Chapter 2
A Paradigm of Inter and Multidisciplinary Research: The ForSEAdiscovery Project

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Abstract The ForSEAdiscovery project, a Marie Curie Initial Training Network funded by the European Union, saw a multi-disciplinary group of experienced and developing young researchers collaborate on a wide-ranging project to address the question of how the expanding Iberian empires secured the forest resources required to supply their fleets of mercantile and military ships from the sixteenth to the eighteenth centuries. This project aimed for a consilience between historians, archaeologists, and earth scientists in furthering our study of the synergies of shipbuilding technologies; forestry practice and regulation; timber selection, trade and supply; and developing innovative approaches to examining our pasts through dendro-archaeology in its widest sense.

1 Introduction

> Arsenals have been widely using soft pine wood which can only be found in Northern countries. The quality of the pine wood from Navarra and Segura is second to none. The timber used for hinges (*roldanas*) and pulley wheels (*pernos*) all comes from America; black poplar trees from Spain are also widely used: oak can be found in Catalonia, Asturias, Biscaya and Santander; pine for masts and hull come from Burgos, Segura, Navarra and Seville, as well as holm and gall oak (*quejigos*) timber for ribs (*cuadernas*); beech wood

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(*hayedos*) comes from the Pyrenees and Asturias. Even if we regard these forests as depleted, your majesty's vast forests in America appear endless[1]

For centuries the knowledge of shipbuilding has been considered a science subject to the development of local industries. In fact, local tradition and regional studies have marked the historical and archaeological studies on naval architecture and the evolution of the modern ship. This report written in 1802 by the sailor and last viceroy of New Spain, Juan Ruiz de Apodaca, reflects, however, a global vision of the origin of the main resource used in shipbuilding: wood and its provenance was an experimental science marked by the geographical changes and the nature of a resource that consists of a flexible and resistant material with which the different types of trees generate their trunks, growing year after year through a system of concentric and circular layers (tree-rings). There are multiple types of wood, whose characteristics vary enormously. But in general terms, it is an extremely useful material for human beings, who have used it since ancient times. Wood is an abundant, renewable, inexpensive, and easy-to-work raw material that, processed in the correct way, can withstand the onslaught of time for many years, in addition to, when used in construction, it offers a feeling of warmth and ancestral protection, for which it is a fundamental element in almost all human industries (Adams 2018). In its structure, the wood has an outer and inner bark (or cambium), sapwood (*Albura*, in Spanish terms), its central part or nuclei and a pith. There are many types of woods depending on their properties and appearance. The master ship carpenters knew these circumstances and characteristics empirically, and they developed a science to use in order to develop the most precise architectural techniques and avoid the susceptibility of wood to any action by environmental elements. During the sixteenth to eighteenth centuries an empirical science on forests was developed in order to know the anatomy of trees, their organography, devices were invented to determine the resistance of wood to bending and traction, all in order to use the resources of the forest in the main driving force of the maritime empires: the ship and its architectural science.

2 Historical Background

The European voyages of discovery and the connected seaborne European expansion of the fifteenth and sixteenth centuries were overwhelmingly dominantly carried out by Spain and Portugal. Both kingdoms build their own intercontinental empires with settlements and colonies in Africa, Asia, and America. In the seventeenth century the Iberian powers encountered stiff competition by the Dutch, the English, and the French and in the eighteenth-century Great Britain gained imperial primacy and dominance of the seas. Nevertheless, Spain and Portugal retained their American and Asian colonies and maintained their maritime connections with them throughout the early modern period. Oceangoing ships were the only means of communication and transport

[1] Juan de Apodaca, Report. "Informe que Don Juan Ruiz de Apodaca, brigadier del Real Arsenal de la Carraca dio a la Junta del Departamento de Cádiz, como vocal de ella, sobre el surtimiento de efectos para los reales arsenales de S. M." 23 de abril de 1802. Imprenta Real de la Marina, Isla de León, 1806.

between the near and distant parts of the Iberian empires. To build and maintain these vessels Portugal and Spain needed large amounts of timber, predominantly oak (*Quercus* spp.) and pine (*Pinus* spp.) but also many other species that were used to make various parts of the ship, and that are mentioned in Apodaca's text. Nevertheless, the question where that timber had been produced has hardly been asked and even less researched. Also, historiography has neglected the study of the influence that the commercial, maritime, and colonial European expansion had in the use of forests resources. Up to date, a few relevant works exist that relate expansion and deforestation, but their coverage of the Early Modern Period focuses on the eighteenth century, leaving references to sixteenth and seventeenth century brief and shallow (Albion 1926; Perlin 1989; McNeill 2004; Warde 2006). Inedited written sources are still available in certain geographic areas which may shed light on these relationships, especially those documentary sources derived from the efforts carried out by the Superintendency of mountains and plantations (*Superintendencia de montes y plantíos*) dedicated to managing the forest masses for the Navy and the Marine Departments (*Departamentos de marina*), created in 1724 for the administration of the forests of the Iberian Peninsula divided by provinces (Martínez González 2015; Wing 2015).

Historical studies have provided some theories about shipbuilding in the Hispanic Monarchy, including the age of the Iberian Union between the two crowns of Portugal and Spain (1580–1640). But what does History say about it? And what kind of innovative perspective could be offered by an interdisciplinary project? History of shipbuilding in Spain has developed around specific topics around dockyards stories and naval policies with only a few mentions of the use of timber and how wood had an influence on naval construction stages. A quantitative analysis of the frequency of topics on Spanish Naval History show that only the 11% of research works have been made about ships and shipbuilding and the majority of studies focused on exploration and colonies, navigation, naval battles, and biographies. Nevertheless, there is some important research about shipyards with particular focus in the eighteenth century. In fact, the eighteenth century sees new policies implemented for the construction of shipyards and arsenals (Cádiz-La Carraca 1717; La Graña and Ferrol 1726; Cartagena in 1728) and the new maritime departments were organized in which all timber supplies for the navy was arranged (Casado Soto 1991; Valdez-Bubnov 2018; Valdéz-Bubnov 2019). In the second half of the seventeenth century shipyards were built in Gibraltar with the cooperation of the British merchant in Cádiz (Serrano Mangas 1992). Also relevant was the creation of shipyards in colonial America, where it seems that many vessels used in the Indies were built, especially in Havana and in Guayaquil (Laviana Cuetos 1984; Serrano Alvarez 2008). Also, Galician ports on the Cantabrian seaboard had long enjoyed a prosperous relationship with Andalusian partners around wood trade for naval purposes as well as for making kegs and barrels. From Ribadeo and Viveiro wood was regularly shipped to Seville and Cadiz throughout the seventeenth century. The skippers were not from Galicia, and Portuguese merchants were also involved, especially until 1615. After that year, ships from England, the United Provinces, Lübeck, Hamburg, and Rotterdam, were introducing timber in Spanish ports. Cantabrian ports and Galicia became the most important shipbuilding area of the sixteenth century, with the well-known dockyards of Guarnizo. The location of Guarnizo as particularly suitable for shipyard site appears to be closely linked to the figure of Cristóbal de Barros (Superintendente de Fábricas, Montes y Plantíos), Superintendent of Factories, Forestry, and Plantations on the coast of Cantabria, whom Philip II in 1581 commissioned a series of nine galleons for the defence of the Indies (Martínez González 2015).

Since the Middle Ages, merchants from Guipuzcoa, Alava, and Vizcaya developed profitable trading activities with the North of Europe and their shipbuilding industry grew accordingly. From this area trade with other areas in the Cantabrian seaboard and beyond also flourished at Ribadeo, Llanes, San Vicente, and other ports in the Santander province. Their trade networks reached the Galician ports and soon after Oporto and Lisbon in Portugal and an important route to Andalusia soon began from the Basque Provinces. Soon afterwards important trade networks reached Barcelona, Genoa, Sicily and Sardinia. Basque fleets carried Castilian wool, wine and other produce to Flanders- Bruges and Antwerp- and the ports that changed hands from the English to the French, such as Bayonne, Bordeaux, La Rochelle, Harfleur, and Rouen. The Hanseatic ports were reached soon afterwards. This trade was regulated by the Bilbao Municipal Ordinances.[2] In the sixteenth century almost all sea villages in Cantabria boasted a working shipyard although the most important were at Colindres and Guarnizo, in which the largest galleons at the time were built. As a result of Cristóbal de Barros being appointed by Philip II to revitalize naval construction in the Cantabrian yards, it was there where most of the royal armadas sent against England were built. The shipyard at Folgote, established in 1475, became a Royal Shipyard in 1618. It was thought to be well defended from enemy attacks as it was located at the bottom of Santoña Bay. However, as a result of being placed under attack by the French in 1639, activity dwindled and was transferred to Guarnizo like other Cantabrian shipyards. Apparently Guarnizo was the yard in which La Pinta was built, as well as many other vessels among the largest at the time. As for naval construction, it is worth highlighting the conservationist policy applied by Philip II, reflected in his Royal Ordinances, and later copied by the English. Such policy ensured the sustainability of the forestry resources to be used in shipbuilding, the vast forests in Northern Spain. When this policy was later abandoned in the eighteenth century, a rapid degradation of the Cantabrian forests took place, almost to the point of total depletion.

3 The ForSEAdiscovery Methodological Framework

In order to build a historical-archaeological narrative of the origin of wood in Hispanic shipbuilding, several theoretical meanings have been raised in the research work of the ForSEAdiscovery project. Various theories and hypothesis have produced important results, some of which are explained throughout these two

[2] Bilbao Municipal Ordinances, 1477–1520. Medieval documental sources from the Basque Country in a 1996 edition.

volumes. Firstly, studies of social and economic theory about the relation between forestry resources and the competition among maritime empires must be made within this perspective on network cooperation and competition for organizing political and economic behaviour around forest resources and in the so-called Environmental History (Crespo Solana 2019). The ForSEAdiscovery project has tried to take research on the matter a few steps further in order to answer some important questions related to understand the ecological history of the Iberian forests and to explain to what extent and how the Iberian powers succeeded in maintaining the size and quality of their fleets. Key questions to be addressed in this context are: could Iberian forest resources sustain this increasing demand for timber or was the wood imported from elsewhere? If so, how were the trade networks organized? Did a scarcity of raw materials encourage the technological changes which occurred in shipbuilding in the sixteenth century or were they a result of socio-technological exchange between Mediterranean and Atlantic shipbuilding traditions? Did demand for timber lead to sustainable changes in forestry practice in the Iberian Peninsula or deforestation and increased dependence on imported material? Where had the timber which was used for building the ships of the Iberian fleets been produced? The case of the "Iberian Timber" is related to the arsenals and cages built in maritime-port areas and their link with the forestry logistics of the Iberian Peninsula where forestry management and timber felling were carried out. In various historical stages, institutions for good governance and forest exploitation were created, such as the Superintendency of Forests, the Maritime Departments or other offices such as the "Real Negociado de Maderas de Segura" (a bureau specialized in management timber in Sierra de Segura in Spain).

An added value of the ForSEAdiscovery Project is that it has tried to relate the history of naval construction and the progress of the Atlantic maritime trade with deforestation and the value of timber resources, and to find out if all this had an impact on the shipbuilding between the sixteenth to the eighteenth centuries. A line of research also has been developed regarding the theoretical framework of the social, economic, and politico-administrative framework in which the collection, commerce, distribution, and utilization of the forest resources were carried out, but also about the purveyance of timber used in shipbuilding, and the merchant networks behind this trade, getting to know the policies on naval construction in the period and their impact on the distribution channels of the forest resources. The secular relationship between the forest and the appropriation of its resources by agents and political powers, the use of wood for shipbuilding affected forest regulations (Crespo Solana 2016; Varela Gomes and Trapaga Monchet 2017).

Perhaps one of the most obvious lines of research in this project has been to identify a methodological connection between the information offered in the historical sources and the archaeological evidence with chemical and laboratory methods in order to establish new knowledge for the study of the woods used in shipbuilding. As the document cited at the beginning of this chapter exemplifies, historical data offers a wealth of references and empirical data from which to start building an authentic catalogue of historical woods. Apodaca wrote a short but very illustrative report on the types of wood and their provenance that should be used for each part of a ship. This text is perhaps one of many discourses that were already present in the writers and navigators' documents from the sixteenth century, and in the debates of the "Juntas" (Boards) on shipbuilding that took place in Spain and Portugal's government at various times. This, and other unpublished documents on the latent existing concern about the origin of the wood was, in fact, a question of the first magnitude for the political administrations in Spain and Portugal from the very beginning of the overseas expansion. These discourses on the utilitarianism of wood were parallel to the learning of the oceanic experience of Spain and Portugal and served to create the design of the so-called Iberian ship, present in literature and maritime historiography and to which several chapters are dedicated in this book (Chaps. 4, 5, 6, 7, 8, 9, 10, 11, and 12).

Part of the timber employed in local shipyards and naval industries was extracted from Iberian forests but significant quantities of timber were imported (Reichert 2016; Gallagher 2016; Gasch-Tomás et al. 2017; Kumar 2018; Jiménez Montes 2020). Despite the repeated protectionist policies of the Spanish Crown for the ships to be "national" Spanish; that is, owned by Spaniards and built in the Iberian Peninsula with Iberian timber, the very historical evolution of the Hispanic Monarchy, ruled by the Flemish-German Habsburg dynasty and which, for a time also, ruled Portugal, made the navies and fleets always depend on the provision of foreign resources. Several factors (which are analysed) in the works present in this book, such as the consolidation of mercantile capitalism, supported by a continuous background of wars, especially wars at sea, and the formation of extensive commercial and financial networks that controlled production and transportation of timber, made the Spanish Crown always dependent on a large-scale global trade, and even dependent on its enemies, who brought the timber into Spanish ports with the collusion of local authorities and through intermediaries. Consequently, sea power, forestry, and international trade became inextricably linked. From the historical perspective we have carried out new historical research that enabled us to identify forest regions in the Iberian Peninsula from where timber has been extracted for shipbuilding (Varela Gomes and Trapaga Monchet 2017; Trápaga Monchet 2019a, b). In relation to wood provenance sciences, the knowledge of how the historical "montes de marina" was managed by the political institutions and local administration is crucial in order to create reference chronologies (with "living trees" and historic buildings) for dating and identifying the origin of timber. Some works carried out by members of the team have delved, precisely, into this interdisciplinary narrative on the history and evolution of the naval models of the Iberian empires in the context of maritime expansion, the politicization of forest resources, the global timber trade and its environmental causes and consequences from the sixteenth to eighteenth centuries. Some results refer to the relationship between forest administration and shipbuilding regulation. The characteristics of the original regions from which wood was extracted have also been established, not only from the "montes de marina" but some "Reales Sitios" (Royal Sites) have also been included, as well as other areas close to coastal maritime sites, mountains, and pastures, all in Andalusia and the Basque Country, important centres of shipbuilding, where various shipyards were located (Trindade 2015; Jiménez Montes 2016).

The various causes of forest exploitation in locations directly administered by the Crown, such as the so-called Soto de Roma (in Fuente Vaqueros, Granada), and in the regions of Asturias, Cantabria, Galicia, or large areas of Portugal have also been analysed. Data collected from these spatial studies allow us to know the strong pressure that both the Crown and the local noble and ecclesiastical elites had on the Iberian forests, as well as the commercial networks themselves, which tried to organize from very early on a reorganization of forest resources and regions that oversized the areas established by the later (and curiously late) regulations on the marine mountains and the creation of the Maritime Departments between 1726 and 1748.

4 Interdisciplinarity

The methodological framework of the ForSEAdiscovery project also implies an interdisciplinary training programme to increase the background and experience of researchers in interdisciplinary techniques. Research has produced reference datasets comprising historical, archaeological, and wood science data such as dated ring-width series (Crespo Solana et al. 2018; Rich et al. 2018; Domínguez-Delmás et al. 2019). Dendro-archaeology, as well as the techniques for the study of the origin of the wood, has been used to analyse the timber found in numerous suspected Iberian shipwrecks investigated as part of the suite of scientific activities of the project. This discipline allows dating of archaeologically recovered wood to determine the year in which the trees were felled, transported, and used in the construction of ships (Nayling 2008). This complements the historical knowledge of these wrecks and allows the validation of the information extracted from documentary sources, which is applied for the first time in the field of Spanish and Portuguese naval history. Related to this, it is important to know how the timber trade networks were organized from the production areas. The main problem raised in the project refers to the different origins of the wood located in wrecks and the large amount of information available in historical databases on how wood was transported from North and East Europe to the Iberian Peninsula between the sixteenth to eighteenth centuries, something that is undoubtedly related to the speculation that at the time itself was had on forest resources (see Vol. Chap. 1, 3, 4, 5, 7, and 9). Historical documents can link information with dendro-archaeological analysis. Their study certainly contributes very much to increasing our insight. The scope of these sources and the information they produce, however, are, as so often is the case, limited. Therefore, ForSEAdiscovery has explored a combination of three sets of additional methods to gain a better insight into the matter. This combination of methods involves archaeology, dendrochronology, and wood chemistry. It aims at determining the provenance of the timber of wrecks of relevant Iberian ships: where and when grew the trees that were processed into this timber? Archaeological research enables us to identify relevant wrecks and to take samples from their wooden parts. Dendrochronology and wood chemistry enable us to analyse these samples and possibly determine their provenances.

An inventory of the historical and geographical sources on wood supplies (sixteenth-eighteenth centuries) has been produced, which serves as the basis for knowledge about the sources of tree species, especially oak and pine and other woods most used for shipbuilding. This literature catalogue has been carried out in different archives in Spain, Portugal, and other European countries. In this way, we know a large part of the wood acquisition process, its selection, trade, and transport, as well as the management practices and specific laws enacted to sustain and protect forest resources. This research has been the subject of two doctoral theses within the project and 4 individual research works. The information has been enriched with the comparison, where appropriate, with databases, such as The Sound Toll Registers Online.[3] And they have also used the databases on historical and archaeological shipwrecks of the repositories The ShipLAB (TAMU A&M), DynCoopNetData Collection (or CrespoDatabase Atlantic Trade), which are currently: NADL (The Nautical Archeology Digital Library) and the DynCoopNet-ForSEAdiscovery interface and web viewer of the CSIC's GIS Laboratory. (Gallagher 2016; Kumar 2018; Trindade et al. 2020) (see Chap. 13 in this book).

The GIS model integrates and combines information from the different disciplines involved in the project (history, archaeology, the provenance of wood) to provide a tool for the study of the use of forest resources. The ForSEAdiscovery database not only integrates data from the aforementioned pre-existing databases (whose data have already been conveniently inserted) but has also been enriched with a large amount of data from various information sources related to historical (with historical data on each ship) and archaeological vessels (with data on excavated wrecks and archaeological information. In these wrecks we have proceeded to collect samples of structural wood in order to compare it with dendrochronological analyses of woods made in laboratories. These wood samples have been obtained in fieldwork with living trees and in historical buildings. These data are being processed to be entered in the GIS, although so far there are at least three databases interspersed with various ship and shipwreck mappings. The result of this GIS and ForSEAdiscovery database thus integrates information from three different disciplines, but strongly related in terms of data. The historical analysis also offers us an overview of what the process-model of wood provision in shipyards for shipbuilding was like. It must be taken into account, however, that this process varied throughout the three centuries studied.

5 Archaeological Research

A fundamental debate undertaken with the whole project team at the very beginning of the ForSEAdiscovery project considered what we might consider to be an Iberian ship. A number of definitions were forthcoming which helped to define the scope of

[3] http://www.soundtoll.nl/index.php/en/over-het-project/str-online.

the project with regard to which shipwrecks might be considered for multidisciplinary study. Definitions proposed included:

1. Iberian based on construction characteristics. Whilst Oertling (2001, 2004) and others have attempted to define a series of traits or architectural signatures which could characterize carvel-built ships of the fifteenth and sixteenth century constructed by Iberian shipwrights (the so-called Iberian Atlantic tradition), it has to be accepted that many of the shipwrecks included in this category have not been definitively proved to be Iberian, and indeed a number of these traits are present in ships which have proved not be Iberian (e.g. Gresham Ship: Auer and Firth 2007; Maarleveld et al. 2014). In the later centuries of the early modern period, we know, historically, that significant developments in ship design and construction occurred with well documented examples of both English and French influences certainly during the eighteenth century if not before. The developing Early Modern Shipwrecks database hosted by Filipe Castro at Texas A & M University (a ForSEAdiscovery project partner) proved an invaluable resource in identifying shipwrecks of suspected Iberian origin based on construction features. Chapters 4 and 6 provide up-to-date overviews of our present understanding of the beginning of carvel construction in Iberia and its development during the early modern period.
2. Iberian based on timber usage. Such a definition would require the ship to be built largely or completely from timber derived from trees which had grown in the Iberian Peninsula. This definition was clearly preferred from a dendrochronological and wood science perspective where the application of such techniques would depend on the development of reference datasets from geographical areas within the Iberian Peninsula known to have supplied timber for shipbuilding. Conversely, we might hope/expect to be able to identify oak or conifers imported from Northern Europe given the existence of a growing dense network of ring-width chronologies from these areas. The scope of the ForSEAdiscovery project was ambitious enough in hoping to develop regional ring-width and other reference datasets in the Iberian Peninsula. It was felt that attempting to address the use of timber from the expanding Iberian empires (e.g. Asia and the Americas) was certainly too ambitious. This definition raised a critical sub-question could oaks of specifically Iberian distribution be identified through wood anatomy or other methods?
3. Iberian through commission. The Iberian empires, by definition, expanded beyond domestic territories to include lands in the Americas and Asia, and also possessions around the Mediterranean (e.g. Italy) and the North Sea (e.g. the Netherlands). A ship might be built by a decree of the king of Spain or through "asientos"—where private funding was made available to the State on loan—to serve in war missions under the Spanish crown, even if the ship was built in a foreign shipyard and using timber from distant regions. Equally, ships might be purchased or leased from foreign powers for military campaigns (e.g. the 1588 Armada).

Therefore, targeting the archaeological research of the ForSEAdiscovery project depended on effective collaboration with both historical and wood science researchers within the project team. It should perhaps be stressed that this Marie Curie project focused on the training and development of the participating fellows. Hence the research actions undertaken needed to be balanced against achievable goals within the context of numerous Ph.D. studies, and the development of the archaeological dive team in terms of competence, experience, and qualifications. From the outset, the aspiration was to undertake selective archaeological investigations, predominantly of underwater shipwreck sites where sufficient structural remains of the hull were already relatively well-exposed or being excavated by collaborating external teams/projects.

Given the desire of the wood science team to have "control sites" where the identities of the vessels were known or suspected, and hence historical research could clarify the origin of timber used in their construction, three sites in Galicia were selected for investigation with co-ordination by Archaeonauta SL as an associate partner in autumn 2015. The French corvette *Bayonnaise* (launched 1793, grounded and burnt 1803), located off Langosteira beach, Finisterre provided an excellent training ground for the dive team being located in relatively sheltered, shallow waters. A small area of the hull structure was dredged of overlying sand, recorded with a range of techniques including photogrammetry, and then sampled. This exercise provided the team with the opportunity to test and refine recording, and sampling procedures and put their professional diving training into practice. The second site studied, *Santa Maria Magdalena* (launched 1773 wrecked 1810), was investigated with the assistance of the Spanish Navy's Historic Diving Unit. This investigation is presented as a multi-disciplinary case study in Vol. 2 Chap. 9 which details the combined historical, archaeological, and dendrochronological studies undertaken and initially presented at the IKUWA6 conference and subsequently published in its proceedings (Trindade et al. 2020). Diving conditions were more challenging with more variable visibility and a more extensive site to sample. The third site, a most substantial wreck site first noted in the approaches to the port at Ribadeo in advance of dredging in 2010, was thought to be a vessel associated with the 1596 Armada. Again, the results of multi-disciplinary research on this ship are presented in both Vol. 2 Chap. 3 (authored by the lead archaeologist Miguel San Claudio) and Vol. 2 Chap. 4 (presented by a multi-disciplinary team at IKUWA6, Eguiluz Miranda et al. 2020). The dive team, with increased experience, came to terms with a site with relatively narrow dive windows due to the distinctly tidal conditions in the estuarine location. This site, potentially threatened by existing port activity and possible expansion, has become the subject of a sustained project led by Archaeonauta SL with support from the Junta de Galicia, the Spanish Navy and the Institute of Nautical Archaeology. In subsequent years, diving operations on the Yarmouth Roads wreck in the Solent, UK led by project partner Maritime Archaeology Ltd. pushed the dive team further on a designated historic wreck site with very poor visibility and exacting tidal flows (Rich et al. 2020). This site, subject to earlier excavations in the twentieth century, could be the *Santa Lucia*, an Iberian merchant vessel lost in 1567 off the coast of the Isle of Wight (Watson and Gale 1990; Dunkley 2001; Plets et al. 2008; Traoré et al. 2018). Samples taken from the wreck sites of *Bayonnaise*, *Magdalena*, and Ribadeo provided material for the wood science team on which to test and develop their techniques.

The archaeological team also sought to investigate shipwreck assemblages of suspected Iberian ships which had been previously excavated or, in the case of the Belinho 1 wreck, recently discovered through storm action. The Belinho 1 shipwreck assemblage, washed onto the beach north of Esposende in northern Portugal in the winter storms 2014 and onwards, comprised hundreds of artefacts, and over 70 substantial ship timbers. The recording and sampling of this assemblage was undertaken by an archaeological team led by ForSEAdiscovery partners in 2015 followed up by marine survey and diving operations which located the in situ shipwreck from which this material had been eroded. This project (considered in detail in Vol. 2 Chap. 5) provided an opportunity to blend various developing forms of ship timber documentation including traditional direct measurement and scale drawing alongside multi-image photogrammetry and Faro Arm contact digitisation and the inclusion of systematic collection of dendro-archaeological data from the full timber assemblage (see Vol. 2 Chap. 1).

The nautical archaeology potential of historic reports is perhaps best exemplified by the case study of Lisbon where development over decades has repeatedly led to the discovery of significant shipwreck sites. In addition to re-examining some of these assemblages held in storage (e.g. Cais do Sodre), ForSEAdiscovery also collaborated with teams undertaking post-excavation documentation of ship timber assemblages such as the Boa Vista 1 and 2 ships (Fonseca et al. 2016) and ran workshops to heighten awareness of dendro-archaeological techniques and research potential particularly where urban development in Lisbon is producing new sites. The Delta development in the approaches to the port of Cadiz (see Vol. 2 Chaps. 1 and 6) led to the investigation of three shipwrecks of historic interest. Samples from Delta 1 and 2 were studied by ForSEAdiscovery researcher Marta Domínguez-Delmás (Domínguez-Delmás and García-González 2015; Dominguez-Delmás and García-González 2015), and ForSEAdiscovery partner Nigel Nayling dived on the Delta 3 site to recover samples which demonstrated that this ship was probably Dutch-built and dated to the late-sixteenth century (Domínguez-Delmás and Nayling 2016). Again, this collaboration with major development-led archaeological projects demonstrated how dendrochronology can effectively be integrated within archaeological projects.

The ForSEAdiscovery project also took the opportunity to collaborate with active research programmes on suspected Iberian ships. Renewed research action on the Highbourne Cay shipwreck, Bahamas, one of the suspected Iberian ships included within Oertling's original grouping of Atlantic vessels, was subjected to renewed excavations in 2017. Two members of the ForSEAdiscovery archaeology team (Nigel Nayling and Miguel Adolfo Martins) formed part of the excavation team and undertook observation of in situ timbers and selective sampling and analysis (see Vol. 2 Chaps. 1 and 7). Similarly, samples from the 2017 excavations on the Emanuel Point II shipwreck (one of the wrecks of the *Luna* expedition wrecked off the Pensacola, Florida coast in 1559) were provided by the University of West Florida team, and further samples of the EP II and III shipwrecks were collected by

Nigel Nayling during the 2018 excavations (see Vol. 2 Chap. 1) (Smith 2018; Bendig 2018; Worth et al. 2020).

Beyond site-specific research actions, and the delivery of samples to the wood science team, archaeological research within the ForSEAdiscovery project also supported development of protocols and techniques for shipwreck dendro-archaeological documentation and sampling (Rich et al. 2018; Domínguez-Delmás et al. 2019; Rich et al. 2020), and assisted in the broader ongoing project to develop databases of known early modern Iberian shipwrecks at a global scale (see Chap. 6). Dissemination to academic and professional colleagues was undertaken primarily through engagement with key international conferences, including the International Symposium on Boat and Ship Archaeology in Gdansk 2015 and Marseille 2018 (Litwin and Ossowsky 2017), and the International Congress on Underwater Archaeology (IKUWA) in Cartagena 2014 and Freemantle 2016 (Negueruela Martínez et al. 2016; Rodrigues and Traviglia 2020).

6 Dendro-Archaeology: Wood Provenance and Techniques

In summarizing the range of wood science approaches and results of the ForSEAdiscovery project, this section unashamedly draws on recent technical publications and reviews authored by members of the ForSEAdiscovery wood science team (Domínguez-Delmás 2020; Domínguez-Delmás et al. 2020) The application of dendrochronological techniques to shipwreck assemblages, as a method both for precise dating of the timbers felled for the ship's construction, and to attempt to identify the origin of the timber used (dendroprovenance) has become widespread particularly in northern Europe where a dense network of ring-width site masters and regional chronologies have been developed over the last half century. The temporal extent and geographical density of these reference chronologies is variable and, when considering the early modern period, tends to be most well-developed in regions where there have been long-running programmes of dendrochronological analysis of historical buildings. The organization of these data has allowed for the development of procedures of varying levels of dendroprovenance resolution (Daly 2007). The use of ring-width data alone for provenance of timber is not, however, without its challenges as local site conditions, such as aspect, soil, and altitude can prove significant variables in tree growth—sometimes as significant as climatic variables – leading to potentially misleading results (Bridge 2000, 2011, 2012). The ForSEAdiscovery project, in seeking to both date and provenance timber employed in early modern Iberian ships faced several challenges. The use of dendrochronology, for historical studies, within the Iberian Peninsula was, and still is, less well developed than in other parts of Europe (Domínguez-Delmás et al. 2015). The relative paucity of reference ring-width chronologies covering the last five centuries for the Iberian Peninsula is a fundamental problem. This relative lack of data could not be addressed within the life cycle of single research project—the large number of historical tree-ring chronologies in northern Europe have only been developed through decades of sustained work by a large number of research centres and laboratories. The ForSEAdiscovery strategy was to seek to develop selected ring-width regional chronologies in areas known to have provided timber, predominantly oak and pine, for shipbuilding during the early modern period. This research effort would be complemented by developing other analytical techniques which could assist in refining provenance in timber by integrating ring-width dendrochronology with studies in wood anatomy, wood chemistry, isotopic studies, and ancient DNA.

As part of a precursor project, samples from one of the shipwreck assemblages held in store in Lisbon, the Arade 1 shipwreck, were subjected to dendrochronological analysis (Domínguez-Delmás et al. 2013). Some of these timbers, and also samples from the Cais do Sodre shipwreck, had previously been identified, on wood anatomy grounds as *Quercus faginea*, an oak species with a predominantly Iberian geographical distribution (Castro 2006; Castro et al. 2011, Tables 2–4). Ring-width dendrochronology clearly demonstrated that the Arade 1 oak timbers derived from western France, well outside the natural distribution of *Quercus faginea* and calling into question these identifications. These results challenged the use of microscopic wood anatomical features alone to discriminate between the native deciduous species of oaks found in the Iberian Peninsula and, in some cases, elsewhere (*Q. robur*, *Q. petraea*, *Q. pubescens*, *Q. faginea*, *Q. canariensis*, and *Q. pyrenaica*). The implication was that, based on standard methods of microscopic wood identification (e.g. Schweingruber 1990), these deciduous oaks should be identified only to a subgenus level (*Quercus* subg. *quercus*). This raised the question—how might we discriminate between this group of deciduous oak species, which also tend to hybridize, and hence assist in the identification of timber of specifically Iberian origin?

One approach taken was to examine variations in tree growth rings other than ring-widths (Akhmetzyanov 2019). Using samples from oak forest stands in the Basque Country (six sites) and Cantabria (three sites) in Northern Spain, total ring-width, earlywood and latewood widths, and earlywood vessel area were measured (Akhmetzyanov et al. 2019). Using principal component analysis, it was concluded that combined use of earlywood vessel size (varying response to winter and spring temperature and hence reflecting latitudinal/topographic gradient) and latewood width (varying response to summer temperature) provided the best results in identifying growth site location. These additional tree-ring variables, most usually collected in studies seeking to reconstruct past climate, therefore could have a role in refining dendroprovenancing of timber found in historic buildings and archaeological sites such as shipwrecks and could also assist in discriminating between the different species making up the subgenus group of deciduous oaks (*Quercus* subg. *quercus*). As new methods of non-destructive extraction of tree-ring data from historic material continue to develop, the enticing prospect of being able to collect these data types through use of scanning technologies like MRI, which has the potential to extract digital slices from both waterlogged and conserved archaeological timber, may soon become a reality (Morales et al. 2004; Dvinskikh et al. 2011; Capuani et al. 2020). The use of annually resolved Blue Intensity (BI) measurements of tree-rings has traditionally been used as a proxy for extracting climate data from tree-rings, normally from conifers. Principal Component Gradient Analyses (PCGA) of BI measurements of black pine (*Pinus nigra* Arn.) and Scots pine (*P. sylvestris* L.) on the Iberian Peninsula undertaken by Akhmetzyanov et al. (2020b) demonstrated that this approach can also be used to refine the dendroprovenancing of softwoods from Andalucia and the Central System used for shipbuilding for centuries.

Chemical signatures within wood and timber offered the project a further potential approach in refining our ability to identify the geographical source of timber and the species of trees being exploited – the latter not always possible through traditional visible light microscopy especially for some species which we know, from the historical record, were important resources for Iberian shipbuilding. Traoré, using mainly a combination of pyrolysis in combination with gas chromatography and mass spectrometry (Py-GC–MS) and Fourier transform infrared spectroscopy (FTIR) noted the ability to characterize the degree of degradation of historic building and waterlogged wood, a potentially important advance in the conservation of archaeological wood (Traoré et al. 2016, 2017a). These techniques were used effectively to discriminate between samples from different species of oak within the deciduous oak subgenus group (Traoré et al. 2018), and also between black pine (*Pinus nigra* Arn.) and Scots pine (*P. sylvestris* L.) (Traoré et al. 2017b). As with many of the scientific techniques explored in the ForSEAdiscovery project, the application of FTIR for archaeological wood characterisation shows potential although wood degradation can be a significant challenge.

Isotopic analyses within archaeology continue to broaden their application ranging from provenance through dating to diet. Ratios of stable isotopes of strontium, an example of isotopes independent of climatic variations and dependent on the parent geochemistry had previously been used in attempts to provenance ship timbers (Rich et al. 2012, 2015, 2016). Significant variation in strontium isotope ratios was observed in control sites where both living trees and their surrounding soils were sampled and analysed but analysis of the strontium isotope ratios of waterlogged timbers from underwater shipwrecks still constitutes a challenge (Hajj 2017; Domínguez-Delmás et al. 2020). As timbers become waterlogged and degrade in marine anaerobic environments, their strontium ratios become closer to those of the salt water in which they reside. Hajj's pioneering work points the way to the development of extraction techniques which may yet overcome this challenge.

Advances in the extraction of ancient (a)DNA are revolutionizing bioarchaeology as a branch of scientific archaeology. Groundbreaking work on the extraction of (a)DNA from archaeologically recovered wood including oak heartwood both highlights the challenges faced, but also offers the prospect of a further, parallel and independent line of analysis of waterlogged wood which seemed unlikely to prove feasible just a few years ago (Wagner et al. 2018; Domínguez-Delmás 2020; Akhmetzyanov et al. 2020a).

7 Conclusions

The ForSEAdiscovery project was truly innovative and ambitious in attempting a well-integrated multi-disciplinary research project. Its legacy is diverse and substantial in terms of the young researchers who developed as Marie Curie fellows working together cutting across the disciplinary and methodological barriers which so often define research and, in the process, publishing across the disciplines of history, archaeology, and the earth sciences. The two volumes of this publication include many contributions from members of the ForSEAdiscovery family which further demonstrate the progress made in recent years. This is not to say that our work in understanding the interaction between the Early Modern Iberian empires and forest resources at a time of unparalleled maritime expansion is complete. New understandings and refined techniques offer us the opportunity to push forward this line of research within a broader context of human/nature relations which could be defined as Environmental History. Such advances require the research community, across disciplinary silos, to engage in continued collaboration only achievable through transformative acts of consilience.

References

Adams M (2018) The wisdom of trees. A miscellany. Head of Zeus, London

Akhmetzyanov L (2019) New tools for timber provenancing. Wageningen University

Akhmetzyanov L, Buras A, Sass-Klaassen U et al (2019) Multi-variable approach pinpoints origin of oak wood with higher precision. J Biogeogr 46:1163–1177. https://doi.org/10.1111/jbi.13576

Akhmetzyanov L, Copini P, Sass-Klaassen U et al (2020a) DNA of centuries-old timber can reveal its origin. Sci Rep 10:20316. https://doi.org/10.1038/s41598-020-77387-2

Akhmetzyanov L, Sánchez-Salguero R, García-González I et al (2020b) Towards a new approach for dendroprovenancing pines in the Mediterranean Iberian Peninsula. Dendrochronologia 60:125688. https://doi.org/10.1016/j.dendro.2020.125688

Albion RG (1926) Forests and sea power: the problem of the Royal Navy, 1652–1862. Harvard University Press, Cambridge, MA, London

Auer J, Firth A (2007) The ‘Gresham Ship’: an interim report on a 16th-century wreck from Princes Channel, Thames Estuary. Post-Medieval Archaeol 41:222–241. https://doi.org/10.1179/174581307X318967

Bendig CD (2018) Amidships assembly of the sixteenth-century emanuel point II shipwreck. Int J Hist Archaeol:1–29. https://doi.org/10.1007/s10761-018-0477-y

Bridge M (2012) Locating the origins of wood resources: a review of dendroprovenancing. J Archaeol Sci 39:2828–2834

Bridge M (2000) Can dendrochronology be used to indicate the source of oak within Britain? Vernac Archit 31:67–72. https://doi.org/10.1179/vea.2000.31.1.67

Bridge M (2011) Resource exploitation and wood mobility in northern European oak: dendroprovenancing of individual timbers from the Mary Rose (1510/11?1545). Int J Naut Archaeol 40:417–423. https://doi.org/10.1111/j.1095-9270.2010.00309.x

Capuani S, Stagno V, Missori M et al (2020) High-resolution multiparametric MRI of contemporary and waterlogged archaeological wood. Magn Reson Chem:1–10. https://doi.org/10.1002/mrc.5034

Casado Soto JL (1991) Atlantic shipping in sixteenth-century Spain and the 1588 Armada. In: Rodríguez-Salgado MJ, Adams S (eds) England, Spain, and the gran Armada 1585–1604: essays from the Anglo-Spanish conferences, London and Madrid. Edinburgh

Castro F (2006) The Arade 1 shipwreck. A small ship at the mouth of the Arade river, Portugal. In: Blue L, Hocker F, Englert A (eds) Connected by the sea: proceedings of the tenth international symposium on boat and ship archaeology, Denmark 2003. Oxbow Books, Oxford, pp 300–305

Castro F, Yamafune K, Eginton C, Derryberry T (2011) The Cais do Sodré shipwreck, Lisbon, Portugal. Int J Naut Archaeol 40:328–343. https://doi.org/10.1111/j.1095-9270.2011.00313.x

Crespo Solana A (2019) ForSEAdiscovery: la construcción naval y el comercio de la madera del siglo XVI al XVIII. Rev PH:114–141. https://doi.org/10.33349/2019.96.4279

Crespo Solana A (2016) ForSEAdiscovery: genesis y marco histórico-metodológico de un proyecto interdisciplinar en Humanidades. In: Varela Gomes R, Varela Gomes M (eds) A gestão dos recursos forestais portugueses na construção naval da Idade Moderna: Histórica e arqueología. Universidade Nova de Lisboa, Lisbon, pp 1–14

Crespo Solana A, Nayling N, García-González I (2018) ForSeaDiscovery forest resources for iberian empires: ecology and globalization in the age of discovery Marie Curie. CSIC, Madrid

Daly A (2007) Timber, trade and tree-rings. A dendrochronological analysis of structural oak timber in Northern Europe, c. AD 1000 to c. AD 1650. University of Southern Denmark

Domínguez-Delmás M (2020) Seeing the forest for the trees: new approaches and challenges for dendroarchaeology in the 21st century. Dendrochronologia 62:125731. https://doi.org/10.1016/j.dendro.2020.125731

Domínguez-Delmás M, Alejano-Monge R, Van Daalen S et al (2015) Tree-rings, forest history and cultural heritage: current state and future prospects of dendroarchaeology in the Iberian Peninsula. J Archaeol Sci 57:180–196. https://doi.org/10.1016/j.jas.2015.02.011

Domínguez-Delmás M, García-González I (2015) Investigación dendrocronológica de maderas del pecio Delta II. Cádiz, España

Dominguez-Delmás M, García-González I (2015) Investigación dendrocronológica de maderas del pecio Delta I. Cádiz, España

Domínguez-Delmás M, Nayling N (2016) Investigación dendrocronológica de maderas del pecio Delta 3. Cádiz, España

Domínguez-Delmás M, Nayling N, Wazny T et al (2013) Dendrochronological dating and provenancing of timbers from the Arade 1 shipwreck, Portugal. Int J Naut Archaeol 42:118–136. https://doi.org/10.1111/j.1095-9270.2012.00361.x

Domínguez-Delmás M, Rich S, Daly A et al (2019) Selecting and sampling shipwreck timbers for dendrochronological research: practical guidance. Int J Naut Archaeol 48:231–244. https://doi.org/10.1111/1095-9270.12329

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

Dunkley M (2001) The Yarmouth roads shipwreck. A study in interpretation. University of Southampton

Dvinskikh SV, Henriksson M, Berglund LA, Furó I (2011) A multinuclear magnetic resonance imaging (MRI) study of wood with adsorbed water: estimating bound water concentration and local wood density. Holzforschung 65:103–107. https://doi.org/10.1515/HF.2010.121

Eguiluz Miranda B, Domínguez Delmás M, Trápaga Monchet K et al (2020) The Ribadeo shipwreck (c. 1600): can we identify a ship through a multidisciplinary approach? In: Rodrigues J, Traviglia A (eds) IKUWA6: shared heritage: proceedings of the 6th international congress on underwater archaeology. Archaeopress, Oxford, pp 104–115

Fonseca C, Bettencourt J, Brazao A et al (2016) Boa Vista 1 and Boa Vista 2: first data on two Early Modern ships discovered in Lisbon (Portugal). In: Günter H, Negueruela I (eds) Actas del V Congreso Internacional de Arqueología Subacuática (IKUWA V) Cartagena, 15–18 de octubre de 2014. Ministerio de Educación, Cultura y Deporte, Cartagena, pp 957–967

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

Gasch-Tomás JL, TrápagaMonchet K, Trindade AR (2017) Shipbuilding in times of war: contracts for the construction of ships and provision of supplies in the Spanish empire in the early seventeenth century. Int J Marit Hist 29:187–192. https://doi.org/10.1177/0843871416679124

Hajj F (2017) Utilisation des isotopes stables et radiogéniques du strontium pour tracer la provenance des bois: application à des épaves sous-marines. l'Université de Lorraine

Jiménez Montes G (2020) A dissimulated trade: flamencos and the trade of North European Timber in Seville (1574–1598). University of Groningen

Jiménez Montes G (2016) Las redes comerciales del norte de Europa en el suministro de madera a Andalucía de 1581 a 1621. In: García Fernández M (ed) Familia, cultura material y formas de poder en la España moderna. FEHM, Madrid, pp 693–702

Kumar M (2018) A method for estimating the volume of Baltic timber products exported through the sound and its application to Portugal, 1669–1815. Scand Econ Hist Rev 66:246–263. https://doi.org/10.1080/03585522.2018.1452789

Laviana Cuetos M (1984) La Maestranza del astillero de Guayaquil en el siglo XVIII. Temas Am:26–32

Litwin J, Ossowsky W (eds) (2017) Baltic and beyond: change and continuity in shipbuilding: proceedings of the fourteenth international symposium on boat and ship archaeology, Gdańsk 2015. National Maritime Museum in Gdańsk, Gdansk

Maarleveld T, Auer J, Ditta M, Firth A (2014) The Gresham ship project. A 16th-century merchantman wrecked in the princes channel, thames estuary. Volume I: excavation and hull studies. Archaeop, Oxford

Martínez González AJ (2015) Las Superintendencias de Montes y Plantíos (1574–1748). Derecho y política forestal para las armadas en la Edad moderna. Tirant lo Blanch, Valencia

McNeill JR (2004) Woods and warfare in world history. Environ Hist Durh N C 9:388–410. https://doi.org/10.2307/3985766

Morales S, Guesalaga A, Fernández MP et al (2004) Computer reconstruction of pine growth rings using MRI. Magn Reson Imaging 22:403–412. https://doi.org/10.1016/j.mri.2004.01.015

Nayling N (2008) The application of dendrochronology to underwater archaeology. In: Tsang C (ed) International symposium on underwater archaeology, Taiwan, pp 64–73

Negueruela Martínez I, Belinchón Castillo R, Sánchez Recio P (eds) (2016) Proceedings of the 5th international congress on underwater archaeology. A heritage for mankind. Cartagena, October 15th–18th, 2014. Ministerio de Educación, Cultura y Deporte, Madrid, p 1039

Oertling T (2001) The concept of the Atlantic vessel. In: Alves F (ed) Proceedings of the international symposium on archaeology of medieval and modern ships of Iberian-Atlantic tradition. Instituto Português Archaeologia; Centro Nacional de Arqueologia Náutica e Subaquática, Academia de Marinha Lisboa, Lisbon, pp 233–240

Oertling TJ (2004) Characteristics of fifteenth-and sixteenth-century iberian ships. In: Hocker FM, Ward CA (eds) The philosophy of shipbuilding. Texas A & M University Press, College Station, pp 129–136

Perlin J (1989) Forest journey: the story of wood and civilization. Harvard University Press, Cambridge, MA

Plets RMK, Dix JK, Best AI (2008) Mapping of the buried yarmouth roads Wreck, Isle of Wight, UK, using a chirp sub-bottom profiler. Int J Naut Archaeol 37:360–373. https://doi.org/10.1111/j.1095-9270.2007.00176.x

Reichert R (2016) El comercio directo de maderas para la construcción naval española y de otros bienes provenientes de la región del báltico sur, 1700-1783. Hisp - Rev Esp Hist 76:129–157. https://doi.org/10.3989/hispania.2016.005

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

Rich S, Manning S, Degryse P et al (2015) Provenancing East Mediterranean cedar wood with the 87Sr/86Sr strontium isotope ratio. Archaeol Anthropol Sci:1–10. https://doi.org/10.1007/s12520-015-0242-7

Rich S, Manning SW, Degryse P et al (2016) To put a cedar ship in a bottle: dendroprovenancing three ancient East Mediterranean watercraft with the 87Sr/86Sr isotope ratio. J Archaeol Sci Rep 9:514–521. https://doi.org/10.1016/J.JASREP.2016.08.034

Rich S, Manning SW, Degryse P et al (2012) Strontium isotopic and tree-ring signatures of Cedrus brevifolia in Cyprus. J Anal At Spectrom 27:796–806. https://doi.org/10.1039/C2JA10345A

Rich S, Momber G, Nayling N (2020) Maritime archaeological timber sampling: methods and results from the silty Solent. In: Rodrigues JA, Traviglia A (eds) Shared heritage: proceedings of the sixth international congress for underwater archaeology. IKUWA 6. Archaeopress Archaeology; Western Australian Maritime Museum. Freemantle, Western Australia, Oxford, pp 143–152

Rodrigues JA, Traviglia A (eds) (2020) Shared heritage: Proceedings of the sixth international congress for underwater archaeology. 28 November–2 December 2016, Western Australian Maritime Museum Fremantle, Western Australia. Archaeopress

Schweingruber FH (1990) Anatomy of European woods. Haupt Verlag, Berne and Stuttgart

Serrano Alvarez JM (2008) El astillero de La Habana y la construcción naval, 1700–1750. Instituto de Historia y Cultura Naval, Madrid

Serrano Mangas F (1992) Función y evolución del galeón en la Carrera de Indias. MAPFRE, Madrid

Smith RC (ed) (2018) Florida's lost galleon: the Emanuel point shipwreck. University of Florida Press

Traoré M, Kaal J, Martínez Cortizas A (2018) Chemometric tools for identification of wood from different oak species and their potential for provenancing of Iberian shipwrecks (16th-18th centuries AD). J Archaeol Sci 100:62–73. https://doi.org/10.1016/j.jas.2018.09.008

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

Traoré M, Kaal J, Martínez Cortizas A (2017a) Potential of pyrolysis-GC–MS molecular fingerprint as a proxy of Modern Age Iberian shipwreck wood preservation. J Anal Appl Pyrolysis 126:1–13. https://doi.org/10.1016/j.jaap.2017.07.003

Traoré M, Kaal J, Martínez Cortizas A (2017b) Differentiation between pine woods according to species and growing location using FTIR-ATR. Wood Sci Technol:1–18. https://doi.org/10.1007/s00226-017-0967-9

Trápaga Monchet K (2019a) Guerra y deforestación en el reino de Portugal (siglos XVI-XVII). Tiempos Mod 39:396–425

Trápaga Monchet K (2019b) Las otras armas del rey: barcos y bosques en Portugal en los años finales de la Unión de Coronas (1628-1640). In: Polo Romero LA, Trápaga Monchet K (eds) Arqueología, historia y medio ambiente: visiones cruzadas. Dykinson, Madrid, pp 101–120

Trindade AR (2015) Bourbon naval policy, forestry and timber supply for shipbuilding in Andalucia (1700-1759): brief introductory research notes. In: Varela Gomes R, Trapaga Monchet K (eds) The management of Iberian forest resources in the early modern shipbuilding: history and archaeology. IAP Universidade Nova de Lisboa, Lisbon, pp 57–65

Trindade AR, Domínguez-Delmás M, Traoré M et al (2020) From the forests to the sea, from the sea to the laboratory: the timbers of the frigate *Santa Maria Magdalena* (18th century). In: Rodrigues J, Traviglia A (eds) IKUWA6: shared heritage: proceedings of the 6th international congress on underwater archaeology, December 2016, Fremantle. Western Australia. Archaeopress, Oxford, pp 127–142

Valdez-Bubnov I (2018) Shipbuilding administration under the Spanish Habsburg and Bourbon regimes (1590–1834): a comparative perspective. Bus Hist 60:105–125. https://doi.org/10.1080/00076791.2017.1391219

Valdéz-Bubnov I (2019) Navíos para un imperio global: la construcción naval y la matrícula de mar en España, América y Filipinas durante el siglo XVIII (1670-1834). Tiempo, Espac y Forma 32:123–159

Varela Gomes R, Trapaga Monchet K (2017) Árvores, barcos e homens na Península Ibérica (séculos XVI–XVIII). Pórtico Librerías, Lisbon

Wagner S, Lagane F, Seguin-Orlando A et al (2018) High-throughput DNA sequencing of ancient wood. Mol Ecol 27:1138–1154. https://doi.org/10.1111/mec.14514

Warde P (2006) Fear of wood shortage and the reality of the Woodland in Europe, c.1450–1850. Hist Work J 62:28–57. https://doi.org/10.1093/hwj/dbl009

Watson K, Gale A (1990) Site evaluation for marine sites and monuments records: the Yarmouth Roads Wreck investigations. Int J Naut Archaeol 19:183–192. https://doi.org/10.1111/j.1095-9270.1990.tb00256.x

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

Worth JE, Benchley ED, Lloyd JR, Melcher JA (2020) The discovery and exploration of Tristán de Luna y Arellano's 1559–1561 settlement on Pensacola Bay. Hist Archaeol 54:472–501. https://doi.org/10.1007/s41636-020-00240-w