.e., containing more than 80 tree rings). Therefore, samples with as little as 15–30 rings were also selected for tree-ring analysis in order to acquire growth rates of the trees used for specific elements of the ship. For some shipwrecks (*Triunfante*, Ribadeo, Yarmouth Roads, and *Bayonnaise*) preliminary wood identification and ring counts were carried out under water directly on some of the timbers (Fig. 1.2a, b) to have an estimation of tree species used and tree ages without having to saw off samples from all the timbers.

The collection of samples was carried out under different circumstances and followed, when possible, the methods now detailed in Rich et al. (2018b) and Domínguez-Delmás et al. (2019). Most of the shipwrecks were sampled underwater (*Triunfante*, Ribadeo, San Sebastián, Delta shipwrecks, Yarmouth Roads, *Magdalena*, Cee shipwrecks, *Bayonnaise*, Highbourne Cay, and Emanuel Point), whereas the Matagrana and Barreiros were sampled in an intertidal zone. Waterlogged timbers from the Newport Ship, Arade 1, Ría de Aveiro F and G, and Belinho 1 shipwrecks were sampled on land at different conservation facilities, before undergoing conservation treatment (Fig. 1.2c). In all these cases, samples for dendrochronological research (cross-sections) were removed with a handsaw from the selected structural timbers, as well as from some cargo elements (in the cases of the Ribadeo and the Delta II) (Fig. 1.2d, e). Additionally, fragments of some timbers were also collected for wood identification and to establish whether those timbers may contain enough tree rings for following up dendrochronological research.

In the case of Barceloneta I, sampling was constrained by the fact that the wreck was going to be reassembled and displayed at the Barcelona History Museum after conservation treatment with polyethylene glycol (PEG). Therefore, sampling of timbers by sawing a cross-section was restricted to the fragments of hull planks broken when the backhoe unearthed the wreck. In two of the frames, tree-ring patterns in the notches carved to accommodate the futtocks were photographed (Fig. 1.2f, g). In this way, photographing the surface of several notches after cleaning them with razor blades and applying chalk to enhance visualization of tree rings, it was possible to register the tree-ring patterns from the pith to the outermost rings, which corresponded to the waney edge, representing the cutting year of the tree. Tree rings were also photographed on one hull plank, as the edge was quite smooth and it was possible to clean it with razor blades. Similarly, the barrel staves from the cargo of the Delta II shipwrecks were cleaned with razor blades and analyzed by means of digital photographs.

To analyze the tree rings in the sawn samples, the transverse surface of the wood was cleaned with razor blades from the inner- to the outermost ring. The presence/absence of pith and sapwood was also recorded. This manner of inspection served to identify some species that show distinct anatomical features in the transverse section, which make them distinguishable by the naked eye. Such identification is possible, for instance, for deciduous oaks (*Quercus* subg. *Quercus*), which show large earlywood vessels placed in a ring-porous disposition and large multiseriate

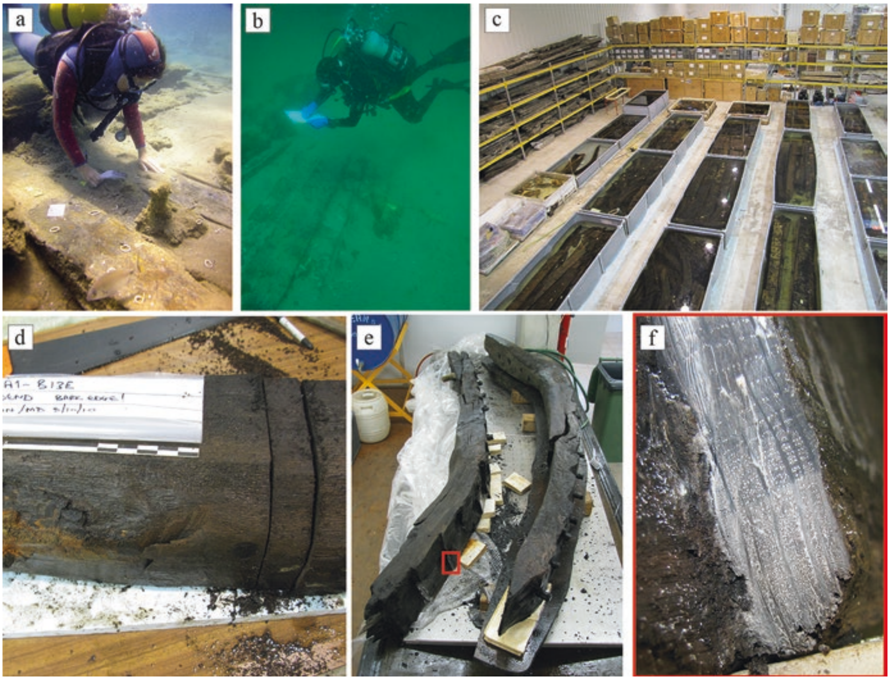

Fig. 1.2 Inspection and sampling of shipwrecks (**a**) examining *Triunfante* timbers to determine the species as oak or conifers. (Source photo: CASC archive), (**b**) underwater registration of Ribadeo timbers prior to sampling. (Photo: R. González Gallero), (**c**) facilities of the IGESPAR in Lisbon where several shipwrecks were inspected and sampled, (**d**) framing timber of the Arade 1 sawn where complete sapwood was present, (**e** and **f**) joggle on framing timbers of Barceloneta shipwreck where tree rings were recorded after cleaning with razor blades and applying chalk powder to enhance the visibility of the tree rings. (Photos **c**–**f**: M. Domínguez-Delmás)

medullary rays; chestnut (*Castanea sativa*), which is very similar to the group of deciduous oaks but lacks the multiseriate medullary rays; beech, ash, etc. (see Schweingruber 1990 for a detailed description of the wood anatomy of those species). The identification of species that cannot be distinguished by the naked eye was done by cutting cube-shaped subsamples of approximately 1 cm^3. Then, thin slices were manually cut with razor blades from the transverse, radial, and tangential sections of the subsamples, in order to observe the micro-characteristics of the wood anatomy of each sample (see http://www.woodanatomy.ch/micro.html Schoch et al. 2004). Transmitted-light microscopes (Zeiss Axioscope40 or Olympus BX40) coupled with a digital camera (Zeiss AxioCam MRc5) were used to visualize and photograph the key anatomical features of each sample. Identifications were made using the keys proposed by Schweingruber (1990), García Esteban et al. (2003), or, in the case of tropical woods, the following online resources: Wood Anatomy of European Species (http://www.woodanatomy.ch/micro.html Schoch et al. 2004) and the Inside Wood database (http://insidewood.lib.ncsu.edu/search Wheeler 2011).

Tree rings were measured in selected samples with a TimeTable measuring device (University of Vienna) coupled with PAST4 software v.4.3.1025 (SCIEM). When samples could not be taken and the research was done through photography, tree rings were photographed with a macro lens using a Sony compact camera on macro mode, and ring widths were measured on screen with CooRecorder (Cybis). The photographs included a ruler to allow the calibration of the measurements. Therefore, the obtained ring widths represent absolute values.

Crossdating between the samples and with reference chronologies was also done with PAST4. To identify potential dates, Student's *t*-values were considered after modifying the data according to Baillie and Pilcher (1973), in combination with the percentage of parallel variation (%PV) (Eckstein and Bauch 1969) and its associated significance (*p*).

4 The Shipwrecks: History, Archaeology, and Results of Dendrochronological Research

The ship finds are presented in approximately chronological order (date of construction) based on a combination of historical and archaeological information including, where relevant, scientific dating by radiocarbon and/or dendrochronology.

4.1 Barceloneta I

The Barceloneta I shipwreck was found in 2008 during development works in the eponymous coastal district of Barcelona (Spain) (Fig. 1.4a). It represents the first archaeological discovery of a clinker-built ship on the Spanish Mediterranean coast. Considering the radiocarbon dates (calibrated at two sigma) of 1310–1440 obtained for the moss found in the ship's hull, the radiocarbon date of 1395 cal CE (maximum probability) obtained for the sediments underlying the wreck, and the *ante quem* date of 1439, when the construction of a harbour dock favoured the intrusion of sand that covered the shipwreck, a possible construction date around the 1410s seems plausible (Soberón et al. 2012, p. 419).

The dismantled shipwreck was transported to the CASC, where Marta Domínguez-Delmás carried out the inspection and sampling. A total of 14 timbers were inspected and identified as deciduous oak (*Quercus* subg. *Quercus*) (Table 1.2). Cross-sections were sawn from nine plank fragments that had been damaged during the excavation on the development site. Five other elements (one hull plank, three frames, and a beam/wale) were photographed on the transverse surface after cleaning with razor blades and applying chalk.

Results showed that the hull planks had been converted radially from the parent trees' trunks, and the samples contained between 85 and 168 tree rings (Domínguez-Delmás 2009). They all lacked pith and sapwood. In contrast, framing timbers had

Table 1.2 Results of dendrochronological research of the Barceloneta I shipwreck

Sample code	Timber element	Dendro code	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
BM-T5A	Hull plank	SBS00011 SBS00012	75 69	– –	0 0	–	1.24	0.37
BM-TSN-E	Hull plank	SBS00020	100	–	0	–	1.03	0.42
BM-TSN-H	Hull plank	SBS00030	88	–	0	–	1.12	0.32
BM-TSN-I	Hull plank	SBS00040	112	–	0	–	1.30	0.37
BM-TSN-K	Hull plank	SBS00050	93	–	0	–	1.06	0.23
BM-TSN-L	Hull plank	SBS00060	166	–	0	–	0.68	0.36
BM-TSN-M	Hull plank	SBS00070	124	–	0	–	1.79	0.76
BM-TSN-N	Hull plank	SBS00080	95	–	0	–	1.24	0.36
BM-TSN-O	Hull plank	SBS00090	85	–	0	–	1.18	0.36
BM-T10A	Hull plank	SBS00100	168	–	0	–	1.31	0.37
BM-PL	Beam/Wale?	SBS00110	37	+	7	3 ± 2	4.25	1.51
BM-Q9	Framing	SBS00120	69	+	22	3 ± 2	5.55	3.01
BM-Q10A	Framing	SBS00130	64	+	25	2 ± 1	3.67	2.57
BM-Q11	Framing	–	29	+	12	LW		

All samples were oak (*Quercus* subg. *Quercus*); N: number of rings; Pith: present (+)/absent (−); SR: sapwood rings; Bark edge: absent (−), estimated number of rings till bark edge (n ± n), latewood present in last ring (LW); MRW: mean ring width; σ: standard deviation

pith and sapwood, even bark edge, allowing an estimation of the age of the trees at around 30 years (BM-Q11, which showed a regular growth pattern) and 80 years (BM-Q9 and BM0Q10A, which showed severe growth reductions). Although there is an important difference in the age of the trees used for framing timbers, their dimensions are very similar, which indicates that the trees were selected based on diameter and shape. This implies that there was a differentiated selection of trees for hull planks (slow-grown, straight-grained oaks) and for framing timbers (fast-grown trees with appropriate curvature; Fig. 1.1e).

Internal crossdating revealed that some samples from hull planks corresponded to the same element, allowing us to refit pieces that broke during the excavation (Domínguez-Delmás 2009). Furthermore, good matches were also found between two sets of hull planks and between two frames, suggesting that the wood originates from the same forest. Attempts at cross-matching these series with reference chronologies and other contemporary shipwrecks have yet to be successful.

4.2 Newport Ship

This clinker-built ship was excavated in the midst of development in this Welsh port in 2002–2003 (Nayling and Jones 2014). Tree-ring dating of a timber structure (constructed from local timber), onto which the ship had been maneuvered, provides a *terminus post quem* for the ship's arrival during spring of 1468 CE. Thousands of individual timbers were recovered for detailed documentation. The recovered

Table 1.3 Summary of Newport Ship timbers by major type

Timber type	Number	Ring count	Dendrochronology samples
Keel	1	0	1
Planks	820 (373)	440	50
Framing	524 (211)	123	32
Fillers	56	34	6
Ceiling	181	51	2
Chock/buttress	22	0	1
Bilge boards	72	41	6
Repairs/refits			
Riders	4	1	2
F10 block	1	0	1
Tingles	18	18	10
Total	939	708	111

Number of recovered pieces (number of discrete timbers in brackets), number for which ring counts and/or average ring widths collected, and number of dendrochronology samples analyzed

timbers were, where possible, assessed for species, annual ring counts, and mean ring widths by Nigel Nayling (Table 1.3). These data were collected to inform our understanding of timber selection and usage in the ship's construction and subsequent repair and alteration as well as informing a sampling strategy for full dendrochronological analysis. Tree-ring dating of a well-replicated oak ring-width mean for the clinker planking of the ship against Basque oak ring-width chronologies provided a precise date for the ship's construction (1449++CE) and provenance (Nayling and Susperregi 2014). In addition to the article publication or the dendrochronological dating of the ship's hull planks, further details are provided in a specialist report and datasets are available in the Archaeology Data Service (Nayling 2013; Nayling and Jones 2017).

The planks were normally radially split from straight-grained trees with minimal knotting. In some cases, trimmed side branches, encapsulated by later tree growth indicate forestry management (Fig. 1.3). Occasional planks exhibited the normally straight grain curving away from the long axis of the plank at one end, suggesting proximity of the crown or root of the parent tree. The age of the parent trees when felled cannot be determined with total confidence due to secondary working after initial splitting of the timber, removing the feather edge in the vicinity of the pith and the bark and some, if not all, of the sapwood from the outer edge. The majority of planks were converted from parent trees more than 100 years old, with many retaining over 140 annual rings. Marked growth trends, with a distinct transition from relatively fast growth (wide rings) to relatively slow growth (narrow rings), were common, suggesting many parent trees had begun growth in relatively open conditions before coming into competition with neighboring trees in an increasingly closed woodland environment (Nayling and Jones 2014, pp. 249–252). The data on age and growth rates are presented graphically in the Discussion (Fig. 1.5) based on a combination of ring counts and dendrochronological analysis of 339 of the 373

Fig. 1.3 Inboard face of Newport Ship hull plank 766 showing pruned side branch encapsulated in later tree growth. A rare example of direct proof of woodland management. (Photo Newport Museum and Heritage Service)

planks recovered. Care needs to be taken in interpreting scatter plots of this type of data. The samples with relatively fast growth rates and low ring counts usually reflect secondary working where radial splits have been cross-split to provide two or more planks from a single radius. Something of the organization of construction is hinted at by the identification of planks from common parent trees (through use of correlation statistics and close visual matching of growth patterns) in three pairs of planks and a further two groups of three planks. As in the case of the Barreiros wreck (below), cross-matching of tree-ring sequences from disturbed portside planking (fifth and tenth strakes) allowed this detached section to be rejoined to the main, coherent section of hull (Nayling and Susperregi 2014, p. 282).

Analysis of 128 framing timbers (floors and futtocks) indicates exclusive use of oak, carefully converted from trees (often consisting of the main stem and a large side branch in the case of floors) with natural curvature closely matching the hull curvature. Ring counts and growth rates were highly variable ranging from 40 to 157 rings (average 58 years) and 1.1 to 7.6 mm/yr (average 2.9), respectively. Eighty-one percent of these timbers retained at least partial sapwood with 16% having surviving bark (waney) edge. As ever, translating these data into parent tree figures is not straightforward. Even where the pith of the tree is present and there is complete sapwood, many of these samples probably come from branches of lower

Fig. 1.4 Some of the shipwrecks researched between 2009 and 2019 (**a**) Barceloneta. (Photo courtesy of Mikel Soberon, CODEX Arqueologia i Patrimoni), (**b**) Barreiros shipwreck at its most exposed. (Photo courtesy of Luis Ángel García), (**c**) Matagrana shipwreck. (Photo IAPH archive), (**d**) close view of *Triunfante*. (Photo CASC archive)

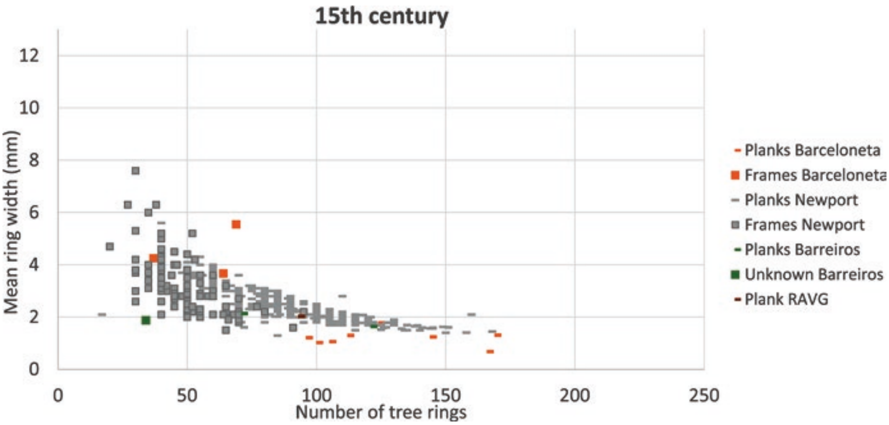

Fig. 1.5 Scatter plot of mean ring width against ring count for studied oak timber assemblages for the medieval (known or suspected fifteenth century) Iberian ships of Barceloneta I, Newport, and Barreiros

age and different growth rates to the stem of the parent tree. Nonetheless, it is evident that the framing timbers were derived from a different group or groups of trees than the planks. None of the ring-width sequences from the framing timbers matched against those of the planks, only a small proportion of them could be cross-matched against each other, and the mean of these series could not be matched against previously dated chronologies or site masters in Spain (or elsewhere). Until we can radically expand the temporal and geographical replication of oak ring width in Cantabric Spain, especially to coastal areas from which compass timber for framing in particular was probably sourced, then ring-width dendrochronology alone is unlikely to provide absolute dating.

Ring-width data (ring counts and average ring widths) were collected from 19 stringers, but none were subjected to full dendrochronological analysis (ring-width measurement). The timber had been sawn from whole or halved, young, fast-grown oaks. Often some sapwood survived on the timbers' corners but never the bark edge. Ring counts averaged 48 (range 29–61) and average ring width 3.6 mm per year (range 1.4–5.4 mm per year).

Lesser numbers of samples were taken from ceiling planks (mostly tangentially sawn from fast-grown oaks), bilge boards (some of which dated against the hull planks and seem to have been derived from the same source), and chocks/buttresses. Samples from repair patches (tingles), and presumed refit timbers including knees and riders dated against British ring-width chronologies, especially from location such as Gloucestershire near the Severn Estuary where the ship was uncovered.

4.3 Barreiros

The Barreiros wreck was uncovered by storms in February or early March 2015 in the intertidal zone of Remior beach near Barreiros, Galicia (NW Spain) (Fig. 1.4b). A substantial section of coherent hull structure was only briefly exposed and, by the time commissioned archaeologists from Zeta Arqueoloxía could visit the site, far less was exposed and available for sampling (Nodar Nodar 2015). The archaeologist of Zeta Arqueoloxía observed that most of the elements were loose boards with negatives of round-section metal nails and a square-head imprint in the wood (some also with a round head, and apparently square section), combined in some cases with round-section treenails of c. 3 cm in diameter. They followed a pattern of two to three metal nails/one treenail (Nodar Nodar 2015). The construction characteristics observed in the preliminary inspection of the wreck pointed to a clinker-built ship, possibly from the fifteenth century or later.

Two hull planks, a floor timber, a treenail, and another timber of unknown function were sampled on site by the archaeologists and sent to the dendrochronology laboratory of the University of Santiago de Compostela, Lugo (Spain).

The four structural timbers sampled were made of deciduous oak (*Quercus* subg. *Quercus*) and lacked pith and sapwood (Table 1.4). However, the treenail was identified as willow (*Salix* spp.). The two hull planks were radially converted and

Table 1.4 Results of dendrochronological research of the Barreiros shipwreck

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
MU01	Hull plank	S0020010	1	71	–	0	–	2.14	0.65
MU02	Treenail	Invalid	2	Ca. 5	+	n.a.	–	–	–
MU03	Hull plank	Invalid	1	25	–	0	–	–	–
MU04	Hull plank	S0020020	1	121	–	0	–	1.65	0.48
MU05a	Floor timber?	S0030031	1	34	–	0	–	1.88	0.41
MU05b		Fragmented; invalid		32	–	0	–	–	–

Adapted from Dominguez-Delmás and García-González (2015f)
Species: *1*, *Quercus* subg. *Quercus*; *2*, *Salix* spp.; N: number of rings; Pith: present (+)/absent (−); SR: sapwood rings; n.a.: not applicable; Bark edge: absent (−); MRW: mean ring width; σ: standard deviation

contain 71 and 121 rings, respectively. MU03 was discarded for dendrochronological investigation because it had only 25 rings. MU05 consists of two different wooden elements, and while they all contained insufficient rings for dendrochronological dating, only one piece (a) (with 34 rings) was included in the research to evaluate its synchronization with the hull planks.

The series obtained from the hull planks do not show a clear synchronization between them. However, the short series obtained from sample MU05a shows an outstanding match with hull plank MU04 (Domínguez-Delmás and García-González 2015f). Crossdating with reference chronologies and with data from potentially contemporary shipwrecks (Barceloneta I and Newport) did not result in a conclusive match.

4.4 Ria de Aveiro G

This shipwreck was located in 2003 following dredging works carried out in connection with the construction of the solid bulk terminal at the Port of Aveiro, Portugal. The disturbed remains comprised a clinker-built ship dated by radiocarbon to 1290–1440 calibrated to two sigma (Bettencourt 2009).

In 2010, timbers held in store were examined at the former *Divisão de Arqueologia Náutica e Subaquática, Instituto de Gestão do Património Arquitectónico e Arqueológico* (DANS/IGESPAR) in Lisbon. Of the dozens of fragments of oak framing and radially converted planks examined, only two plank fragments had more than 50 rings and were sampled. The ring-width series of the two samples exhibited an outstanding visual and statistical match between them indicating that the timbers derived from the same parent tree, or that the fragments sampled originated from the same timber (Table 1.5). Crossdating with reference chronologies did not provide a match. Therefore, these samples remain undated.

Table 1.5 Results of dendrochronological research of the Ria de Aveiro G shipwreck

Sample code	Timber element	Dendro code	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
GR1–006	Plank	PRAG0010	81	–	0	–	2.14	0.97
GR1–008	Plank	PRAG0021	93	–	0	–	1.93	0.91
GR1-6_8	Plank	PRAG_1-2T	93	–	0	–	2.03	0.92

Adapted from Domínguez-Delmás (2010a)
All samples were oak (*Quercus* subg. *Quercus*); N: number of rings; Pith: absent (−); SR: sapwood rings; Bark edge: absent (−); MRW: mean ring width; σ: standard deviation

4.5 Ria de Aveiro F

The Ria de Aveiro F site was identified in 2002 during dredging of the port of Aveiro in Portugal (Lopes et al. 2020). Radiocarbon analyses of wood samples from the scattered remains of at least two vessels (an oak carvel-built vessel with parallels with Ibero-Atlantic ships and a clinker-built boat) gave date ranges of 1280–1420 CE and 1320–1350; 1390–1460 CE, respectively (95% probability at two sigma, see Lopes et al. 2020 Table 2). Recent reanalysis of these assemblages by Lopes et al. (2020) has questioned the usefulness of these radiocarbon dates. Investigations of the construction methods and materials suggest that the carvel-built ship, with some Mediterranean and some Atlantic features, was engaged in the transatlantic trade in the early sixteenth century. The smaller clinker-built boat, which was perhaps a skiff used to support the main carvel-built ship, was made from tropical wood which strengthens the conclusion that the carvel-built Aveiro F shipwreck had been engaged in the transatlantic trade.

In 2010, timbers from the Ria de Aveiro F shipwreck stored at the facilities of the *Divisão de Arqueologia Náutica e Subaquática, Instituto de Gestão do Património Arquitectónico e Arqueológico* (DANS/IGESPAR) in Lisbon, were inspected by Nigel Nayling and Marta Domínguez-Delmás. Through visual observation of several planks from this wreck, it was immediately concluded that they were of some diffuse porous species, i.e., with pores or small vessels distributed across the entire ring width (Schweingruber 1990). We decided to sample some of those planks, together with smaller fragments from other elements, to identify their species and assess their suitability for dendrochronological research. To this end, cross-sections were manually sawn from one end on nine planks. Smaller fragments of approximately 2 cm^3 were taken from two other elements, and a cross-section was cut from a barrel stave that had been found associated with the shipwreck remains.

The barrel stave was found to be made out of chestnut (*Castanea sativa*), whereas the sample from an element that seemed to be made out of branch wood was identified as deciduous oak (*Quercus* subg. *Quercus*) (Table 1.6). Chestnut is commonly spread in Europe, whereas different species of deciduous oaks can be found in Europe and North America.

Table 1.6 List of sampled timbers

Sample code	Description	Wood type	Observations
RAVF 31	Branchwood framing timber Carvel-built vessel	Deciduous oak	Ring porous (tr) Multiseriate medullary rays (tr, tg) Flame-like pore groupings in latewood (tr) 15 rings, no sapwood, no pith
RAVF stave	Barrel stave	Chestnut	Ring porous (tr) Uniseriate rays (tr, tg) Flame-like pore groupings in latewood (tr) Ca. 5 rings
RAVF 258	Hull plank (clinker), tangential	–	Not possible to identify; the subsample was too small and hard to prepare proper micro-slices
RAVF S/R 01	Hull plank (clinker), tangential	Tropical	Diffuse porous Marginal parenchyma bands not convincing One raw of upright cells in the rays (rd)
RAVF 115	Hull plank (clinker), tangential	Tropical	Diffuse porous One raw of upright cells in the rays (rd)
RAVF 353	Hull plank (clinker), tangential	Tropical	Diffuse porous One raw of upright cells in the rays (rd)
RAVF 354_10 RAVF 354_14 RAVF 354_16	Hull plank (clinker), tangential	Tropical	Abundant radially clustered vessels (x2) (tr) Oil cells apparent (rd) Vessel ray pits big and simple Plenty of septate fibers Oil cells present
RAVF 416	Hull plank (clinker), tangential	Tropical	Simple vessel parenchyma cells Oil cells in axial parenchyma?
RAVF 420	Hull plank (clinker), tangential	Tropical	Inter-vessel pits ca. 15 µm Oil cells present (tr) One raw of upright cells in the rays (rd) Parenchyma in bands (rd) Septate fibers present (tg) Vessel ray pits simple (rd) Vessel size ca. 100–200 µm (tr) 2/4 parenchyma strands (tr)
RAVF 3027	Tangential plank (clinker); timber from rear	Tropical	Diffuse porous One raw of upright cells in the rays (rd)

Adapted from Domínguez-Delmás, 2013 and Lopes et al. 2020, Table 1

The nine planks analyzed were determined to be from the same tropical species (see Domínguez-Delmás 2013 for details). Anatomical features found in all these samples were run in the InsideWood database, including other features that were clearly visible in some of the samples. As a result, InsideWood returned between 5 and 27 species from the taxonomic families Anacardiaceae, Lauraceae, and Myristicaceae (Table 1.7). Species of these families are present in Central and South

America, Africa, and Asia, making it extremely difficult to infer the potential construction area or the route sailed.

The most interesting information obtained from this research was the identification of planks made of tropical wood. While the difficulty of narrowing down the species when dealing with tropical wood was explained above, if most of the hull was made with tropical wood, we could infer that the ship was built in a colonial harbor in the tropics. It is vital to remember that oceangoing Iberian ships from this time had access to timbers on a global scale.

The stave made of chestnut probably originated from a barrel that served as a container for food or liquid and that was transported on the ship. The oak sample belongs to an unidentified element, which hampers the possibility of extracting much information from this piece of wood, but which also illustrates the need to compile a thorough register of all individual timbers found at underwater archaeological sites.

Table 1.7 List of species found for each search performed including different anatomical features observed in the tropical-wood samples

IAWA codes	FAMILY and species
1p, 5p, 9a, 10a, 11a, 13p, 22p, 27p, 31p, 32p, 42p, 56p, 61p, 65p, 79p, 89p, 92p, 97p, 106p, 130e, with 0 allowable mismatch	LAURACEAE Alseodaphne spp. Aniba canelilla, A. ferrea, Aniba spp. Beilschmiedia sp. MYRISTICACEAE Staudtia stipitata Warb.
1p, 5p, 9a, 10a, 11a, 13p, 22p, 27p, 31p, 32p, 42p, 56p, 61p, 65p, 79p, 92p, 97p, 106p, 130e, with 0 allowable mismatch	LAURACEAE Alseodaphne spp. Aniba canelilla, A. ferrea, A. rosaeodora Ducke, Aniba spp. Beilschmiedia sp. Endiandra spp. Phoebe posora Phoebe spp. MYRISTICACEAE Staudtia stipitata Warb.
1p, 5p, 9a, 10a, 11a, 13p, 22p, 27p, 31p, 42p, 56p, 61p, 65p, 79p, 89p, 92p, 93p, 97p, 106p, 124e, 125e, 126e, 130e, with 1 allowable mismatch	ANACARDIACEAE Comocladia spp. Mauria heterophylla Pleiogynium spp. Cryptocarya mannii MORACEAE Morus spp. MYRISTICACEAE Endocomia macrocoma Endocomia rufirachis Myristica irya Staudtia stipitata Warb.

(continued)

Table 1.7 (continued)

IAWA codes	FAMILY and species
1p, 5p, 9a, 10a, 11a, 13p, 22p, 27p, 31p, 42p, 56p, 61p, 65p, 79p, 89p, 92p, 97p, 106p, 124e, 130e, with 1 allowable mismatch	ANACARDIACEAE Comocladia spp. LAURACEAE Aiouea impressa Alseodaphne spp. Aniba affinis, A. canelilla, A. férrea, A. rosaeodora Ducke, Aniba spp. Beilschmiedia sp. Cryptocarya mannii Dehaasia spp. Endiandra spp. Licaria subgrp. Canella Licaria subgr. Guianensis Licaria subbullata Mezilaurus itauba Nectandra saligna Nothaphoebe spp. Ocotea globifera Ocotea glomerata Ocotea nigra Ocotea guianensis Ocotea schomburgkiana Persea raimondii Phoebe posora Phoebe spp. Pleurothyrium spp. Ravensara aromatica Ravensara crassifolia Ravensara ovalifolia MYRISTICACEAE Staudtia stipitata Warb.

Descriptions provided following the IAWA code (1989); p = present; a = absent; e = absent required

4.6 Highbourne Cay

The early-modern shipwreck of Highbourne Cay located next to the island of the same name in the Exumas, Bahamas has a long history of investigation (see Chap. 7, Vol. 2 for details). It was recognized as a significant early-sixteenth-century vessel in the Ibero-Atlantic tradition by Oertling (2001). As a part of the most recent campaign of excavation, examination and selective sampling of the *in situ* hull remains from a dendro-archaeological perspective was undertaken by Nigel Nayling and Miguel Adolfo Martins as part of the ForSEAdiscovery project in 2017.

The often-degraded nature of the surface of the timbers of the exposed ship's hull made in situ assessment challenging. It was clear that most of the timbers derived from relatively young and fast-grown oaks (*Quercus* subg. *Quercus*). Samples were recovered from only a limited number of timbers which might have sufficient rings

Table 1.8 Results of dendrochronological research of the Highbourne Cay shipwreck

Timber code	Timber element	Dendro code	N	Pith	SR	Bark edge	MRW (mm)
T0831	Framing	HCW26	14	+	0	–	3
T0829	Framing	HCW27	20	+	0	hs?	4.2
T0835	Framing	HCW29	41	>10	0	–	1.7
T0835	Framing	HCW30	25	>10	0	–	4.5
T0814	Framing	HCW31	31	+	14	?	4.1
T0843 (fifth floor)	Framing	HCW32	21	<5	3	–	5.0
T0824	Framing	HCW33	15	<5	8	–	6.7
Unnumbered	Framing	HCW34	30	+	3	–	3.7
T0834	Framing	HCW35	23	<5	0	–	7.6
T0832	Planks	HCW28	10	+	0	–	6.9
T0841	Plank	HCW28	16	<5	9	–	5.3
NA	Tangentially converted fast-grown oak fragment of (bilge?) board	NA	5	>10	0	–	5.8
NA	Highly eroded plank fragment. Possible TN hole slightly knotty oak	NA	18	>10	0	–	1.9
NA	Oak straight grained bilge board fragment?	NA	3	>10	0	–	7.0
NA	Oak straight grained bilge board fragment	NA	3	>10	0	–	5.0
NA	Conifer straight grained fragment	NA	14	>10	0	–	2.5

All samples were oak (*Quercus* subg. *Quercus*)
N: number of rings; Pith: present (+) absent (−) less than 5 years from pith (<5) more than 10 years from pith (>10); SR: sapwood rings; Bark edge: possible (?) absent (−) possible heartwood/sapwood boundary (hs?); MRW: mean ring width

for dendrochronological ring-width analysis or other forms of high-precision dating such as radiocarbon wiggle match or isotopic dating. Most of these samples were derived from oak framing timbers with relatively fast growth rates (Table 1.8). A group of wood fragments was located forward of the first buttress on the starboard side found within a bag with prelabeled tag from the 1986 excavations. Details of these are provided in Table 1.8 with Timber code NA. These appear to predominantly derive from oak bilge boards.

4.7 *Emanuel Point II*

In 1991, the first shipwreck associated with the Tristán de Luna y Arellano 1559 expedition was discovered in shallow waters off the Florida Coast near Pensacola (Smith 2018). The second vessel, the Emanuel Point II (EP II) shipwreck was discovered by University of West Florida (UWF) archaeologists in 2006. The excavation of this ship, and also terrestrial sites associated with the Luna expedition have been undertaken over many years as research and field training by the Department of Anthropology at UWF (Bendig 2018; Worth et al. 2020). Initially, a selection of samples excavated up to 2017 was sent to Nigel Nayling for analysis. Subsequently, he joined the field team on excavations in 2018 and undertook sampling of the EPII wreck with the assistance of experienced members of the UWF team. The site lies in very shallow water, but visibility is generally very limited/zero meaning that timber selection/location required considerable assistance from the site archaeologists with an expert knowledge of the wreck and the recording frames placed over it, and that selection could be based only on feel. Samples were hand sawn from accessible timbers with a preference for timbers with at least a partially curving cross-section profile which could indicate the presence of surviving bark edge or at least partial sapwood or the heartwood/sapwood boundary.

A total of 33 samples were analyzed comprising framing timbers (futtocks and fillers), planking (hull planks and ceiling), and two chocks (buttresses to the keelson at the point of the expanded mast step (Bendig 2018). All samples were oak (*Quercus* subg. *Quercus*) (Table 1.9). It would appear that most major timbers sampled were derived from relatively young and fast-grown oaks. Even where the growth rates are slower (<2 mm per year), the parent trees do not appear to have been very old when felled. Sample 2 from futtock 7534 had the most rings (86) with partial sapwood, no pith, and an average growth rate of 1.2 mm. The only other timbers with growth rates below 2 mm per year (chock 5336 with pith, possible bark edge, and 51 rings; sample 10 futtock 7542 with pith, bark edge, and 57 rings), even if they were converted from branches, clearly derive from relatively young oak trees. Framing timbers were converted from the whole or half of the tree's stem or branch, while the planking was tangentially sawn.

4.8 Emanuel Point III

The third shipwreck associated with the Luna expedition had only recently been discovered when Nigel Nayling joined the excavations in 2018 and only a very limited area was excavated and available for inspection and sampling. Located in even shallower water than EPII, there was sufficient visibility to allow visual inspection. Only four samples were recovered, all of which were oak (*Quercus* subg. *Quercus*). The single-hull plank sample, tangentially sawn, was from a very fast-grown oak. The three framing timber samples all derived from relatively young oaks, certainly less than 100 years old when felled, with ring sequences running from near the pith to possible or certain bark edge. Their growth rates were slow-medium (Table 1.10).

Table 1.9 Results of dendrochronological research of the Emanuel Point II shipwreck

Artifact / catalogue number	Timber element	Dendro code	N	Pith	SR	Bark edge	MRW
5336	Chock	5336	51	+	18	?	1.48
6698	Chock	6698	53	+	12	–	2.46
7422	Futtock	7422	21	–	0	–	9.12
7423	Futtock	7423	18	–	0	–	2
7424	Filler	7424	31	–	11	–	2.06
7425	Ceiling	7425	4	–	0	–	10
7426	Ceiling	7426	36	–	7	–	2.86
7427	Ceiling	7427	12	–	0	–	3.33
7428	Ceiling	7428	50	–	0	–	3.33
7430	Ceiling	7430	31	–	8	–	3.57
7431	Ceiling	7431	14	–	2	–	5
7432	Plank	7432	16	–	–	–	5.35
7433	Plank	7433	5	–	–	–	9
7533	Futtock	1	37	–	–	–	5.3
7534	Futtock	2	86	–	6	–	1.2
7535	Futtock	3	23	–	–	–	3
7536	Futtock	4	24	–	–	–	4.4
7537	Plank	5	20	–	–	–	3
7538	Futtock	6		+		+	
7539	Futtock	7	41	–	–	hs?	4.1
7540	Futtock	8	54	–	23	+	2.5
7541	Futtock	9	34	+	–	hs	4.1
7542	Futtock	10	57	+	21	+	1.4
7543	Plank	11	12	–	–	–	7.5
7544	Plank	12	27	–	8	–	4.9
7545	Plank	13	9	+	–	–	11.1
7546	Plank	14	32	+	–	–	5.3
7547	Plank	15	21	+	–	–	6.1
7548	Plank	16	45	–	–	–	4.5
7549	Filler	17		–			
7551	Plank	19	40	–	–	–	6.9
7552	Plank	20	24	–	–	–	5.4
7553	Plank	21	43	–	–	–	3.8

All samples were oak (*Quercus* subg. *Quercus*)
N: number of rings; Pith: present (+) absent (−); SR: sapwood rings; Bark edge: present (+) absent (−) possible (?) heartwood/sapwood boundary (h/s) possible heartwood/sapwood boundary (h/s?); MRW: mean ring width

Table 1.10 Results of dendrochronological research of the Emanuel Point III shipwreck

Dendro code	Timber element	N	Pith	SR	Bark edge	MRW (mm)
EP3DS22	Futtock	62	<5	31	?	0.9
EP3DS23	Futtock	42	<5	17	?	3.03
EP3DS24	Futtock	78	<5	24	+	1.53
EP3DS25	Plank	10	–	0	–	6.0

All samples were oak (*Quercus* subg. *Quercus*)
N: number of rings; Pith: less than 5 rings from pith (<5) absent (−); SR: sapwood rings; Bark edge: present (+) absent (−) possible (?); MRW: mean ring width

4.9 *Yarmouth Roads*

The Yarmouth Roads shipwreck, located in the Solent strait of the UK, was first excavated in the 1980s (Watson and Gale 1990). Specific construction features suggest that this could be the remains of a sixteenth–seventeenth-century merchant ship built in a Spanish shipyard.

To assess the date and provenance of some timber elements, a timber sampling campaign was carried out in 2015 by underwater archaeologists of Maritime Archaeology Trust/Maritime Archaeology Ltd. based in Southampton, UK (Rich et al. 2020). Three samples identified as deciduous oak (*Quercus* subg. *Quercus*) were collected by Sara Rich and sent for dendrochronological research to the laboratory of dendrochronology of the department of botany at the University of Santiago de Compostela. They presented an insufficient number of tree rings for dendrochronological research, but ring widths were measured nonetheless to acquire information about the growth rate of the trees selected for those specific timber elements (Domínguez-Delmás and García-González 2015e).

In 2016, another sampling campaign followed and 25 more samples were collected. All samples but one had less than 50 rings, with one sample (YAR01-023W-001S) presenting 161 rings, 15 of which were sapwood (Table 1.11).

Internal crossdating provided good matches between samples 1 and 10 (TBP = 5.11; GL = 76.4***; $r = 0.61$ for 36 rings overlap),[2] whose series were averaged into the mean curve YAR1-10M. The group of samples 6, 7, and 19 also show a good visual and statistical match between them (mean TBP = 6.72, GL = 72.9; rbar = 0.62), and their measurements have been averaged into the mean curve YAR6-7-19M. Although crossdating with reference chronologies has not resulted in the date of the samples, the internal matches indicate that the wood of those samples was sourced in the same area.

[2]TBP: Student's *t*-value adapted for dendrochronological studies by Baillie and Pilcher (1973); GL: percentage of parallel variation as defined by Eckstein and Bauch (1969), asterisks represent the signification level of GL (***, $p < 0.001$); *r*: correlation coefficient.

Table 1.11 Results of dendrochronological research of the Yarmouth Roads shipwreck

Sample code	Timber element	Dendro code	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
A-YAR01-001W-001S	Framing at bow	YAR010	47	0	0	–	3.46	1.09
A-YAR01-002W-001S	Framing at bow	YAR020	35	0	6	–	3.91	1.40
A-YAR01-003W-001S	Framing at bow	YAR030	24	0	3	–	4.05	1.05
A-YAR01-004W-001S	Plank at starboard amidships	YAR041	29	0	0	–	3.45	0.70
A-YAR01-005W-001S	Stanchion(?) at starboard side of stern	YAR050	21	+	0	–	4.11	1.89
A-YAR01-006W-001S	Plank at stern	YAR060	42	+	0	–	2.86	1.43
A-YAR01-007W-001S	Plank at stern	YAR071	41	c.10	sb	–	2.90	1.07
A-YAR01-008W-001S	Plank at stern	YAR081	15	0	0	–	5.80	2.48
A-YAR01-009W-001S	Plank at stern	YAR091	28	0	0	–	4.51	1.04
A-YAR01-010W-001S	Plank at stern	YAR100	44	+	4	–	3.17	0.75
A-YAR01-011W-001S	Frame at stern	YAR111	10	0	0	–	11.53	3.14
A-YAR01-012W-001S	Framing at stern	YAR120	22	0	0	–	5.11	1.80
A-YAR01-018W-001S	Plank at starboard amidships	YAR181	26	c.5	0	–	3.51	0.63
A-YAR01-019W-001S	Plank at starboard amidships	YAR190	44	c.5	0	–	2.57	1.14
A-YAR01-020W-001S	Plank at starboard amidships	YAR201	39	+	0	–	2.50	0.59
A-YAR01-023W-001S	Plank at starboard amidships	YAR230	161	0	15	–	0.89	0.34
A-YAR01-028W-001S	Plank at starboard amidships	YAR281	36	0	0	–	2.58	0.84

All samples were oak (*Quercus* subg. *Quercus*)
Pith: present (1)/absent (−); N: number of rings; Pith: present (+)/absent (−) approximate number of rings to pith (c.*n*); SR: sapwood rings; Bark edge: absent (−); MRW: mean ring width; σ: standard deviation

4.10 Belinho 1

The Belinho 1 shipwreck, initially represented by a collection of artifacts and structural ship timbers washed ashore north of Esposende, Portugal in the winter storms of 2013–2014, is presented in detail in Chapter 5, Vol. 2. That chapter is an updated version of a paper presented at the IKUWA6 conference in Fremantle, Australia and published in its conference proceedings (Martins et al. 2020). During documentation of the ship timbers by a ForSEAdiscovery team in 2015, dendro-archaeological records were made by Nigel Nayling and Miguel Martins for each of the 75 timbers recorded and 15 of them were sampled for tree-ring analysis or wood identification which was subsequently carried out by Marta Domínguez-Delmás et al. (2016).

Of the 75 timbers documented in 2015, all those which could confidently be categorized as structural ship timbers were made from oak (*Quercus* subg. *Quercus*). Of these, the ring count and average ring width of 48 timbers could be determined and are presented in Table 1.12 and the scatter diagram of sixteenth-century shipwrecks (Fig. 1.6). This table includes the ring widths and, for those samples subjected to formal dendrochronological analysis, ring variability (σ) reported. During this analysis, two oak samples (Timber numbers 13 and 24 (BEL01-013W-01S and BEL01-024W-01S)) crossdated with each other showing a strong visual and statistical match, which together with the fact that both end in the same heartwood ring, indicates that these timbers derive from the same parent tree or from trees growing

Table 1.12 Results of dendrochronological research of the Belinho 1 shipwreck

Sample code	Timber element	Notes	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
3	Plank	Radial plank fragment	24	>10	0	–	11.30	
4	Plank	Very knotty tangential plank end. Major side branch	10	–	0	–	3.00	
6	Plank	Tangential fast-grown plank	12	–	0	–	5.40	
7	Plank	Tangential fast-grown plank	35	–	0	–	6.00	
9	Plank	Radial straight grained plank fragment	50	–	0	–	1.94	0.90
11	Plank	Intermediate plank fragment	10	–	0	–	3.50	
12	Plank	Tangential plank fragment	20	>10	0	–	1.70	
13	Plank	Radial slow-grown plank with encapsulated side branch	134	+	0	–	0.71	0.43
14	Framing	Tangential frame fragment medium growth straight grained	30	–	0	–	2.70	
15	Plank	Fast-grown tangential oak plank fragment	5	>10	0	–	7.20	
16	Plank	Medium growth straight grained plank fragment	20	>10	0	–	2.00	
17	Plank		10	–	0	–	7.00	
18	Plank		4	>10	0	–	5.00	
20	Plank	Straight grained medium growth radial plank fragment	25	>10	0	–	2.00	
21	Plank		9	–	0	–	8.30	
23	Plank	Tangential to radial plank fragment	92	–	0	–	1.28	0.71
24	Plank	Radial plank fragment	128	–	0	–	1.00	0.65

(continued)

Table 1.12 (continued)

Sample code	Timber element	Notes	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
27	Framing	Tangential framing fragment	11	–	0	–	9.50	
28	Plank	Tangential plank fragment	17	–	0	–	3.60	
29	Plank	Fast-grown plank fragment	12	–	0	–	12.50	
31	Plank	Fast-grown tangential plank fragment	24	–	0	–	5.00	
32	Yframe	Two core samples taken	54	+?	0	hs?	0.60	0.27
33	Plank		8	–	0	hs?	3.70	
34	Framing	Framing fragment with stem and side branches	32	+	0	hs	4.20	
35	Framing	Very knotty framing fragment	82	+	0	hs?	2.39	1.42
36	Yframe		32	+	0	hs	3.00	
37	Yframe		24	+	0	hs?	2.40	
40	Yframe		50	+	0	hs?	4.60	
43	Yframe		18	+	0	hs	2.80	
44	Floor	Curvature closely follows grain, some knots at one end	15	+	0	–	8.30	
49	Waterway		24	–	0	–	5.00	
50	Plank	Fast-grown stealer plank	10	–	0	–	5.00	
51	Mast step		30	+	0	hs?	4.30	
52	Plank		33	–	0	–	3.30	
53	Plank	Straight grained parallel to one edge	13	–	0	–	4.60	
54	Plank		100	–	0	–	1.51	0.58
57	Plank	Straight grained	5	–	0	–	6.00	
58	Plank	Tangential plank fragment with two knots and wavey grain	14	–	0	–	2.90	
59	Plank	Straight grained until grain runs away toward upper edge. No major knots	5	–	0	–	5.00	
60	Plank	Straight grained	24	–	0	–	3.00	
61	Plank		55	–	2	–	2.45	0.90
64	Plank		5	–	0	–	6.00	
66	Plank		5	–	0	–	5.60	
67	Plank	Wavey grained plank fragment	20	–	0	–	10.50	
69	Framing	Framing fragment with cross-grain	68	–	0	–	2.62	0.77
73	Sternpost	Dendro core sample	56	–	0	hs?	1.55	0.78
74	Plank		36	–	0	–	5.70	
75	Plank		47	–	0	–	1.77	0.54

All samples were oak (*Quercus* subg. *Quercus*); N: number of rings; Pith: present (+) absent (−) number of missing rings (>*n*); SR: sapwood rings; Bark edge: present (+) absent (−) possible (?) heartwood/sapwood boundary (h/s) possible heartwood/sapwood boundary (h/s?); MRW: mean ring width; σ: standard deviation

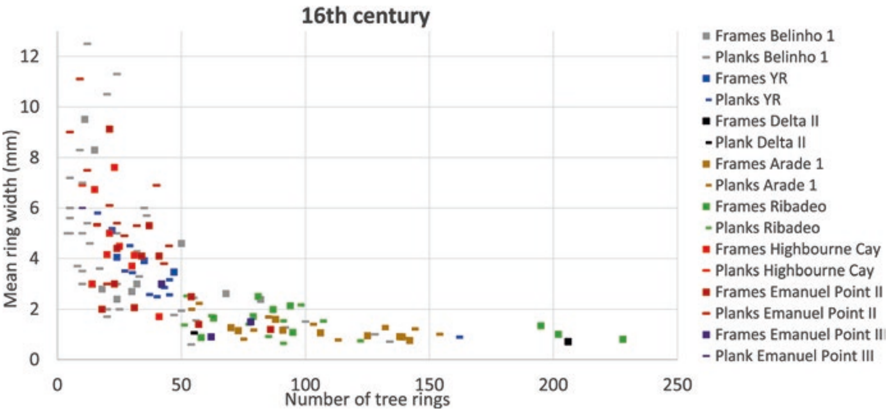

Fig. 1.6 Scatter plot of mean ring width against ring count for studied oak timber assemblages from sixteenth-century shipwrecks Belinho 1, Yarmouth Roads, Delta II, Arade 1, Ribadeo, Highbourne Cay, and Emanuel Point II and III

in the same conditions in the same area. The last ring present in those samples could represent the heartwood–sapwood border. A mean curve of 104 rings was made with both series (BEL2_4MM). The comparison of the mean curve BEL2_4MM and the other individual series between them and with European reference chronologies did not produce statistically sound results. Therefore, all samples remain for now undated.

Analysis of the ship timber assemblage indicates that many timbers were derived from relatively young oak trees. Trees with bifurcating branches were specifically chosen for the Y-frame timbers forming specialized floor timbers located toward the stern of the ship. While gauging the age of these trees at the time of felling is difficult due to the total loss of sapwood, either due to its intentional removal during woodworking or, more probably, due to postdepositional degradation and erosion, most appear to come from trees that were considerably less than 100 years old and relatively fast-grown. This is also true for the few other framing timbers where species, curvature of the parent tree, and sufficient scantling appear to have been key selection criteria. One of these (Timber 34W) had been made using the main trunk and part of a side branch to produce the required curvature of what, given the presence of a dovetail scarf, was probably a futtock (Castro et al. 2015, p. 46). The stern-knee (*coral*), timber 072W (not in table as no ring data collected), was converted from a stem and side branch at the correct acute angle. The mast step on the keelson (051W) was made using a swelling in the parent tree, probably where the main branches spread to form the crown. The majority of the planks were tangentially sawn from very fast-grown oaks. There are exceptions however. The two cross-matched plank fragments 013W and 024W could well come from the same timber, both with countersunk nail holes and one with evidence of a hood end (Castro et al. 2015, p. 100 and p. 110). The timber was radially converted from very slow-grown oak, probably over 150 years old when felled, with an encapsulated side branch reminiscent of the Newport Ship hull planks.

4.11 Delta II

The Delta II wreck was detected during work in the port area of the Bay of Cádiz, Spain. It preserved a length of 18 m and a maximum beam of 5 m. The cargo and the construction characteristics pointed to a mid-sixteenth-century Mediterranean merchant ship (Higueras-Milena and Gallardo 2016).

The archaeologists from TANIT company collected underwater some cross-sections and fragments of wood to determine the dating of the wreck and the species of different structural and cargo elements. The cargo was fully recovered, while the ship structure was documented and reburied in another part of the harbor.

A preliminary inspection of the collected fragments was carried out in 2015 by the authors (MDD) at the facilities of the Centre for Underwater Archaeology of Cádiz (CAS). The material inspected at the CAS consisted of a total of 49 samples, including structural parts of the ship, as well as individual parts of the cargo, which consisted of barrels (staves, heads, and twigs used as hoops) and chests.

Of the 49 samples inspected, 35 were oak (*Quercus* subg. *Quercus*), whereas the rest of the samples were of diverse species (Tables 1.13 and 1.14).

Crossdating of the oak samples between them allowed identification of elements of the barrels that were obtained from the same tree (for details, see Domínguez-Delmás and García-González 2015d):

- Barrel 1: staves B1.1 and B1.13 (their series have been averaged into the curve DLT5-17T, with 58 rings), staves B1.3, B1.10, and B1.16 (DLT7-14-20T, 63 rings);
- Barrel 2, staves B2.1 and B2.3 (DLT21-23T, 51 rings), staves B2.4 and B2.8 (DLT24-28T, 67 rings);
- Barrel 4, cover 1, tables A and B (DLT29-30T, 161 rings);
- Barrel 2, stave 7 and Barrel 5, stave 1 (DLT27-33T, 81 rings)

In addition to these synchronizations between barrel elements obtained from the same individual trees, correlations have been found between some series that indicate that the wood originated from the same forest (e.g., DLT21-23T, DLT24-28T and DLT00221; and DLT5-17T with 27-33T, which either originate from the same tree or the same forest).

Crossdating of the mean curves and the rest of the individual oak series with reference chronologies of oak from Northern, Central, and Eastern Europe (England, France, the Netherlands, Germany, Poland, Denmark, Norway, and Sweden) provided absolute dates for some barrel staves and the head of a barrel with chronologies from the southeastern Baltic (Table 1.15). The rest of the samples remain undated.

Table 1.13 Results of the species identification and dendrochronological research

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
M116	Frame	DLT00010	2	71	1	53	LW	0.92	0.43
M119	Frame	DLT00020	1	54	–	13	–	1.07	0.52
M126	Frame	DLT00030	1	206	–	14	–	0.72	0.29
M127	–	DLT00041	1	66	–	0	–	0.65	0.22
B1.1	Barrel 1, stave 1	DLT00051	1	58	–	0	–	1.14	0.44
B1.2	Barrel 1, stave 2	DLT00061	1	29	–	0	–	1.63	0.40
B1.3	Barrel 1, stave 3	DLT00071	1	39	–	0	–	1.60	0.50
B1.4	Barrel 1, stave 4	DLT00081	1	72	–	0	–	0.89	0.18
B1.5	Barrel 1, stave 5	DLT00091	1	47	–	0	–	0.66	0.21
B1.6	Barrel 1, stave 6	DLT00101	1	32	–	0	–	1.60	0.41
B1.7	Barrel 1, stave 7	DLT00111	1	36	–	0	–	1.23	0.19
B1.8	Barrel 1, stave 8	DLT00121	1	46	–	0	–	1.15	0.32
B1.9	Barrel 1, stave 9	DLT00131	1	57	–	0	–	1.19	0.22
B1.10	Barrel 1, stave 10	DLT00141	1	37	–	0	–	1.67	0.53
B1.11	Barrel 1, stave 11	DLT00151	1	24	–	0	–	1.88	0.34
B1.12	Barrel 1, stave 12	DLT00161	1	36	–	0	–	1.64	0.47
B1.13	Barrel 1, stave 13	DLT00171	1	33	–	0	–	1.70	0.58
B1.14	Barrel 1, stave 14	DLT00181	1	31	–	0	–	1.79	0.43
B1.15	Barrel 1, stave 15	DLT00191	1	57	–	0	–	1.09	0.25
B1.16	Barrel 1, stave 16	DLT00201	1	45	–	0	–	1.40	0.36
B2.1	Barrel 2, stave 1	DLT00211	1	40	–	0	–	1.36	0.54
B2.2	Barrel 2, stave 2	DLT00221	1	47	–	0	–	1.22	0.27
B2.3	Barrel 2, stave 3	DLT00231	1	50	–	0	–	1.04	0.31
B2.4	Barrel 2, stave 4	DLT00241	1	42	–	3	–	1.48	0.23
B2.5	Barrel 2, stave 5	DLT00251	1	59	–	0	–	0.87	0.40

(continued)

Table 1.13 (continued)

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
B2.6	Barrel 2, stave 6	DLT00261	1	34	–	0	–	1.55	0.30
B2.7	**Barrel 2, stave 7**	**DLT00271**	1	81	–	0	–	1.09	0.39
B2.8	Barrel 2, stave 8	DLT00281	1	66	–	2	–	1.40	0.29
B4. T1A	**Barrel 4, lid 1, tabla A**	**DLT00291**	1	146	–	1	–	0.93	0.39
B4. T1B	Barrel 4, lid 1, tabla B	DLT00301	1	161	–	–	–	0.99	0.36
B4. T2B	Barrel 4, lid 2, tabla B	DLT00311	1	107	–	–	–	1.27	0.34
B4. T2C	Barrel 4, lid 2, tabla C	DLT00321	1	82	–	–	–	1.68	0.33
B5.1	**Barrel 5, stave 1**	**DLT00331**	1	61	–	–	–	1.11	0.36
M51	Hoop	–	4	ca. 22	+	n.a.	+, LW	–	
M92	Stave	–	1	30	–	0	–	Insufficient number of rings for dendrochronological analysis	
M117	–	–	2	ca. 18		0	–	–	
M120	Keelson	–	2	4	–	0	–	–	
M129	–	–	1	11	+	0	–	Insufficient number of rings for dendrochronological analysis	
M136	–	–	1	35	–	0	–	Inspected at CAS but was not transported to the laboratory at USC	
M139	–	–	3	28	–	n.a.	+, LW	Insufficient number of rings for dendrochronological analysis	
M140	Bulkhead	–	3	24	ca. 5	n.a.	–	Insufficient number of rings for dendrochronological analysis	

Species: 1, *Quercus* subg. *Quercus*; 2, unidentified conifer; 3, *Fagus sylvatica*; 4, *Rhamnus* sp.; N: number of rings; Pith: present (1)/absent (–); SR: sapwood rings; n.a.: not applicable; Bark edge: present (LW, latewood)/absent (–); MRW: mean ring width; σ: standard deviation of MRW. Barrel elements from which a wood sample was sectioned for dendrochronological analysis have been marked in bold. The rest of the elements of the barrels were analyzed using digital photographs

Table 1.14 Samples taken for observation of anatomical characteristics and species identification

Sample code	Timber element	Species/observations
M132	–	No identification
M133	–	No identification
M141	–	No identification
M915	–	No identification
Box 2	lid	Tropical, unidentified
Box 6, M936	Front piece	Tropical, unidentified
Box 6	Lateral A	Tropical, unidentified
Box 6	Lateral B	Tropical, unidentified

4.12 Arade 1

While the timbers are housed at the *Divisão de Arqueologia Náutica e Subaquática, Instituto de Gestão do PatrimónioArquitectónico e Arqueológico* (DANS/IGESPAR) in Lisbon, the wreck was originally discovered by recreational divers in 1970, then rediscovered in 2001 and excavated and recorded in several years by divers of the former *Centro Nacional de Arqueologia Náutica e Subaquática* (CNANS) and students from Texas A&M University.

The Arade 1 was a skeleton-first, carvel-built vessel, and radiocarbon dates placed its construction between the fifteenth and seventeenth centuries (Castro 2006). Preliminary dendrochronological dating (conducted by Tomasz Wazny in 2005) on five timbers produced a felling date for one of the parent trees between 1577 and 1589, which provided a *terminus post quem* for the ship's construction, thus tightening the range yielded by the previously conducted ^{14}C analyses.

Also in 2005, 18 samples of wood from the wreck were analyzed by the *Centro de Investigacão em Paleoecologia Humana* (CIPH) of the former *Instituto Português de Arqueologia* in Lisbon, and were identified as Portuguese oak (*Q. faginea*) and cork oak (*Q. suber*). These identifications led to the hypothesis that the ship had been constructed locally with materials from the Iberian Peninsula; however, the basis for this hypothesis was called into question when the identification key used by researchers of the CIPH was not made available to us to reproduce those identifications. Since the discrimination of deciduous oaks such as *Q. faginea* is not possible based on wood anatomical features alone, we decided to revisit those identifications.

With the aim of dating the ship's construction and find out what species was used in its construction, we carefully selected and collected new samples from 42 timbers, including 6 of the timbers previously sampled for wood identification (the ones identified as *Q. faginea* and *Q. suber*). New identifications were performed on all 42 samples in accordance with Schweingruber (1990). Of the total timbers represented, 40 were identified as deciduous oak, including one of the timbers previously identified as cork oak (which is an evergreen species) and two others were identified as chestnut (*Castanea sativa*) (Domínguez-Delmás et al. 2013). These

Table 1.15 Results of the dendrochronological dating of Delta II

Sample code	Dendro code	N	SR	Bark edge[a]	First year	Final year	Felling date	TBP	CC	Gl	Chronology
B1.1, B1.13	DLT5-17T	58	0	>8	1512	1569	After 1577	5.67	0.60	69**	sch1115m[b]
B4.T1A, B4.T1B	DLT29-30T	161	1	8–23	1418	1578	Between 1586 and 1601	5.85	0.41	65.8***	NLARTPOL[c]
B2.7, B5.1	DLT27-33T	81	0	>8	1498	1578	After 1586	6.73	0.59	69.8***	sch1115m
B1.1-B1.13 B2.7-B5.1	DLT5-17_27-33M	81	n.a.	n.a.	1498	1578	n.a.	7.63	0.64	74.7***	sch1115m

N: number of rings; SR: sapwood rings; TBP: Student's *t*-value adapted according to Baillie and Pilcher (1973); CC: correlation coefficient; Gl: percentage of parallel variation as defined by Eckstein and Bauch (1969); asterisks represent the signification level of Gl (**, $p < 0.01$; ***, $p < 0.001$)

[a]Estimation of sapwood rings missing till the bark edge based on Wazny (1990) for a 90% confidence interval

[b]Bauch et al. (1972), Eckstein et al. (1975)

[c]Jansma et al. (2004)

species grow and coexist over vast areas of European continent, so the hypothetical construction site of Iberia had to be withdrawn.

The dendrochronological research included 4 tree-ring series obtained by Wazny and 24 series obtained from the newly collected samples. Internal cross-matching demonstrated that six of the planks originated from the same three trees. Most of the planking elements had high statistical correlations internally, as did most of the framing elements, which demonstrates a homogenous group of parent trees, lending itself to successful dating and provenance of the wreck assemblage.

Crossdating against master and local chronologies produced precise felling dates for frame samples that retained bark edge between the spring/summer of 1579 and the spring/summer/winter of 1582/1583 (Domínguez-Delmás et al. 2013). These dates, combined with the *terminus post quem* of the dated samples without sapwood, led to the conclusion that all the trees used in the ship's construction were felled from the late 1570s to 1583, suggesting soon after 1583 as the likely time of construction. Furthermore, the oak series (and separately, the chestnut samples) produced a strong statistical correlation with the oak reference chronology for the area of Western France along the Loire River in Fontevraud, where the timber—oak and chestnut—for this ship was likely sourced. Where it was constructed, however, remains unknown, although a shipyard in France or the Iberian Peninsula remains likely.

4.13 Punta Restelos

The Punta Restelos shipwreck was located in 2007 by Archeonauta S.L. at Punta Restelos, near the Finisterre Cape in the northwestern coast of Galicia (Spain) (San Claudio Santa Cruz 2008, 2009). Preliminarily, it was identified as the wreckage of the galleon *Santa María la Anunciada*, a ship that was built in Vietri sul Mare, Salerno, around 1590, and that sunk in 1596 while taking part on the fleet commanded by Martin de Padilla during the Anglo-Spanish War (San Claudio Santa Cruz 2012, 2015).

During an archaeological campaign in 2012, seven pieces of timber fragments were recovered from the wreck site with the aim to date and provenance the wood, although none of these timbers was removed from the ship's structure itself, so their relationship to the site is questionable.

All the samples were identified as deciduous oak (*Quercus* subg. *Quercus*). Only two samples had 90 rings or more. The rest had less than 50 rings (Table 1.16). However, one of those samples with only 41 rings presented a very sensitive growth pattern, so it was included in the dendrochronological analysis to assess its synchronization with the longer, suitable, samples.

The internal crossdating revealed a match between the tree-ring series from samples 1 and 7, while no match was found between samples 1 and 3.

Crossdating with reference chronologies resulted in the dating of the three samples with chronologies from northeastern Poland (Domínguez-Delmás 2014).

Table 1.16 Results of the wood identification and suitability of the samples for dendrochronological research for the Punta Restelos wreck

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
1	Unknown	S0010020	1	90	–	4	–	1.52	0.60
2	Unknown	Invalid	1	12	–	0	–	–	–
3	Unknown	S0010010	1	116(+8)	–	6(+8)	–	0.79	0.28
4	Unknown	Invalid	1	29	+1	0	–	–	–
5	Unknown	Invalid	1	10	–	0	–	–	–
6	Unknown	Invalid	1	31	+1	0	–	–	–
7	Unknown	S0010030	1	41	–	0	–	0.74	0.16

Adapted from Domínguez-Delmás (2014); Pith: present (+1)/absent (−); SR: sapwood rings; Bark edge: present (+)/absent (−); MRW: mean ring width; σ: standard deviation

The most recent ring measured in sample 3 dates to 1566, and accounting for the presence of six measured sapwood rings and another eight that could be seen but not measured, an interval for the felling of the tree was estimated between 1574 and 1584. Sample 1 contained four sapwood rings and the outermost one dated to 1438. Given the provenance of the wood in northeast Poland, the estimated felling date of this tree was established between 1443 and 1458. The relative match between samples 7 and 1 allowed anchoring the former in time, with an absolute date for the outermost ring of 1414. This tree was cut sometime after 1422, but the lack of sapwood hampers the possibility to estimate the felling date within a range of years.

Although most of the recovered elements contain an insufficient number of tree rings to be considered suitable for dendrochronological research, the three selected samples could be dated, and their provenance was established in northeastern Poland. The estimated felling date for the parent tree of sample 3 (1574–1584) would allow placing this timber in the context of a ship from Padilla's 1596 fleet. However, the fact that this timber was found out of context (i.e., not directly linked to the ship's structure) calls for caution when inferring conclusions regarding the date or identity of the ship. The same applies to the other two dated samples. Given that they were not found in connection with the ship's structure, it is not possible to infer further information from their date and provenance. Furthermore, the estimated interval for the felling of the parent tree of sample 1 (1443–1458) would exclude this timber as an original element from a ship built in the second half of the sixteenth century. The likelihood that this could be a reused timber in a ship from this period seems very slim. Given that this element was found out of context, it seems more likely that it belongs to another shipwreck. The lack of sapwood in sample 7 impedes the placement of this element within a temporal context other than after 1422, which is a *terminus post quem*.

The Polish provenance of the wood does not exclude the possibility that the ship(s) was (were) built in the Iberian Peninsula. Import of different species of Baltic wood to markets in Western Europe has been broadly reported (e.g., Albion 1926; De Vries and Van der Woude 1997 and references therein; Brand 2007). More specifically, Bogucka (1969) describes the export of products (including wood) from Poland to the Iberian Peninsula, and Casado Soto (1998) reports that a 1522 inventory of ships from Cantabrian harbors included ships built with local oak and oak from Northern Europe. Other scholars also refer to the import of wood from Northern Europe to Iberia for shipbuilding (Bauer 1980; Aranda y Antón 1990; García Fernández 2005), but often these references are very generic and unspecific, or cover later periods (seventeenth to eighteenth centuries). Therefore, the recovered material could very well belong to a ship or ships built in Iberia with imported wood.

In spite of the limitations presented by the analyzed material, the results are very promising. Future campaigns should be directed at locating the remains of the ship's hull and sampling structural timbers from it, so that future dendrochronological results can be placed in a more specific context and so that more specific conclusions can be drawn.

4.14 Ribadeo

In 2011, the wreckage of a galleon was found during dredging works in the river near the town of Ribadeo (NW Spain). Archaeological investigations carried out in 2012 estimated a sixteenth-century date based on associated artifacts and construction features (San Claudio Santa Cruz et al. 2013). Two chapters in this volume describe the site in more detail—in Chapter 3, Vol. 2, Miguel San Claudio, the lead archaeologist provides an overview, while in Chapter 4, Vol. 2, the ForSEAdiscovery multidisciplinary team which worked on the site reprise the paper presented at the IKUWA6 conference in Fremantle, Australia in 2016 and published in the conference proceedings (Eguiluz Miranda et al. 2020). These Chapters 3 and 4, therefore, contain a detailed account of the dendrochronological analysis of the Ribadeo wreck timber samples.

4.15 Delta I

The Delta I wreck was detected during work in the port area of the Bay of Cádiz (see also Chapter 6, Vol. 2). The construction characteristics point to the ship of Iberian–Atlantic construction, and the silver bars from the cargo date it around the mid-seventeenth century (Higueras-Milena and Gallardo 2016).

In an attempt to date the shipwreck, fragments of wood of different sizes were sawn underwater from several structural elements by archaeologists from TANIT. A preliminary inspection was carried out at the facilities of the Underwater Archaeology Centre of Cádiz (CAS), to be researched subsequently at the dendro lab of the University of Santiago de Compostela.

All the samples except four corresponded to the subgenus of deciduous oaks (*Quercus* subg. *Quercus*) (Table 1.17, adapted from Domínguez-Delmás and

Table 1.17 Results of the species identification and dendrochronological research

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
M13	?	Invalid	2	9	–	0	–	–	–
M16	?	Invalid	3	35	–	0	–	–	–
M20a	Peg	S0030051	1	43	–	0	–	0.63	0.14
M20b	Peg	S0030061	1	36	–	0	–	0.70	0.21
M20c	Peg	S0030071	1	28	–	0	–	0.78	0.19
M20d	Peg	S0030081	1	23	–	0	–	1.11	0.49
M21	?	Invalid	1	10	–	0	–	–	–
M25	?	Invalid	1	10	1	0	–	–	–
M26	Peg	Invalid	1	21	–	0	–	–	–
M27	?	Invalid	1	11	–	1	–	–	–
M28	?	Invalid	1	28	ca.10	0	–	–	–
M29	?	Invalid	1	7	–	0	–	–	–
M30	?	Invalid	1	18	–	0	–	–	–
M31	?	Invalid	1	20	–	0	–	–	–
M32	?	Invalid	1	21	–	12	1+/−1	–	–
M33	?	S0030090	2	88	–	0	–	1.02	0.38
M34	Plank	Invalid	1	38	1	0	–	–	–
M35	Plank	S0030020	1	139	–	0	–	1.00	0.22
M36	Peg	Invalid	1	15	–	0	–	–	–
M37	?	S0030100	2	83	–	0	–	1.27	0.40
M38	?	Invalid	1	23	–	0	–	–	–
M39	?	S0030040	1	81	–	0	–	1.26	0.56
M40	?	Invalid	1	4	–	0	–	–	–
M41	?	Invalid	1	7	–	0	–	–	–
M42	Floor timber	S0030030	1	122	ca. 20	0	–	1.29	0.53
D770	Keel	S0030010	1	90	–	0	–	2.56	1.81

Adapted from Domínguez-Delmás and García-González (2015)
Species: 1, *Quercus* subg. *Quercus*; 2, *Pinus sylvestris/nigra*; 3, *Fagus sylvatica*; N: number of rings; Pith: present (1)/absent (−); SR: sapwood rings; Bark edge: present (+)/absent (−); MRW: mean ring width; σ: standard deviation. Pith: present (+1)/absent (−); Bark edge: present (+)/absent (−)

García-González 2015g). Three elements (M13, M33, and M37) were identified as pine (*Pinus* sp.) of the type *P. sylvestris/nigra*, and one sample (M16) as beech (*Fagus sylvatica*).

Four samples of oak (M35, M39, M42, and D770) and two of pine (M33 and M37) contained more than 80 rings, so they were selected for dendrochronological research. The treenails that made up the M20 sample were also analyzed to test whether their tree-ring series synchronized with each other. The rest of the fragments had been collected for wood identification and contained less than 40 rings, hence were not suitable for dendrochronological investigation. However, considering that many of them were only fragments and showed slow growth, it is justifiable to assume that a complete cross-section of those timbers would provide sufficient rings for the research. Those observations were therefore noted in case a future campaign on this shipwreck is ever carried out (see Domínguez-Delmás and García-González 2015g for details) (Table 1.17).

Crossdating attempts between the samples did not produce matching results. It was also not possible to synchronize the series obtained from the treenails of the M20 sample. The comparison with reference chronologies of oak and pine from Northern, Central, and Eastern Europe (England, France, the Netherlands, Germany, Poland, Denmark, Norway, and Sweden) did not provide conclusive results.

Should another sampling campaign be planned on this shipwreck, it is strongly recommended to take samples (complete cross-sections) of the elements whose fragments showed slow growth (M28, M30, M31), as well as the elements whose fragments showed fast growth, but could have dendrochronological potential if the specimen is large (timbers M25, M27, and M32). Likewise, given the number of rings present in the oak samples M35, M39, and M42, and in the pine M33 and M37 samples, it is recommended to carry out a new intervention on the wreck in order to sample more construction elements of the same type, as that would increase the chances to find cross-matches between the samples to develop an object chronology, which are usually easier to date than series derived from single timbers.

4.16 Delta III

Like Delta I and II, the Delta III wreck was detected during works to expand the harbor in the bay of Cadiz. To find the primary construction date of the ship and identify the species used in different structural elements, 12 wood samples were taken from several structural elements and barrel staves in June 2016 by Nigel Nayling during diving operations.

Seven samples were oak (*Quercus* subg. *Quercus*), three were pine (*Pinus sylvestris/nigra*), and two others were beech (*Fagus sylvatica*) (Table 1.18).

Crossdating of the oak samples between them allowed identifying correlations between the samples 6, 7, 8, and 9 (see Domínguez-Delmás and Nayling 2016 for details). These series have been averaged into the object chronology DEL4MMMM (191 rings). Comparison of this mean curve and all the individual oak series with the reference chronologies has resulted in the absolute dating of DEL4MMMM (Table 1.19). The presence of sapwood in sample 7 made it possible to estimate the cutting date of the tree between 1663 and 1675. For the other three samples, only *terminus post quem* dates (dates after which the trees were felled) could be estimated. In all three cases, these dates are earlier than the estimated cutting interval for the Dendro 7 sample.

The reference chronology providing the best correlation with the dated series (NLGERM05, Domínguez-Delmás, unpublished) which is made up of series from

Table 1.18 Results of the species identification and dendrochronological inspection

Sample code	Timber element	Dendro code	Species	N	Pith	SR	MRW (mm)	σ (mm)
Dendro 1	Frame	DEL00011	1	62	–	–	1.53	0.83
Dendro 2	Sacrificial planking	–	2	–	–	–	–	–
Dendro 3	Sacrificial planking	DEL00021	2	60	–	?	2.04	0.68
Dendro 4	Sacrificial planking	–	2	–	–	–	–	–
Dendro 5	Hull plank	DEL00030	1	65	–	–	1.99	0.35
Dendro 6	Hull plank	DEL00040	1	106	–	–	1.72	0.40
Dendro 7	Ceiling plank	DEL00051	1	153	Ca.5	2	1.37	0.53
Dendro 8	Ceiling plank	DEL00060	1	115	–	–	1.55	0.36
Dendro 9	Ceiling plank	DEL00071	1	91	–	–	2.20	0.86
Dendro 10	Ceiling plank	–	1	35	–	–	–	–
Dendro 11	Keel	–	3	20		n.a.	–	–
Dendro 12A	Stave	DEL00081	3	25	–	n.a.	2.93	1.19
Dendro 12B	Stave	DEL00091	3	64	–	n.a.	1.15	0.58

Adapted from Domínguez-Delmás and Nayling (2016)
Species: 1, *Quercus* subg. *Quercus*; 2, *Pinus* sp. type *sylvestris/nigra*; 3, *Fagus sylvatica*; N: number of rings; Pith: present (1)/absent (−); SR: sapwood rings; n.a.: not applicable; Bark edge: present (+)/absent (−); MRW: mean ring width; *σ*: standard deviation

wood found in archaeological sites in the Netherlands, but that was imported from West Germany. Therefore, it is likely that the dated timbers from the Delta III originate from the same or neighboring geographic areas.

The oak sample Dendro 1 shows distortion in the growth pattern that, together with the low number of rings ($N = 62$), may have contributed to impede the dating of this element. The pine samples (Dendro 2, 3, and 4) also remain undated, as do the beech samples from the barrel staves (Dendro 12A and 12B).

Although the end year of sample Dendro 6 dates from the second half of the sixteenth century, it is possible that many rings are missing in the outermost part of the sample. Therefore, it cannot be ruled out that this wood is contemporary with the other three dated samples. If all the dated samples belong to the original construction of the ship, it is probable that the felling of the trees took place between 1663 and 1675, as has been estimated for sample Dendro 7.

The dendrochronological results have also allowed us to infer the area of origin of the dated wood, which is native to West Germany. In the seventeenth century, this area supplied timber to the low countries (e.g., De Vries and Van der Woude 1997), which is consistent with the initial assessment of the ship being a Dutch merchantman.

Table 1.19 Results of the dendrochronological dating for the Delta III wreck

Sample code	Dendro code	N	SR	Bark edge[a]	First year	Final year	Felling date	TBP	CC	Gl	Chronology
Dendro 6	DEL00040	106	–	>13	1461	1566	After 1579	6.61	0.562	70.8***	NLGERM05
Dendro 7	DEL00051	153	2	[12–24]	1499	1651	Between 1663 and 1675	6.75	0.465	71.9***	NLGERM05
Dendro 8	DEL00060	115	–	>13	1528	1642	After 1655	5.12	0.422	69.6***	NLGERM05
Dendro 9	DEL00071	91	–	>13	1531	1621	After 1634	5.01	0.462	72***	NLGERM05
Dendro 6 Dendro 7 Dendro 8 Dendro 9	DEL4MMMM	191	–	–	1461	1651	–	8.88	0.532	77.7***	NLGERM05

[a]Estimation of sapwood rings missing till the bark edge based on Hollstein (1980) for oaks 100–200 years old

N: number of rings; SR: sapwood rings; TBP: Student's *t*-value adapted according to Baillie and Pilcher (1973); CC: correlation coefficient; Gl: percentage of parallel variation as defined by Eckstein and Bauch (1969), asterisks represent the signification level of GL (***, $p < 0.001$)

4.17 *Matagrana*

In 2008, Atlantic storms caused sand dunes to recede at Portil Beach in Huelva (Spain), revealing a shipwreck of 16.81 m long and 5.48 m wide (Fig. 1.4c). The wreck assemblage was excavated, documented, and reburied again by a team of the *Centro de Arqueología Subacuática* (CAS) of Cadiz, and has been interpreted as an English merchant vessel dating from the late seventeenth to the mid-eighteenth century (Rodríguez Mariscal 2016).

A sample from a framing element (MATA/HU-08/M1) was examined for wood identification and was determined to be *Quercus ilex* (Menguiano Chaparro 2008), an evergreen oak species native to the Iberian Peninsula. Another sample from a different framing element (frame 21) was collected by manual sawing and subjected to tree-ring analysis (Table 1.20; Domínguez-Delmás 2010b). The species corresponded to the group of deciduous oaks (*Quercus* subg. *Quercus*) and a series with 88 rings was obtained. The sample contained the pith but lacked sapwood, and it remains undated.

Based on those initial identifications, the archaeologists could establish that most of the framing elements were made of deciduous oak, whereas only a few were made of oak holm (*Q. ilex*).

4.18 *Triunfante*

Triunfante was the first ship from the Spanish navy ever being excavated by nautical archaeologists in Spain. This 68-gun ship of the line was built in Ferrol shipyard (NW Spain) between 1754 and 1756, and after almost four decades of service, it sunk in 1795 in the Mediterranean off the Cabo de Rosas (NE Spain) (Fuente de Pablo 2006, p. 138).

In 2009, a section of the shipwreck was excavated by the Centre d'Arqueología Subacuàtica de Catalunya (CASC) and Marta Domínguez-Delmás was invited to inspect the shipwreck and collect samples. The excellent visibility of the shallow (7–8 m depth) Mediterranean waters where *Triunfante* is resting allowed identifying the framing elements as deciduous oak, whereas the hull planks were made of a conifer species (Fig. 1.4d). Ring counts were carried out underwater on the end grain of the framing elements. With approximate dimensions of 40 × 40 cm and 38–45 rings, it was immediately understood that the oak frames were derived from

Table 1.20 Results of dendrochronological research of the Matagrana shipwreck

Sample nr	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
21	Frame	SMG00010	1	88	1	0	–	1.12	0.33

Species: 1, *Quercus* subg. *Quercus*; Pith: present (1)/absent (−); SR: sapwood rings; Bark edge: present (+)/absent (−); MRW: mean ring width; σ: standard deviation MRW young, fast-grown trees, which according to historical documents originate from the north of Spain, possibly from the Basque Country (Fuente de Pablo 2006, pp. 104–106). Samples were collected from six hull planks, and from three additional planks (two of conifer and one of oak) which were on the wreck but out of context.

Once at the laboratory of the Ring Foundation in the Netherlands, all the conifer samples collected were identified as pine (*P. sylvestris/nigra*) (Table 1.21). Crossdating between the samples revealed excellent matches between five of the pine samples (dendro codes SST010, 20, 30, 40, and 60; Domínguez-Delmás, 2010c), indicating that these pines originate from the same area. These series have been averaged into an object chronology (SST5MM). Sample SST050 shows a weaker match and has been left out of the mean curve. SST070 shows no correlation with the mean curve or with sample SST050. Similarly, no correlation was found between the oak samples indicating that either they do not cover the same period (or overlap just a few years) or that they originate from different areas. However, given that those oak samples and the pine sample SST070 were out of context, no information can be extrapolated from them.

Triunfante sailed for almost 40 years, and it is known that it underwent repairs in several occasions, probably at Cartagena shipyard, which is where the ship had its base (Pujol i Hamelink et al. 2013). The presence of iron nails in the hull planking indicates that the outer hull was repaired after 1764, therefore the researched hull planks do not belong to the original construction (Pujol i Hamelink et al. 2013, pp. 146–147 and 179). Unfortunately, crossdating with reference chronologies did not result in a date, hence we cannot attest when the pines for the hull planks were potentially cut.

Table 1.21 Results of the species identification and dendrochronological inspection of samples from *Triunfante* (Domínguez-Delmás 2010c)

Sample code	Timber element	Species	Dendro code	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
T1E	Hull plank	2	SST010	117	1	–	–	1.46	0.70
T13E	Hull plank	2	SST020	222	C.10	–	–	0.79	0.56
T2?E	Hull plank	2	SST030	56	1	–	–	2.62	1.25
T2?E	Hull plank	2	SST040	184	C.10	46	–	0.91	0.60
T3E	Hull plank	2	SST050	140	1	–	–	1.25	0.60
T14E	Hull plank	2	SST060	155	C.5	15	–	1.07	0.87
–	Plank out of context	2	SST070	103	–	–	–	0.95	0.33
–	Plank out of context	1	SST080	93	–	s.b.	–	0.90	0.30
–	Plank out of context (found under T14E but without number)	1	SST090	94	C.5	26 + 1	–	1.89	1.02

Species: 1, *Quercus* subg. *Quercus*; 2, *Pinus* sp. type *sylvestris/nigra*; 3, *Fagus sylvatica*; *N*: number of rings; Pith: present (1)/absent (−); SR: sapwood rings; n.a.: not applicable; Bark edge: present (+)/absent (−); MRW: mean ring width; σ: standard deviation

4.19 Magdalena

The *Santa Maria Magdalena* ship was a frigate of the Spanish Royal Navy built in Ferrol (province of Galicia) in 1778 which sank off Covas in Viveiro (province of Lugo) on November 2, 1810. Chapter 9, Vol. 2 in this volume describes the site in more detail where the ForSEAdiscovery multidisciplinary team which worked on the site reprises the paper presented at the IKUWA6 conference in Fremantle, Australia in 2016 and published in the conference proceedings (Trindade et al. 2020). The chapter contains a detailed account of the dendrochronological analysis of the *Magdalena* wreck timber samples.

4.20 San Sebastián

This shipwreck, known as "*pecio de los bajos de San Sebastián,*" corresponds to a mid-size military vessel dating to the late eighteenth or early nineteenth century based on associated archaeological material (see Chapter 6, Vol. 2 and Martí Solano 2013). A sample was obtained from one radial hull plank, which delivered a series with 77 rings (Table 1.22; Domínguez-Delmás 2010d). Pith and sapwood were absent on the sample, and it remains undated.

4.21 Bayonnaise

Bayonnaise was a corvette from the French Royal Navy. Built in Bayonne (France) in 1794, she wrecked in 1803 at Playa Langosteiras, Finisterre (province of Coruña, Spain). The shipwreck was located in 2010 by Archaeonauta S.L. during an inventory of underwater archaeological heritage along Galician coasts. The underwater archaeology team of the ForSEAdiscovery project carried out a campaign in June 2015 and collected samples from ten timber elements for dendrochronological research.

The preliminary inspection served to identify all the samples as deciduous oak (*Quercus* subg. *Quercus*). Only four samples (A-BAY01-007W-01S, -008W-01S, -009W-01S, and -010W-01S) were selected for tree-ring analysis, and from those, only two had 60 rings or more (Table 1.23) (Domínguez-Delmás and

Table 1.22 Results of dendrochronological research of the San Sebastian shipwreck

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
–	Hull plank	SSE0001071	1	77	–	0	–	1.438	1.061

Adapted after Domínguez-Delmás (2010d). Species: 1, *Quercus* subg. *Quercus*; N: number of rings; Pith: present (1)/absent (−); SR: sapwood rings; Bark edge: present (+)/absent (−); MRW: mean ring width; σ: standard deviation

Table 1.23 Results of dendrochronological research of the Bayonnaise shipwreck

Sample code	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
A-BAY01-007W-01S A-BAY01-007W-02S	Frame	BAY00010	1	60	+	5	–	2.92	1.23
A-BAY01–008W-01S	Frame	BAY00021	1	67	–	0	–	2.33	1.01
A-BAY01-009W-01S	Frame	BAY00031	1	36	–	0	–	2.31	1.26
A-BAY01-010W-01S	Frame	BAY00041	1	36	–	0	–	2.64	1.12
A-BAY01-001W-01S A-BAY01-001W-02S	Frame Frame	– –	1	27 28	– –	– –	– –	Not measured due to low number of tree rings	
A-BAY01-002W-01S A-BAY01-002W-02S	Plank Tree nail	– –	1	20 17	+ –	– –	– –	Not measured due to low number of tree rings	
A-BAY01-003W-01S	Frame	–	1	ca.15?	+	–	–	Unsuitable sample for dendrochronological research due to severe damage by *T. navalis*	
A-BAY01-004W-01S	Frame	–	1	Unknown	?	–	–	Unsuitable sample for dendrochronological research due to severe damage by *T. navalis*	
A-BAY01-005W-01S	Frame	–	1	ca.20?	–	–	–	Unsuitable sample for dendrochronological research due to severe damage by *T. navalis*	
A-BAY01–006W-01S	?	–	1	8 20 12	– – –	8 0 0	– – – –	Unsuitable sample for dendrochronological research due to severe damage by *T. navalis*	

Species: 1, *Quercus* subg. *Quercus*; *N*: number of rings; Pith: present (1)/absent (−); SR: sapwood rings; Bark edge: present (+)/absent (−); MRW: mean ring width; σ: standard deviation MRW

García-González 2015c). The rest of the samples were either too damaged by *Teredo navalis* or too fragmented to contain more than 30 rings in a continuous series.

Most of the samples presented severe damage caused by *Teredo navalis*, which resulted in the fragmentation of the samples into pieces where no tree-ring series could be retrieved. Furthermore, the samples where continuous tree-ring series could be measured contained between 36 and 67 tree rings. Such short series are far from the optimum of what can be considered suitable for dendrochronological research, so not surprisingly, the crossdating of tree-ring series from this site, as well as with European oak reference chronologies, did not produce statistically sound results. Therefore, all samples remain for now undated.

4.22 Cee 1

The location of the *Cee 1* shipwreck at Corcubion Bay (province of A Coruña, Spain) was communicated to San Claudio Santa Cruz (Archaeonauta S.L.) by sport divers in the village of Cée (San Claudio Santa Cruz, pers. comm.). In a photograph of Corcubion Bay from the late nineteenth to early twentieth century, a wrecked ship can be observed still floating at the approximate point where the shipwreck lies today. Therefore, this is probably a late-nineteenth-century ship, which has tentatively been identified as the Spanish brig *Francisca Rosa*, abandoned at this site in 1904. In June 2015, ForSEAdiscovery's nautical archaeology team carried out a campaign on the site to collect wood samples for dendrochronological research.

Five of the samples were identified as deciduous oak (*Quercus* subg. *Quercus*) and one as a conifer, although the species of this conifer sample could not be determined (Table 1.24) (Domínguez-Delmás, M. García-González 2015a). One oak sample was discarded for further research, as it contained insufficient rings.

The comparison of the tree-ring series between them, as well as with European oak reference chronologies, did not produce statistically sound results. Therefore, all samples remain for now undated.

4.23 Cee 2

The *Cee 2* shipwreck was located in June 2015 at Corcubion Bay (province of Coruña, Spain) by the underwater archaeology team of the ForSEAdiscovery project, while carrying out the search for the *Cee 1* shipwreck. The wreck site was inspected, and three samples were collected for dendrochronological research.

The samples were identified as deciduous oak (*Quercus* subg. *Quercus*). The presence of pith and sapwood was registered, but the ring count revealed that the samples had insufficient rings for dendrochronological research (Table 1.25) (Domínguez-Delmás, M. García-González 2015b).

Table 1.24 Results of species identification and dendrochronological research

Sample nr	Timber element	Dendro code	Species	N	Pith	SR	Bark edge	MRW (mm)	σ (mm)
CEE01-002W-01S	Slice taken from hull plank	CEE00011	2	41	+	0	–	3.20	1.35
CEE01-003W-01S	Sawn from in situ copper pin	CEE00021	1	130	–	10	–	0.97	0.32
CEE01-004W-01S	Stray copper pin with surrounding wood; framing element?	CEE00030	1	50	ca.5	0	–	2.15	0.63
CEE01–006W-01S	Stray eroded fragment	CEE00041	1	68	+	–	–	1.31	0.85
CEE01-007W-01S	Stray long copper pin	CEE00050	1	62	+	9	–	2.34	0.77
CEE01-005W-01S	Wood sample from upper end of in situ copper pin	–	1	14	–	0	–	Not suitable for dendro research	

Species: 1, *Quercus* subg. *Quercus*; 2, conifer (unidentified); *N*: number of rings; Pith: present (1)/absent (–); SR: sapwood rings; Bark edge: present (+)/absent (–); MRW: mean ring width; σ: standard deviation MRW

Table 1.25 Results of species identification and dendrochronological research

Sample nr	Timber element	Species	N	Pith	SR	Bark Edge
A-CEE02-001W-01S	Frame	1	40	+	0	–
A-CEE02-002W-01S	Plank	1	24	–	6	–
A-CEE02-003W-01S	Frame	1	34	+	–	–

Species: 1, *Quercus* subg. *Quercus*; *N*: number of rings; Pith: present (1)/absent (–); SR: sapwood rings; Bark edge: present (+)/absent (–)

5 Discussion

Over these years and through the study of each new shipwreck, whether built in the Iberian Peninsula or elsewhere, our knowledge has increased, not only about matters related to wood supply and shipbuilding but also about how to approach the research of shipwreck assemblages. In this discussion, we first want to highlight some observations and patterns that emerge when compiling the data of several contemporary shipwrecks, to then conclude by reflecting on some particular aspects of the lessons learned throughout these years, and ways to move forward in the research of shipwreck timbers.

5.1 Selection of Trees for Shipbuilding

The analysis of structural ship timbers of shipwrecks from different periods allows us to infer information about timber procurement even when the wood has not been absolutely dated. Through the research of structural timbers regardless of their suitability for dendrochronological dating, we have learned that fast-grown oaks were selected for the framing timbers of several ships, namely Barceloneta I, Highbourne Cay, Emanuel Point II and III, Yarmouth Roads, *Bayonnaise*, and *Triunfante* (Figs. 1.5, 1.6, and 1.7). Most of the frames of *Magdalena* also fall into this category, although several slower grown oak framing timbers were also found in this wreck. All these ships were built (some presumably) in shipyards on the Atlantic coast between Ferrol and Bayonne (France), and since their chronology ranges from the fifteenth to the eighteenth century, it suggests that fast-grown oak trees were consistently preferred for framing elements throughout the centuries. However, the selection of trees for planks changes in this time frame. The hull planks of the three clinker-built ships investigated (Barceloneta I, Barreiros, and the Newport Ship) derive from old, slow-grown oaks, and were obtained most likely by radial splitting of the stem of the tree (Fig. 1.5). This is a pattern that is dominant in clinker-built construction throughout the Medieval Period in Northern Europe where splitting of the timber for the hull planks normally required straight-grained, old oak trees of the highest quality. At least one hull plank each from the Yarmouth Roads and Belinho 1 ships, both carvel-built vessels of suspected sixteenth-century date, were also converted radially from slow-grown trees but the majority of their hull planks derive from much faster grown oaks which had been tangentially converted. However, in the sixteenth century, the trees used for planking and framing elements in North Iberian shipyards appear to be consistently rather young and fast grown, with predominance of average yearly mean growth increments of 2 to 10 mm (see in Fig. 1.6 the graphs of the ships likely to have been constructed in the Iberian Peninsula from domestic timber, namely Belinho 1, Yarmouth Roads, Highbourne Cay, and Emanuel Point II and III in Fig. 1.6). The planking elements in these ships have been processed tangentially by sawing the timbers. This demonstrates a change in the woodworking techniques from the fifteenth to the sixteenth century, and suggest also an adoption of forestry practices meant to deliver a fast-turnover of oak wood (e.g. coppicing). In contrast, the wood used in the ships built in the same century in Italy (Delta II, Ribadeo) and possibly in the Northeast of France (Arade 1), derived from slow grown oaks (average yearly growth below 2 mm), indicating the existence of dense forests in the supply areas. The planks found in those shipwrecks had also been processed tangentially by sawing. In the eighteenth century (we lack data from the seventeenth century to make inferences), the wood used appears to be more diverse, both in growth rates and species (the hull of the *Triunfante* is made of pine) (Fig. 1.7), but the planking elements continued to be processed tangentially by sawing the timbers, regardless of the species. In this century, there was a great diversity of species available at the Royal shipyard of Ferrol (Trindade et al. 2020). We have also encountered pine in framing elements and

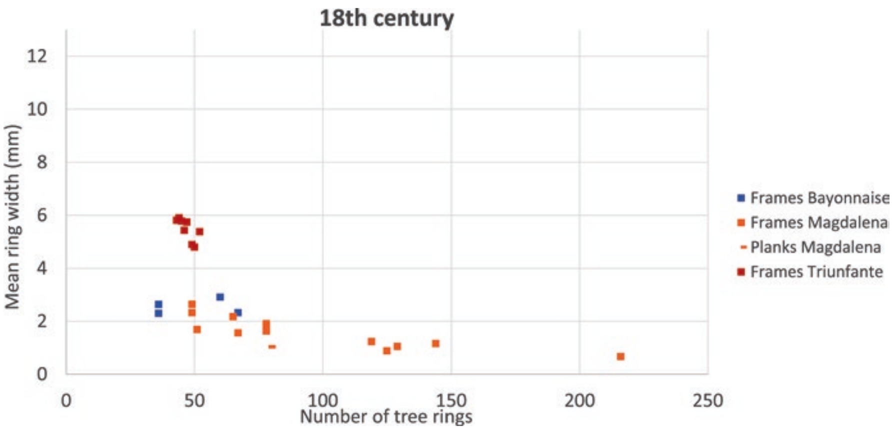

Fig. 1.7 Scatter plot of mean ring width against ring count for studied oak shipwreck timbers from eighteenth-century ships *Bayonnaise*, *Magdalena*, and *Triunfante*

ceiling planking of *Magdalena*. However, we cannot discard those elements as repairs, although archaeological and historical research suggest that the pine hull planks from *Triunfante* correspond to later repairs in the Royal shipyard of Cartagena (Pujol i Hamelink et al. 2013).

The use of young, fast-grown oaks for both hull planks and framing timbers in sixteenth century ships has been observed by archaeologists studying other shipwrecks. Such is the case of the *San Esteban* (wrecked 1554) seen on display in or stored at the Corpus Christi Museum of Science and History (Arnold and Weddle 1978), those of the early-sixteenth century Studland Bay wreck where only 17 of the 189 timbers assessed were suitable for dendrochronological analysis (Hamilton and Tyers 2011), and those of the Western Ledge Reef wreck (Bojakowski 2011, 2012). The data are not sufficiently well-replicated or consistent to argue for very limited samples taken from the surviving timbers of a systematic use of cohorts of trees of tightly controlled age, as Loewen has suggested for the framing of the Red Bay wreck (c.1565) or the "transitional" Cavaliere-sur-Mer vessel (c.1479?) (Loewen 1998; Loewen and Delhaye 2006). A pattern of the use of young, fast-grown oak is however emerging. Does this shift in timber selection, apparently coincident with the shift in shipbuilding technology from clinker to carvel, have a causal link? Addressing this question requires more data on timber selection, greater dating precision for these important ship finds, and a more considered study of the use of saws both in the conversion of tangential planking for shipbuilding and in contemporary crafts such as timber-frame construction of buildings. Can we begin to see a change in Iberian forestry practice during this period which is specifically designed to deliver the ideal product for shipbuilding in the most efficient time frame, as Loewen has suggested? The Arade 1 ship, likely built in the French Atlantic coast, is constructed from an homogeneous group of French timber (Domínguez-Delmás et al. 2013) with many of the trees employed for both planking and framing timbers over 100 years old when felled. The Ribadeo vessel comprises very substantial timbers (it is a much larger ship than the others studied from this century and specifically military in design), derived from oaks of rather variable age but including some trees over 200 years old when felled. The historical evidence suggests that this timber was sourced from Italy and around the Adriatic (see Chapter 4, Vol. 2). Seeing the selection (and even management/cultivation) of trees for shipbuilding in context requires a regional, even local, perspective, e.g., Iberian/Cantabrian/Biscayan situated in a European sphere of influence (see Chapter 6, Vol. 1). Just as we may glimpse a specifically Cantabrian forestry/shipbuilding interaction in the sixteenth century rather different interactions are evidenced elsewhere. The Drogheda boat, built in Ireland between 1525 and 1535 and repaired between 1532 and 1560 was constructed in the old clinker method with radially split oak planking (Schweitzer 2012). A few decades later, the armed merchantmen now labeled the Gresham ship, was built in carvel fashion from very old (150 years +) oak trees on the East coast (probably Essex) of England (Nayling 2014).

Our evidence for the eighteenth century is perhaps too sparse to make sustained comment (Fig. 1.7). As always, more data would be welcome. The information from *Bayonnaise* is limited to four framing timbers from the same, relatively small section of hull. The oak framing timbers of the *Triunfante* appear consistent in both age structure (young trees) and fast growth in contrast to the timbers from *Magdalena*, which are apparently derived from young through to very old trees.

5.2 Dendrochronological Dating of Iberian Shipwrecks

Our results illustrate the challenge of dating timbers from shipwrecks made of wood from areas where a dense network of long, well-replicated reference chronologies is lacking, such as the Balkans, Italy, or the Iberian Peninsula. Most samples of the Arade 1, Delta III, and Punta Restelos shipwrecks and some barrel staves from the Delta II could be dated because the wood originates from areas in Northern Europe with a long tradition of dendrochronological studies. However, dating three timbers from *Magdalena* indicates that we are heading in the right direction in the development of such reference datasets for the Iberian Peninsula.

Still our dating success is very low (only 15% of oak samples have been dated in total), which could be due to different reasons. First of all, it must be noted that although tree-ring analyses were carried out on hundreds of timbers, the majority of these had significantly fewer rings than the number traditionally recommended (e.g., 100 given by Baillie 1982), as series of such length provide statistically sound results when compared with the right chronologies. This minimum number of tree rings can be lower in certain circumstances (e.g., Billamboz 2008). Still, other samples containing more than 200 rings remain undated. Another reason for this could be that some of the new reference chronologies were not developed in the exact areas mentioned by historical sources (Domínguez-Delmás et al. 2020). Those areas are mostly located by the coast (Casado Soto 2006), where currently old-grown oaks are no longer to be found. A third possibility is that the growth patterns in the samples collected do not reflect the growing conditions of the trees that have been included in the reference chronologies. For example, if branches were used for framing elements it is likely that their growth patterns differ from the main chronology obtained from stems. Or if forked or twisted trees were selected for compass timber, it is also likely that their tree-ring patterns are distorted, hampering crossdating with the reference chronologies. This would also explain the lack of internal correlation between samples of the same shipwreck, although such a lack of matches between samples could also be the consequence of the trees for the same ship being sourced in different geographical areas, as historical documents demonstrate for ships such as *Magdalena* (see Chapter 9, Vol. 2) and *Triunfante* (Pujol i Hamelink et al. 2013). Finally, the possibility that the researched shipwrecks may not correspond to Iberian-built ships cannot be overstated. As presented above, research in historical archives regarding the Ribadeo shipwreck suggests that the ship may have been the *Santiago de Galicia* galleon, built in Naples in the early 1590s (see Chapter 3, Vol. 2). Similarly, the Delta II has been identified as an Italian ship (Ridella et al. 2016) and the Delta III as a Dutch merchant vessel (González 2017).

5.3 Sampling Strategy

Having a concerted timber sampling strategy is a requisite for obtaining a dendrochronological return on the archaeological investment. Shipwrecks are the remains of complex machines, that are themselves the result of complex networks of timber acquisition and conversion. In the decade of research presented here, however, we were not always the ones carrying out the sampling. Some of the shipwrecks discussed above exemplify the importance of having a well-planned and executed strategy, and played a crucial role in the development of the sampling protocols (Rich et al. 2018a) and guidelines (Domínguez-Delmás et al. 2019) that are now taken as the standard to interrogate shipwreck assemblages. Some lessons learned regarding the sampling strategy are summarized here.

As demonstrated by the case of the Punta Restelos wreck, samples should be attached to the wreck rather than detached or freely floating near the wreck site. Without substantial further investigation, there is no way of knowing if a loose timber came from the wreck under investigation or a different wreck nearby. Taking "opportunistic samples" from a site may yield promising data, but without archaeological context, it has no meaning.

Tree rings can still be seen and measured in samples containing galleries of *Teredo navalis*, but samples full of galleries often break, and chances of obtaining long, continuous tree-ring series are lost, as illustrated prominently by the *Bayonnaise*, but also by other shipwrecks. Therefore, sampling campaigns should target samples in parts of the timbers where the damage by *Teredo navalis* is less severe or, ideally, absent. In this way, the chances of furnishing several timbers suitable for dendrochronological research will increase, thereby increasing the chances of successfully crossdating the timbers within the site and with reference chronologies.

Sampling of the Barceloneta shipwreck was constrained by the desire to retain the integrity of timbers through documentation and conservation. Unfortunately, this limited the amount and quality of data that could be collected. Having observed cross-matches between some planks and between some frames could indicate that each of those groups represents a homogeneous cohort, maybe originating from the same area (e.g., frames were sourced from coastal, fast-grown oaks, and the planks from inland, slow-grown trees). However, this observation could only be confirmed by the sampling of more elements of the shipwreck. Musealisation is not incompatible with the sampling of ship timbers, as illustrated by the Viking ships in Roskilde and, more recently, by the dendrochronological research carried out in the Bremen cog ship (Belasus and Daly pers. comm) and the Batavia shipwrecks (Daly et al. 2021). Close collaboration between dendrochronologists and conservators can result in an extensive sampling of a shipwreck in display that is barely visible to both trained and untrained eyes.

Magdalena exemplifies an appropriate collection of samples, where a wide variety of approximately 20–30 timbers were targeted on the basis of (i) the timber element (i.e., frame, plank, strake, etc.), (ii) tree type (conifers and dicotyledons, for example, which can be differentiated underwater), (iii) presence of bark or sapwood, and (iv) if possible, ring count (a visual estimation is also possible even under water if the transverse section is exposed). High ring counts (over 80) have a greater probability of being crossdated with a reference chronology, thereby providing both a *terminus post quem* and a location, or the year (after which) and place (near where) the parent tree was felled. Greater precision in space and time can be achieved if samples retain bark or at least sapwood, which is often the case as seen with almost all the shipwrecks. A variety of tree types also increases the odds of being able to crossdate with existing chronologies, especially for oak and pine, and because some species have limited growth distributions, they can also be useful in provenancing the timber. Even if crossdating proves impossible, sampling from a variety of places on the wreck, from a variety of structural timbers, also provides valuable information about what kinds of trees (species, age, growth rate, etc.) were sought by shipwrights for certain architectural functions.

At this point, a caveat must be provided, especially in regard to targeting samples with many rings. This is an appropriate strategy only if ascertaining the date and provenance are the sole objectives. If research questions are broadened to include those relating to the types of timbers sought for certain elements, forestry practices, etc., then seeking only timbers with large numbers of growth rings will introduce bias into the samples. From the samples collected from the Yarmouth Roads, only one had more than 50 rings, which indicates that most of the structure was built with very young trees. Crossdating of short series is extremely challenging (Domínguez-Delmás 2020), but novel approaches such as tree-ring dating based on stable oxygen isotopes have proven successful in other areas (Loader et al. 2019) and may hold the key to date these types of timbers in the future.

Finally, the implementation of a sampling strategy will be all the more successful if it is achieved within the context of a multidisciplinary research program, as exemplified by the *Ribadeo*. As already stated, the lack of context hampers the interpretation of facts, while the integration of multiple disciplinary approaches (archaeological, historical, and dendrological) to the investigation of wreck sites can yield extraordinary results.

5.4 Use of Novel Approaches for Provenancing

The ForSEAdiscovery project has been a major promoter for the development of reference datasets and the exploration of novel techniques to provenance timber from shipwrecks (Domínguez-Delmás et al. 2020). The possibilities of using strontium isotopes to provenance cedar (*Cedrus* sp.) shipwreck timbers had already been tested in the Mediterranean by Rich et al. (2012, 2015, 2016), but the method was taken a step further with the in-depth study by Hajj (2017) who demonstrated that the isotopic signal of (sea)water prevails in waterlogged wood. These results were also attested by Van Ham-Meert et al. (2020), with the conclusion that due to diagenesis occurring in waterlogged wood, the original strontium isotopic ratio of the timber prior to submersion cannot be determined, and therefore, strontium isotope analysis is not a reliable method to provenance submerged shipwreck timbers.

The suitability of using the organic compounds in wood for wood identification and DNA for wood provenancing has also been tested. The degradation of organic compounds in waterlogged wood is a major obstacle for the determination of the wood species based on chemical composition (Traoré et al. 2018). Similarly, the retrieval of long DNA sequences from ancient, waterlogged timbers is a challenge, but advances in DNA amplification methods are making it possible to obtain DNA from ancient and historical wood (Wagner et al. 2018; Linar et al. 2020). The resolution of current DNA methods to pinpoint the provenance of wood remains low, hence future efforts should further explore the potential of genetics to refine the origin of wood in combination with other methods (Domínguez-Delmás 2020).

6 Conclusions

This synthesis of dendroarchaeological research on Iberian ships and timber selection identifies shifts in patterns of timber use, especially during the period of technological change from clinker to carvel construction in the fifteenth to sixteenth centuries. The relationship between these technological innovations, the adoption of different methods of timber conversion, and possible developments in woodland management pose a research challenge that requires not only more data but a consilience between archaeology and history. Can we see attempts at centralized oversight of forestry practice and woodland exploitation during the Early Modern Period in Iberia reflected in the type of timber employed in the shipwrecks we discover? Arguably, the dataset presented here is biased toward ships employed in explorations, expeditions, and private mercantile or fishing enterprises. A more balanced view might be achieved through examination of more shipwrecks of military vessels and those associated with the highly controlled activities of the *Carrera de Indias*. Equally, the sampling strategies we advocate need to be employed more widely so that we might compare the nature of timber usage in Iberian shipbuilding with adjacent regional industries especially on the Atlantic façade.

The absolute dating of Iberian timber found in shipwrecks remains a challenge. Continued development of Iberian ring-width chronologies for the Early Modern Period, particularly from areas known to have been exploited for timber shipbuilding, is a long-term and necessary project which will deliver benefits in refined dating of parallel timber industries such a vernacular, urban, ecclesiastical, and palatial architecture. For those ships built from young, and possibly highly managed, oaks we will need to develop alternative approaches, probably focused on harnessing recent refinements in radiocarbon and isotopic dating.

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