DENDROARCHAEOLOGY APPLIED TO THE PORTUGUESE CULTURAL HERITAGE BETWEEN THE XV AND XIX CENTURIES: PAINTINGS AND MUSICAL INSTRUMENTS AS WITNESSES OF ARTWORK AND WOOD TRADES BETWEEN PORTUGAL AND EUROPE

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THESIS PRESENTED TO OBTAIN THE DOCTOR DEGREE (PhD) IN FORESTRY ENGINEERING AND NATURAL RESOURCES

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“A grande conquista é o resultado de pequenas vitórias que passam despercebidas.”

Paulo Coelho

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Lastly, the dedication would not be complete without acknowledging and mentioning my parents and brothers. I hope I have honoured you with this PhD.

ABSTRACT

The current study focuses on the dendrochronological dating of seventy Portuguese and foreign artworks from the XV to the XIX centuries from public and private collections. Among the artworks examined are a collection of 34 Portuguese and Flemish paintings, as well as 36 musical instruments of Portuguese and foreign construction. The study investigates the wood's provenance within the historical context of Portuguese maritime commerce with Europe. This research aims to develop a reference chronology, which will be useful for future dendrochronological studies, with a focus on artworks on Baltic oak wood support.

The adopted methodology took into consideration the impossibility of obtaining samples from artworks and musical instruments, as well as the restrictions to their handling. Therefore, the dendrochronological analysis was based on direct observation using photographic and video material adapted to the size and shape of each piece, followed by statistical processing by ARSTAN, COFECHA, TRiCYCLE, and TSAPWIN software. The dating of each piece and the study of the dendroprovenance used public and restricted access reference chronology databases.

The results obtained from the study of the support of Portuguese and Flemish paintings reinforce their chronological attributions and confirm the use of Baltic oak. The dendrochronological data obtained from these pieces, in conjunction with data provided by the IJF-DGPC and research projects conducted by the CEF-ISA, enabled the construction of a reference chronology spanning between the years 1149 to 1599.

The pioneering dendrochronological study on Portuguese violins, cellos, and pianofortes from the XVIII and XIX centuries corroborates the historical dates inscribed on the respective musical instruments. It also revealed that the Portuguese workshops used woods from the Alpine region of Switzerland, Germany, Austria, and Italy, which is consistent with the several historical sources on the Portuguese maritime trade with Europe.

In conclusion, dendrochronology based on artworks enabled the construction of historical knowledge, as well as the interpretation of paintings and musical instruments as evidence of goods traded between Portugal and Europe between the XV and XIX centuries.

Keywords: Dendrochronology; painting; musical instrument; heritage; European wood trade.

RESUMO

A presente pesquisa versa sobre a datação dendrocronológica dum conjunto de 70 obras de arte portuguesas e estrangeiras do século XV ao século XIX, pertencentes a colecções públicas e privadas, dando o seu contributo sobre a atribuição artística de cada obra. A selecção das obras abrangeu um conjunto de 32 pinturas portuguesas e flamengas e 36 instrumentos musicais de construção portuguesa e estrangeira. A investigação abordou a proveniência das madeiras, tendo em consideração os factos históricos sobre o comércio marítimo português com a Europa. A pesquisa pretendeu desenvolver uma cronologia de referência com ênfase nas obras de arte em suporte de madeira de carvalho, considerada uma ferramenta de elevada importância para futuros estudos dendrocronológicos.

A metodologia adoptada teve em consideração a impossibilidade de recolha de amostras nas pinturas e nos instrumentos musicais, evitando também o seu manuseamento, pelo que a análise dendrocronológica se baseou na observação directa com recurso a material fotográfico e de vídeo adaptado à dimensão e forma de cada peça e posterior tratamento estatístico pelos softwares ARSTAN, COFECHA, TRiCYCLE e TSAPWIN. Para a datação de cada peça e para o estudo da dendroproveniência recorreu-se a bases de dados de cronologias de referência de acesso público, assim como de acesso restrito.

A investigação sobre o suporte das pinturas portuguesas e flamengas analisadas reforçou as respectivas atribuições cronológicas e certifica a utilização de carvalho proveniente da região do Báltico. Os dados dendrocronológicos obtidos para estas peças, em complementaridade com os dados facultados pelo IJF-DGPC e provenientes de projectos de investigação desenvolvidos pelo CEF-ISA, permitiram a construção de uma cronologia de referência para o período de 1149 a 1599.

O estudo dendrocronológico pioneiro sobre violinos, violoncelos, clavicórdios e pianofortes de construção portuguesa dos séculos XVIII e XIX corrobora empiricamente as datações históricas inscritas nos respectivos instrumentos musicais. Paralelamente, revela a utilização de madeiras provenientes da região alpina da Suíça, Alemanha, Áustria e Itália pelas oficinas portuguesas, facto este que está em concordância com as diferentes fontes históricas sobre o comércio marítimo português com a Europa.

Em conclusão, a dendrocronologia permite construir conhecimento histórico com base nas obras de arte e ver as pinturas e os instrumentos musicais como testemunhos de bens comercializados entre Portugal e a Europa do século XV ao século XIX.

Palavras-chave: Dendrocronologia; pintura; instrumentos musicais; património; comércio europeu de madeiras.

RESUMO ALARGADO

A presente pesquisa estuda um conjunto de 70 obras de arte portuguesas e estrangeiras do século XV ao século XIX, pertencentes a colecções públicas e privadas, utilizando uma abordagem dendrocronológica dando o seu contributo sobre a prévia atribuição artística de cada obra. A investigação estuda igualmente a proveniência das madeiras, tendo em consideração os factos históricos sobre o comércio marítimo português com a Europa.

A selecção das obras abrangeu um conjunto de 32 pinturas portuguesas e flamengas dos séculos XV e XVI, e 36 instrumentos musicais de construção portuguesa e estrangeira dos séculos XVIII e XIX. A análise dendrocronológica baseou-se na observação directa com recurso a material fotográfico e de vídeo adaptado à dimensão e forma de cada peça de arte, dada a impossibilidade de recolha de amostras neste tipo de objectos. Os anéis anuais de crescimento da madeira foram medidos, analisados e o tratamento estatístico foi realizado com os programas ARSTAN, COFECHA, TRiCYCLE e TSAPWIN. Perante a multiplicidade de critérios disponibilizados na literatura relativos à seleção dos parâmetros estatísticos a considerar na datação de uma obra, neste estudo foram selecionados os seguintes de acordo com os tipos de obras estudadas: (1) para a pintura, *t-value* adaptado por BAILLIE and PILCHERH (1973) (t_{BP})≥5.0 e P≥0.999; e (2) para os instrumentos musicais, *t-value* adaptado por HOLLSTEIN (1980) (t_H)≥4.0 e *Gleichläufigkeit* (Glk)≥60%. Pelo facto de a datação de uma obra de arte, e o respectivo estudo da dendroproveniência, requerer a consulta de bases de dados de cronologias de referência, foram seleccionadas cronologias de referência de *Quercus* sp. para as pinturas e de quatro espécies florestais para os instrumentos musicais (*Picea abies* Karst, *Larix decidua* Mill., *Abies alba* Mill. e *Pinus cembra* L.). As cronologias de referência pertencem a bases de dados públicas e privadas, publicações científicas e relatórios científicos de laboratórios de dendrocronologia de instituições estatais e universitárias.

A investigação realizada sobre o suporte de madeira de 15 pinturas dos séculos XV e XVI atribuídas a notáveis pintores flamengos, incluídas na colecção do Museu de Arte Sacra do Funchal, assim como das 17 pinturas portuguesas que compõem dois retábulos do século XVI classificados como de interesse nacional e pertencentes ao Museu Nacional de Arte Antiga, revelou que as datações dendrocronológicas corroboram empiricamente as respectivas datações histórico-estilísticas. A investigação certificou a utilização de madeira carvalho proveniente da região do Báltico nos suportes das pinturas flamengas e portuguesas, tal como expectável de acordo com fontes históricas e outros estudos dendrocronológicos. A datação cruzada de uma nova cronologia baseada nas pinturas portuguesas (PORTMNAAVSTSFE, 1201-1504) com quatro cronologias de referência resultantes do estudo de material arqueológico proveniente da Lituânia e da Polónia produziu resultados estatísticos promissores. Contudo, será fundamental uma replicação rigorosa dos dados com outras cronologias destes territórios para propor uma origem mais circunscrita das madeiras utilizadas nos retábulos portugueses.

O estudo dendrocronológico direccionado para os instrumentos musicais é pioneiro em Portugal e abrangeu um conjunto de violinos, violoncelos, clavicórdios, cravos e pianofortes de construção portuguesa e estrangeira. Nele se incluem dois instrumentos musicais classificados como tesouros nacionais pertencentes ao Museu Nacional da Música: (1) violoncelo *Chevillard-Rei de Portugal*, 1725 (MNM 047) - o único conhecido instrumento atribuído ao famoso *luthier* italiano Antonio Stradivari existente em Portugal; e (2) cravo Taskin, 1782 (MNM 1096), atribuído ao construtor francês Pascal-Joseph Taskin. A investigação corroborou algumas das datações históricas inscritas nos respectivos instrumentos musicais. As informações disponíveis sobre as possíveis origens das madeiras utilizadas nestes tipos de instrumentos musicais portugueses basearam-se na consulta de documentos históricos referentes ao comércio marítimo nos séculos XVIII e XIX, nomeadamente manuscritos de instituições aduaneiras, correspondência consular e periódicos. Os registos referem como principais origens os portos marítimos de vários países do norte da Europa, e com menor relevo Itália, para a qual se menciona a exportação para Lisboa de "*caixas de fundos e faixas pª ghitaras*", *"tampos de viollas", "madeira pª violeiros"* e *"madeira pª viollas".* Este facto histórico é corroborado pelo sucesso da datação de alguns instrumentos musicais de oficinas portuguesas através de cronologias de referência da região alpina da Suíça, Alemanha, Áustria e Itália.

Para além da corroboração empírica das datações históricas inscritas nos instrumentos musicais, a investigação mostrou outras contribuições da dendrocronologia, tendo por base um conjunto de violinos e violoncelos datados dos séculos XVII e XVIII: **(1)** aplicação em investigações forenses, provando falsas datas e atribuições de instrumentos com interesse histórico e artístico; **(2)** enquadramento do instrumento num contexto histórico caso a sua autoria seja desconhecida; e **(3)** complemento aos dados históricos de construtores de menor relevância, tendo em consideração a informação divulgada no instrumento.

Na presente tese foram desenvolvidas duas importantes ferramentas de análise de dados que deverão ser consideradas como novos recursos para a dendrocronologia sobre o património cultural português e reforçadas com novas medições a obter em futuros estudos: **(1)** uma cronologia de referência de carvalho para a região do Báltico (PORTHER01), referente ao período de 1149 a 1599, que assenta em 256 sequências dendrocronológicas independentes e datadas provenientes das bases de dados do IJF-DGPC e do CEF-ISA, assim como nas sequências obtidas nas 32 pinturas portuguesas e flamengas analisadas na actual pesquisa; e **(2)** uma base de dados de 166 sequências dendrocronológicas independentes e datadas (CEF-ISA database), tendo por base o estudo inicial de 130 instrumentos musicais estrangeiros essencialmente provenientes de coleções privadas (nos quais se incluem 15 violinos e violoncelos atribuídos a Antonio Stradivari), e reforçada com a inclusão dos 36 instrumentos abordados na presente investigação.

A investigação dendrocronológica forneceu também informações relevantes sobre determinadas técnicas de construção dos suportes das pinturas, das peças frontais dos violinos e violoncelos, assim como dos tampos harmónicos dos instrumentos de teclas analisados, tendo por base de comparação as técnicas europeias em vigor na respetiva época. Fica assim comprovado que a dendrocronologia possibilita um enriquecimento do conhecimento sobre os bens culturais e, consequentemente, deve ser considerada uma metodologia relevante na história técnica da arte, sobretudo nos estudos sobre protecção, conservação e restauro do património. Ao mesmo tempo, a dendrocronologia permite construir conhecimento histórico baseado nas obras de arte e ver as pinturas e os instrumentos musicais como testemunhos de bens comercializados entre Portugal e a Europa do século XV ao século XIX.

Palavras-chave: Dendrocronologia; pintura; instrumentos musicais; comércio de madeiras; Europa.

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ABBREVIATIONS

ADF-DGPC	Arquivo de Documentação Fotográfica - Direcção Geral do Património Cultural
a.s.l.	above sea level
CEF-ISA	Centro de Estudos Florestais - Instituto Superior de Agronomia
CRMM	Museu Municipal Carlos Reis (Torres Novas, Portugal)
IJF-DGPC	Instituto José de Figueiredo - Direcção Geral do Património Cultural
ITRDB	International Tree-ring Data Bank
MASF	Museu de Arte Sacra do Funchal
ME	Museu de Évora
MNAA	Museu Nacional de Arte Antiga (Lisbon, Portugal)
MNM	Museu Nacional de Música (Lisbon, Portugal)
MNMC	Museu Nacional Machado Castro (Coimbra, Portugal)
NMCPSMS	Núcleo Museológico da Capela do Espírito Santo dos Mareantes de Sesimbra
STR online	Sound Toll Registers database

INTRODUCTION AND OBJECTIVES

1. INTRODUCTION

The present PhD thesis, entitled *Dendroarchaeology applied to the Portuguese cultural heritage between XV and XIX centuries: paintings and musical instruments as witnesses of artwork and wood trades between Portugal and Europe*, is based on dendrochronological research carried out on material assets that, according to the Portuguese Law No. 13/85 of 6th July, "*are recognised as having their own value and should be deemed of relevant interest for the permanence and identity of Portuguese culture over time*".

A painting and a musical instrument marvel us with their image and sound. Why not be amazed by their history? Answering questions about the origin and conception of an artwork, knowing details about its life, not only deepens our relationship with it, but also bridges socio-economic facts from different eras. Documentary and material science help to write this history.

The present research focuses on the study of wood growth rings in the visible and accessible parts of the artworks. This approach is based on dendrochronology (*dendron*-tree; *khronos*-time; *logus*-study), sub-discipline dendroarchaeology, a science that examines the annual growth trend of trees at the local/regional level and compares it with reference values for dating purposes, allowing to estimate the most recent year found on the piece under study. This allows to determine the limit year after which the artwork may have been made (i.e., the *terminus post quem*), based on direct observation and statistical analysis of the measurements taken on each piece of wood.

Publications referencing the dendrochronological analysis of Portuguese paintings are scarce, as well as paintings of foreign authorship belonging to Portuguese collections. According to the available literature, only three musical instruments ascribed to Portuguese luthiers and belonging to foreign collections, as well as the Neapolitan mandolin assigned to Vincentius Vinaccia from the national collection belonging to MNM (Lisbon), have been dendrochronologically dated. The possibility of access to Portuguese artworks from public and private collections for a detailed study of the wood material is therefore an excellent opportunity for expanding dendrochronological studies in Portugal.

The methodological approach of the present PhD thesis is the *case-study*, described in the Dictionary of Sociology as "*the detailed examination of a single example of a class of phenomena, a case study cannot provide reliable information about the broader class. But it may be useful in the preliminary stages of an investigation since it provides hypotheses, which may be tested systematically with a larger number of cases (…). Many case-study investigations in fact use more than a single case, in order to get some idea of the range of variability in the population under consideration (…)*"

(ABERCROMBIE *et al.*, 1984). COUTINHO and CHAVES (2002) highlight five main characteristics of *case-studies*: **(1)** about "something" that needs to be established in order to give the study focus and direction; **(2)** "a limited system" with time, event, or process boundaries that are not always explicit and precise; **(3)** preserve the unique, specific, different, complex character of the case; **(4)** occur in the natural environment; and **(5)** multiple data sources and very diverse collection methods. These requirements are met in the present study: **(1)** a dendrochronological research of artworks from Portugal cultural heritage; **(2)** time restriction: between the XVI and the XIX centuries; **(3)** two unique altarpieces by Portuguese painters, Flemish paintings, and musical instruments from public and private collections; **(4)** artworks analysed in museums, luthier's workshops, and laboratory; **(5)** use of multiple data sources, such as databases, historical documents, catalogues, scientific reports and articles, as well as direct observations.

The case-study typology of the current thesis is defined as instrumental, which means that it is examined to provide insight into an issue, to refine a theory, or to provide knowledge of something that is not exclusively the case, according to COUTINHO and CHAVES (2002). In terms of the current study's scope, the analysis of the artworks through growth tree-rings provides relevant and valuable knowledge for other fields of study, with special emphasis on art history, history of the Portuguese maritime trade, conservation and restoration and organology.

In a case-study, sampling is always purposeful, based on pragmatic and theoretical criteria rather than on probabilistic criteria. COUTINHO and CHAVES (2002) indicate some similar characteristics for purposive sampling: **(1)** the sampling process is dynamic and sequential, and it can be changed/increased as the analysis progresses to complement or contrast the data already collected; **(2)** automatic adjustment of the sample whenever new working hypotheses arises; and **(3)** saturation or redundancy is the main criterion for considering the complete sampling process. In the present PhD thesis the sampling was not random, and the initial selection of the artworks was based on different criteria: accessibility of museums, historical interest of the pieces, and studies to be carried out by multidisciplinary teams. The sample changed over time as a result of practical constraints and expanded with the possibility of including a previously unconsidered type of artwork. The definition of the artworks for the dendrochronological study of Portuguese painting on two altarpieces was partly based on the redundancy of the results, but also limited to the availability of the museums and the time factor.

2. OBJECTIVES AND OVERVIEW

The research focuses on the dating of artworks, enabling to question the assumed artistic attribution.

The research hypotheses of the present doctoral thesis are the following:

I. The dendrochronological study of the original Flemish and Portuguese paintings from two public collections, can

1. define the *terminus post quem*, according to the databases available?
2. illustrate the type of commodities traded by sea between Europe and Portugal (mainland and islands) in the XV and XVI centuries?
3. estimate the provenance of the wood used by the Portuguese workshops, according to the databases available?
4. provide dendrochronological data as reference values for future dendrochronological dating?

II. The dendrochronological study of the musical instruments of Portuguese and foreign construction from the National Museum of Music and private collections, can

1. define the *terminus post quem*, according to the databases available?
2. test the authenticity of the historical date inscribed in some musical instruments?
3. estimate the provenance of the wood used by the instrument makers, according to the databases available?
4. illustrate the type of commodities that were commercialized by sea between the Mediterranean and Portugal from the XVII to the XIX centuries?

The present PhD thesis is structured in four chapters.

This first chapter - *Introduction and objectives* - provides a brief introduction to the thesis and the research, the key aims, and structure, scientific publications and dissemination activities carried out as part of the doctoral thesis.

The second chapter - *State of the art* – introduces the current knowledge on the application of dendrochronology to cultural heritage, namely in paintings and musical instruments. Given the probability of the use of imported woods in the Portuguese paintings and musical instruments, historical research was carried out on the timber trade between Portugal and Europe during the time relevant to the historical dates previously identified for the artworks. The lack of studies on the materials used in the construction of musical instruments from the XVII to the XIX centuries also justified further investigation.

The third chapter - *Original research* - presents the original investigation organized by two main sub-chapters - Material and methods, and Results and discussion. The first sub-chapter provides: **(1)** a description of the artworks based on museum catalogues, literature, and historical information; and **(2)** a description of the standard or innovative methods applied to each type of object. The sub-chapter Results and discussion includes two scientific articles on the study undertaken on Flemish paintings belonging to the Museum of Sacred Art of Funchal and on violins and cellos manufactured by Portuguese and foreign manufacturers. The results concerning the Portuguese paintings, as well as the harpsichords and fortepianos are also detailed in this sub-chapter.

The fourth chapter - *Conclusions and Future Works* - includes the conclusions and the perspective for future works.

3. DISSEMINATION OF THE RESEARCH

PUBLICATIONS

Lauw, A., Jansma, E., Pereira, H. (2021). The art trade between Flanders and Madeira Islands in the 15th and 16th centuries – the contribution of dendrochronology to the history of Portuguese heritage. *Journal of Archaeological Science: Reports*, *42*, 103379. DOI: 10.1016/j.jasrep.2022.103379

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PRESENTATIONS

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Datação de um violoncelo de construção portuguesa da coleção do Museu Nacional da Música. Uma abordagem dendrocronológica [oral communication]. Exhibition "Violinos de Construção Portuguesa". Museu Nacional da Música, Lisboa, 4 January 2016.

AWARD

2017 *Prémio Científico, Sesimbra 2017 - "Descobrindo o manto: decifrando a paleta e a técnica do pintor Gregório Lopes com um estudo sobre a pintura Mater Misericordiae"* Research team: Vanessa Antunes (ARTIS-FLUL, LIBPhys-UNL) António Candeias (LJF-DGPC, Laboratório HERCULES-UE); Maria J. Oliveira (LJF-DGPC); Maria L. Carvalho (LIBPhys-UNL); Cristina B. Dias (Laboratório HERCULES-UE); Ana Manhita (Laboratório HERCULES-UE); Maria J. Francisco (Museu de Setúbal); **Alexandra Lauw (CEF-ISA-UL)**; Marta Manso (LIBPhys-UNL; Faculdade de Belas-Artes, UL).

STATE OF ART

1. THE WOOD TRADE BETWEEN PORTUGAL AND EUROPE

The development of the trade relations in the XV and XVI centuries between Portugal and the rest of the world promoted the growth of the Portuguese shipbuilding industry, with the need for more vessels for the new routes and the conquest of new lands in addition to the fleets that ensured the trade with Europe (DEVY-VARETA, 1986; COSTA, 1996).

The Portuguese expansion and the need for timber naturally impacted the forest exploitation, with increased deforestation and forest depletion of tall trees (DEVY-VARETA, 1986). The "noble" woods of the Portuguese forest were selected for shipbuilding including the cork oak (*Quercus suber* L.), oaks (*Q. faginea* Lam. and *Q. robur* L.) and pines (*Pinus pinaster* Aiton and *Pinus pinea* L.) (DEVY-VARETA, 1986; LOURENÇO, 1990; AZEVEDO, 1997; CARVALHO *et al.*, 2008). The cork oak, with an opulent branching and a hard wood, resistant to attack by worms and fungi and with low water absorption, presented the necessary qualities for the construction of the boat parts in contact with water (LOURENÇO, 1990; AZEVEDO, 1997). The oak trees with a lighter wood and large branches were directed for the manufacture of galleys (LOURENÇO, 1990). It should be noted that the value of the cork oak was given by its wood and not from the cork that had negligible commercial value since its regular exploitation only began in the XVII century. Holm oak (*Quercus rotundifolia* L.) was less used in spite of similar tree and wood qualities similar to the cork oak because of the importance of its fruit and furthermore because the holm oak forests were located in inland areas, far from the sea, making its use more expensive due to transport costs. Maritime pine (*Pinus pinaster* Aiton) was valued for its high stem with few knots and was targeted for the parts of the boat that were not in contact with the water since the wood was very easily attacked by the teredo (*Teredo navalis* L.). The stone pine (*Pinus pinea* L.), with an opulent branching and many natural curves, with a wood resistant to the attack of destructive agents, was used for the boat components in contact with water (AZEVEDO, 1997).

This continuous exploitation mainly based on slow-growing forest species, such as oak and cork oaks, naturally resulted in a decrease of the productive capacity of the Portuguese forests leading to concerns on the supply of good quality wood of the shipbuilding sector (DEVY-VARETA, 1986). At the end of the XV century, the first references emerged regarding the need to restrict the use of trees for "galleys and ships" and the Crown was forced to take measures to ensure the sustained growth of the forests, namely by moving away the sugar and glass kilns located in the Lisbon area and prohibiting the sale of pinecones and pine nuts. Among other reasons, the lack of raw material and the consequent use of green wood, not advisable for shipbuilding purposes, may have contributed to the considerable increase of shipwrecks towards the end of the XVI century (CARVALHO *et al.*, 2008). Despite this, Portugal had a forested area larger than the other Mediterranean countries, enabling the construction of boats for foreign shipowners and the export of wood to Spain.

The present research on the timber trade between Portugal and Europe in the XV and XVIII centuries was based on two major sources of information: **(1)** handwritten and printed historical documents; and **(2)** the *SOUND TOLL REGISTERS* database (http://www.soundtoll.nl) (*STR online*). This database is based on historical records of toll payments levied by the King of Denmark for passage through the Sound (between Sweden and Denmark), and it allowed us to analyse the types of products imported and exported by Portugal from the XV century onwards.

1.1.XV and XVI centuries

In the XV and XVI centuries, given the scarcity of national timber to guarantee the population and industry needs, Portuguese wood imports were made by shipments from northern Europe, the Madeira and Azores Islands and Brazil (REBOREDO and PAIS, 2012; CARITA, 2016).

Considering the focus of the present dendrochronological research on Portuguese artworks from the XV and XVI centuries, an in-depth review of timber imports from northern Europe includes a prior description of the trading ties between Portugal and the Hanseatic League from the last quarter of the XIV century until the end of the following century. The Hanseatic League (or Hansa), founded in 1307, consisted of an alliance of several cities in northern Germany with the mutual goal of promoting trade with the whole of Europe as well as defending trade routes on land and at sea. The number of Hansa cities varied, hitting a high of 166 in the XV century. Hansa was divided into four groups according to geographical area and importance: **(1)** Wendische Städte, in which the cities of Lübeck, Hamburg, Bremen, Rostock, Wismar and Lüneburg were highlighted; **(2)** Dutch towns; **(3)** Prussian cities (Danzig, Königsber e Thorn) and Livonian cities, actually Latvia and Estonia (Riga, Tallinn e Pernau); and **(4)** some towns in the State of North Rhine-Westfalia (Germany), namely Koln, Dortmund and Münster (MARQUES, 1959). Until the end of the XV century, most of the economic ties between Portugal and Hansa were established with the Eastern group, namely with Danzig, Riga, and Tallinn. Despite the unavailability of information on the timber trade flux in the following decades, it is reasonable to conclude that supplies were maintained on a regular basis (ARNOLD, 2019). Hanseatic traders came to Portugal mainly to purchase agricultural products (including wine, olive oil, honey, fruit, cereals, and meat), fish (primarily whale and sardine) and salt (MARQUES, 1959;

ARNOLD, 2019; COELHO, 2019). Salt was an outstanding commodity of Portuguese exports, as seen in the STR database (Figure 1).

Date	Shipmaster	Place	Departure - Destination	Commodity
21-4-1558	Reymer Sass	Bremen	Lysbon - -	Salt
21-4-1558	Pouell Beckmandt	Da-sken	Lysboned - -	Salt
21-4-1558	Jorgen Ned-mandt	D-ke	Lysbone - -	Salt
12-8-1558	Gert Woltmandt	Reuell	Scti. Thius - -	Salt
27-9-1558	Mickell Papecke	Danske	Scti. Theus - -	Salt
27-9-1558	Frerick Hase	Dansken	S. Theus - -	Salt
27-9-1558	Peder Willekatt	Dansken	Scti. Theus - -	Salt
27-9-1558	Pouell Dummellreysse	Danske	Scti. Theus - -	Salt
27-9-1558	Hanns Wegener	King-berg	Scti. Theus - -	Salt
9-3-1568	Geysbertt Petterss	Amsterdam	Liseboen - -	Salt
9-3-1568	Simon Simonss	Schellinguow	Lyseboen - -	Salt
17-5-1574	Pouill Beeckmann	Anncklam	Sintiuis - -	Salt
6-8-1574	Pettir Pettirssen	Emdenn	Synntiuis - -	Salt
6-8-1574	Jochym Gøntir	Lypcke	Sinntius - -	Salt
2-11-1574	Jørgenn Maessenn	Danschenn	Syntiuis - -	Salt
2-11-1574	Carstenn Branndtt	Kiønngsberigh	Syntiuis - -	Salt
2-11-1574	Pettir Hornemand	Danschenn	Syntiuis - -	Salt
2-11-1574	Jacob Wildekatt	Danschenn	Syntiuis - -	Salt
2-11-1574	Hennrick Duen	Danschenn	Syntiuis - -	Salt
2-11-1574	Branndt Diiricksen	Danschenn	Syntiuis - -	Salt
2-11-1574	Jochym Steickmann	Danschenn	Sintiuis - -	Salt
2-11-1574	Hanns Niizsche	Danschenn	Sintiuis - -	Salt
2-11-1574	Bartolomeus Janicke	Danschenn	Sintiuis - -	Salt
2-11-1574	Claus Mewe	Danschenn	Syntiuis - -	Salt
2-11-1574	Hennrick Wornecke	Danschenn	Syntiuis - -	Salt

Figure 1. Registers of vessels from Lisbon (*Lysbon/Lysboned/Liseboen*) and Setúbal (*Scti. Thius/Scti. Theus/Sintiuis/ Synntiuis*) to Hansa cities carrying salt, from 1558 to 1574 (SOURCE: STR online, accessed on 11.06.2020).

Other historical records relating to the timber trade between Portugal and the rest of Europe during the XV and XVI centuries are based on royal decrees on the reduction or suspension of import duties on certain commodities, including wood and its products. In certain cases, the directives often applied to other benefits for domestic and international traders (MARQUES, 1959; ARNOLD, 2019; COELHO, 2019). For example, in 1494, King John II exempted the import charges for masts from ships of at least ten *braça*[1] long for a span of ten years (HANSISCHES URKUNDENBUCH, 1916). MARQUES (1959) referred to a 1488 statement written by a Hansa's merchant in Bruges, informing about a shipment of timber from the Netherlands that had landed in Lisbon.

Travellers' descriptions are also mentioned by ARNOLD (2019) as a historic source on timber trade. He exemplified with the voyage of Hieronymus Münzer, a German physician, geographer, and humanist who visited Portugal and Spain in late 1493 and early 1494, and boarded the ship owned by Bernhard Fechter, a Danzig ship's master on 30th November 1494.

[1] *Braça* is an ancient measure of length equivalent to 1,8288 meters [in Dicionário infopédia da Língua Portuguesa. Porto: Porto Editora, 2003-2021. [Accessed on 2021-04-26]. Available on internet: https://www.infopedia.pt/dicionarios/lingua-portuguesa/braça]

From the STR onlie of maritime registrations destined for Portugal before 1634, there are a few evidence of timber goods imports (Figures 2 and 3). Since 1634, several vessels were bringing wood items and, in particular, oak pieces from northern Europe (Figure 4). The discrepancies in the number of documents available before and after 1634 can be explained by the fact that the *STR online* archive was begun with the most recent records and gradually increased with the oldest. Therefore, a more detailed and extended analysis over time of the wood trade in Portugal may be carried out when the database will be completed.

Imported timber was primarily intended for shipbuilding (MARQUES, 1959; GOMES, 2016). Most ships and galleons were constructed in *Ribeira das Naus*, in Lisbon, which was well positioned to be supplied with imported timber (COSTA, 1996). Discharge letters (*Cartas de Quitação*) from *Ribeira das Naus* and the royal Portuguese trading post in Antwerp provide essential documents on the Hanseatic Portuguese trade with masts, logs, and planks (ARNOLD, 2019). Discharge letters were royal charters provided by the financial division *Casa dos Contos*, in Lisbon, to Crown officials from the central or local administration who oversaw collecting all types of income and incurring expenses on the monarch's behalf.

The national timber, coming primarily from the centre of the country, was transported by cabotage, overland or by river (DEVY-VARETA, 1986; LOURENÇO, 1990; COSTA, 1996). Aside from shipbuilding, wood and coal were transported to cover the needs of urban and industrial life. The ports of the northern region had more difficulties in importing timber suitable for shipbuilding from the hinterland by the river and thus, in the XV century, these ports increased the import of timber from other ports with which trade ties had already been developed, namely from Galicia, Vizcaya, France, Flanders and England (DEVY-VARETA, 1986).

Recordid	4628196
Date	2-5-1587
Passage#	0
Shipmaster	Hennrickh Boemgardt from Wismer
Section:	Skriver og Tøndepenge, Wendische
Register:	Indtægt (Morten Jensen) 1587 5 1 - Indtægt (Morten Jensen) 1588 5 1
Tonnage	
Cargo	

Depart.	Dest.	Amount	Unit	Commodity	Toll	Toll (num)
1. Wismer	Liisebonn	-	-	Deller		
				Skriver og Tøndepenge	+ Da	0.5 Da

Figure 2. Registration of the vessel from Wismar (Wismer, Germany) to Lisbon (*Liisebonn*) carrying wood (*deller*) in the year 1587 (SOURCE: STR online, accessed on 11.06.2020).

Recordid	4473190
Date	24-9-1596
Passage#	0
Shipmaster	Willum Franndttssen from Memelinch
Section:	Skibstold, Nederlendere etc., Østen aff
Register:	Indtægt og udgift (Morten Jensen) 1596
Tonnage	
Cargo	

Depart.	Dest.	Amount	Unit	Commodity	Toll	Toll (num)
1. Dannschenn	-	-	-	-		
2. Dannschenn	Lyssebon	-	-	Gotz		
				Tøndepenge Leftside	+ Da	0.5 Da
				Under 100 lester	ii Ro i Da	2 Ro 1 Da
				Skibstold	i Ro i Da	1 Ro 1 Da

Figure 3. Registration of the vessel from Gdansk (*Dannschenn*, Polónia) to Lisbon (*Lyssebon*) carrying ship's wood (*skibstold*) in the year 1956 (SOURCE: STR online, accessed on 11.06.2020).

Date	Shipmaster	Place	Departure - Destination	Commodity
26-12-1672	Hanss Krussen	Københaufen	Københaufen - Lisabon	Eege plancker
27-6-1673	Jacob Wielcke	Lubeck	Dantzig - Lisabon	Ege plancker
21-7-1673	Herman Mau	Liubech	Rigga - Lisbon	Ege plancher
21-11-1673	Gouerdt Walterssdorf	Liubech	Dannsig - Lisbon	Ege plancher
9-1-1674	Hanns Krusse	Københ.	Eckellnfør - Lissbonn	Egge plancher
12-11-1675	Tommes Willemssen	Lunden	Kønssberg - Lisbonn	Ege plancker
10-4-1676	Daniel Pape	Liubech	Liubech - Lissbonn	Egge plancher
3-8-1676	Hanns Sager	Liubech	Kønissberg - Lissbonn	Egge plancher
20-11-1683	Hendrich Dereck	Dantzich	Dantzich - Liissabon	Ege planker a 1 Dr.
13-8-1684	Jan Janssen Beurt	Amster.	Dantzig - Lissabon	Ege plancker
2-5-1690	Hendrich Doeck	Dantzig	Dantzig och Lebo - Lisabon	Ege plancker a 1 Dr
5-5-1690	Adrian Jansen Kessels	Vlie.	Leba - Lissabon	Eege plancker
22-5-1690	Jacob Isbrandsen	Vliel.	Dantzig og siden fra Leba - Lyssebon	Eege plancker a 1 Dr
22-9-1690	Johan Blan	Amster.	Riiga - Lisabon	Ege plancker
7-10-1690	Christian Otto	Dantzig	Dantzig - Lyssebon	Eege plancker
8-10-1690	Willem Jansen Swemmer	Elbingen	Narva - Lyssebon	Eege plancker
26-12-1690	Caspar Wichman	Dantzig	Dantzig - Lyssebon	Eege plancker a 1 Dr
20-3-1691	Willem Doeck	Dantzig	Dantzig - Lisabon	Eege plancker a 1 Dr.
9-4-1691	Hendrick Albertsen	Dantzig	Dantzig - Lissabon	Eege plancker a 1. Ort
8-8-1691	Anthon Elmers	Putzig	Leba - Lissabon	Eege plancker a 1 Dr
30-8-1691	Willem Janssen Swemmer	Elbing	Riga - Lisabon	Ege plancker a 1 Dr.
4-9-1691	Jochumb Høss	Dantzig	Dantzig - Lisabon	Egge plancker a 1/2 Ort
15-10-1691	Boye Jansen	Pernau	Riga - Lissabon	Eege plancker
8-9-1692	Frands Wugand	Kiøbenhafn	Dantzig - Lissabon	Eege plancker a 1 Dr.
14-3-1693	Charle Francois Roderigo	Genua	Dantzig - Lisabon	Ege plancker

Figure 4. Registration of the vessel from Hansa towns to Lisbon (*Lisabon/Lisbon/Lissbon/Lissabon/ Lyssebon/*) carrying oak planks (*Eege plancker*), from 1672 to 1693 (SOURCE: STR online, accessed on 11.06.2020).

1.2. XVIII and XIX centuries

To analyze the Portuguese wood trade flows in the XVIII and XIX centuries, a customs system approach is required. However, the occurrence of successive customs systems and reforms makes this study overly complex. *PAÇO DA MADEIRA* was a Portuguese government agency directed to wood and other trades between Portugal and the rest of the world. In 1644, the first Rules of Procedures were signed, determining that timber and other commodities should only be discharged at certain locations. The entire movement of incoming and outgoing goods and the regulated sales and chartering of vessels were specified by the order of King João IV (PAÇO DA MADEIRA [PM], 1695)):

> "*As madeiras, mais fazendas que pertencem à dita Caza, e nella pagarão os direytos da dizima e siza por entrada são os seguintes (…) Todo o Taboado qie uier de fora do Reyno, e das Ilhas, ou de outra qual quer parte que venha à esta Cidade por mar, ou por Terra*[2]"
>
> (*"Traslado autêntico do foral e regimento do Paço da Madeira de 1694",* CAP. 6. *Das fazendas que pertencem ao Paço da Madeyra)*

> *"E porque muitas vezes acontece q̅ os Navios que uem com fruita seca e uerde, ou outras couzas q̅ pertencem ao Paço da Madeyra vinde fretados para esta Cidade, entrão em o porto de Setuval ou em outros portos por razão de suas comodidades, e mandão alguãs das ditas mercadorias à esta dita Cidade por terra: Hey por bem, e mando que todas a fruita seca e uerde, de madeiras, e outras quaes quer couzas (…) paguem na dita Caza os direitos de dizima e siza (…)*[3]*"*
>
> (*"Traslado autêntico do foral e regimento do Paço da Madeira de 1694",* CAP. 8. *Das couzas que pertencem ao Paço da Madeira que uierem de outras partes por Terra)*

In addition to these two taxes, a third tax was created after the 1755 Lisbon earthquake by the Royal Decree of 2sd January 1756. Lisbon's rebuilding was carried out in part by the 4% donation on manufactured goods. The *siza* and donation were collected in cash and the tithe in kind.

During the successive customs reforms, by order of King José I, a new institution was established in 1774 - *Contadoria da Superintendência Geral dos Contrabandos, e Descaminhos dos Reaes Direitos* (General Superintendence Accounting of Smuggling and Embezzlement of Royal Rights). The major goal was to develop a new yearly register scheme for Portuguese commerce and to identify the Empire's resources. There was an interruption in customs reports due to the Portuguese civil war between 1828 and 1834, known as Liberal Wars, and the latest records from the 1840s revealed a distinct data structure (MOREIRA, 2015).

The handwritten customs documents of two governmental institutions with distinct compilations (*PAÇO DA MADEIRA* and *JUNTA DO COMÉRCIO* [JC]), the STR online archive, as well as the periodical publications GAZETA DE LISBOA (1758, 4th October 1816) and CORREIO MERCANTIL E ECONÓMICO DE PORTUGAL (1794, 1798) are the most noteworthy historical references that support and describe

[2] Author's free translation: "The timber, as well as supplies belonging to the Caza, on which the tithes and fees will be charged by arrival, are as follows: (…) *all wood planks that come from outside the Kingdom, and from the Islands, or from any part that comes to this City by sea or by land."*

[3] Author's free translation: *"And because it often happens that the ships that come chartered to this city [Lisbon] with dried and green fruit, or other things that belong to the Paço da Madeyra, enter the port of Setubal or other ports because of their facilities, and send some of the merchandise to this city by land: I order that all dried and green fruit, wood, and any other things (...) pay in the said Caza the duties of tithe and siza.*"

the type of goods exchanged between Portugal and Europe in the XVIII century. The data cannot be directly compared since the relevant documented sources differ in terms of dates and units of study. Such details should therefore be used further to contextualize each European country in the XVIII century map of Portuguese imports, deliberately excluding the Portuguese territories.

The analysed historical economic series do not always reflect the total truth of trade flows (MOREIRA, 2006). In the case of the *JUNTA DO COMÉRCIO* registry, products were classified into different categories, but the parameters were not consistent, as the item could be classified differently (MOREIRA, 2015). Some other factors contributed to the inaccuracy of the customs data, particularly transcription lapses, political strategy problems, smuggling, misrepresentations of incompetence or fraud, the absence of an annual analysis by customs officials of official figures and, as a major mistake, the geographical distribution information, i.e., the origin and final destination of the products (MOREIRA, 2006). In the case of the historical documents relating to *PAÇO DA MADEIRA* (PM, 1695), the possible mismatch between the registered details and the reality of the commercial flows could also derive from the stipulated laws. Paying of duty on imported goods was not the same for all, with certain citizens receiving benefits, including exemption, therefore hindering the real review of customs documents. In the other hand, customs fees and exemptions were based on "questionable" oaths and obligations on the destination of the goods, which may have skewed the truth of the trade balance. Despite the uncertainty surrounding the exact scale of trade flows, the details found in the economic series are complemented by other documentary sources and constitute the starting point for this comparative study of the XVIII century timber trade. The description of "wood" is based on the different definitions described, including "wood", "planks", "beams", "masts", "staves", "Nordic pine planks", "Flanders pine" and "oak".

At the end of the XVIII century, according to customs reports (JC, 1796, 1797, 1799), the type 'wood' accounted for 2.7% of the total value of Portuguese imports, with a declining trend in the first third of the following century (MOREIRA, 2006). However, “wood and boards” were both listed as “timber” and “several genera”, assuming that comparative evidence on the importation of this sort of product were undervalued.

According to STR online, in the XVII century, a quarter of all ships from the Baltic Sea and the North Sea to Portugal brought timber and woodwork (Table 1). Trade was not consistent during the year, becoming more intense throughout the period from May to December (Figure 5). Weather conditions were the primary explanation for this seasonality, with navigation avoiding the more stringent winter months (ELORANTA *et al.*, 2015). Throughout the century, the import of timber on this sea route shows a rising pattern (Figure 6). Considering the three major Portuguese ports with customs registers spanning the entire century (Lisbon, Oporto and Setúbal), and also including the general description "Portugal", it is noted that in the first third of the XVIII century, only 3% of the vessels bore wood. The average annual increase in the number of vessels with wood was 22.5%, much higher than the increase in the total number of vessels (7.3%).

The Baltic region, Russia, England, Denmark, the Netherlands, and Italy were the most common sources of timber landed in Portugal (PM, 1771, 1772, 1774-1776; JC, 1796, 1797, 1799). The cities of Stockholm (Sweden), Riga (Latvia), Västervik (Sweden) and Dantzig (Poland) stand out in a more detailed study of the sources of ships from the Baltic Sea and the North Sea to Portugal for wood transport (Table 1). In the XVIII century, Sweden distinguished itself as the leading source of wood and timber from Northern Europe, with 74% of all vessels landing in Portugal leaving from 14 Swedish ports. Stockholm stands out as the largest shipping port for all active Portuguese ports. According to MOREIRA (2015), a significant bilateral commercial relationship was established between Portugal and Sweden, with four categories of items generating a greater quantity of exports to Sweden: tar, timber, salt, and wine.

Table 1. Wood trade to Portugal from northern Europe and the main sources in the XVIII century. "Portugal" is the word in the manuscripts, not specifying the harbour of destination (SOURCE: STR online, accessed on 03.03.2018).

PORTUGUESE HARBOUR OF DESTINATION	PERIOD OF CUSTOMS RECORDS	NO. OF TOTAL VESSELS	VESSELS WITH WOOD		
			NUMBER	%	MAIN HARBOUR OF DEPARTURE
Aveiro	[1765-1799]	81	67	82.7	Stockholm [95%] Others (4) [5%]
Faro	[1712-1799]	15	3	20.0	Lubeck, Memel and Wyborg
Figueira da Foz	[1752-1799]	438	41	9.4	Stockholm [78%] Pärnu [10%] Memel [6%] Danzig [3%] Riga [3%]
Lisbon	[1700-1799]	5.465	1.424	26.1	Stockholm [49%] Riga [9%] Västervik [6%] Dantzig [5%] Copenhagen [3%] Kalmar [3%] Abo [3%] Others (22) [22%]
Oporto	[1700-1799]	2.403	391	16.3	Stockholm [66%] Riga [17%] St. Petersborg [6%] Memel [2%] Pärnu [2%] Others (14) [7%]
"*Portugal*"	[1700-1799]	351	211	60.1	Stockholm [91%] Gävle [2%] Others (9) [7%]
Setúbal	[1700-1799]	395	122	30.9	Stockholm [35%] Karlskrona [13%] Västervik [7%] Kalmar [6%] Abo [5%] Carlshafn [5%] Friedrichshafen [3%] Gävle [3%] Others (16) [23%]
Viana do Castelo	[1725-1799]	76	58	76.3	Stockholm [96%] Kønigsberg [2%] Landskrona [2%]
Vila do Conde	[1775-1799]	28	28	100.0	Stockholm [96%] Gävle [4%]
Total	-	9.252	2.345	25.3	Stockholm [58%] Riga [9%] Västervik [4%] Dantzig [4%] St. Petersborg [2%] Memel [2%] Kalmar [2%] Abo [2%] Karlskrona [2%] Copenhagen [2%] Gävle [2%] Nordkiøping [2%] Others (40) [10%]

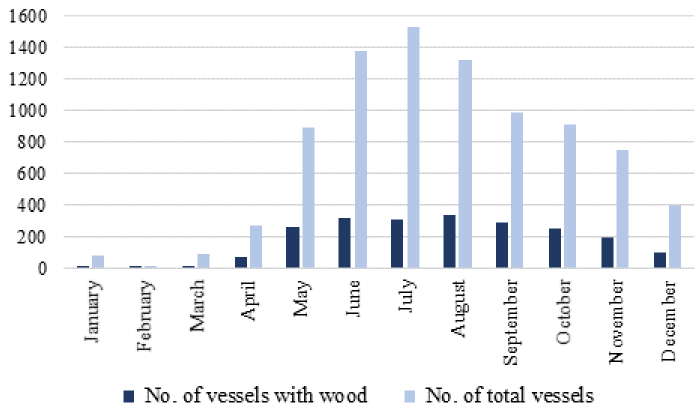

Figure 5. Shipping throughout the year from the Baltic region to Portugal (harbour of destination: Lisbon, Oporto, Setúbal and "Portugal") in the XVIII century (SOURCE: STR online, accessed on 03.03.2018).

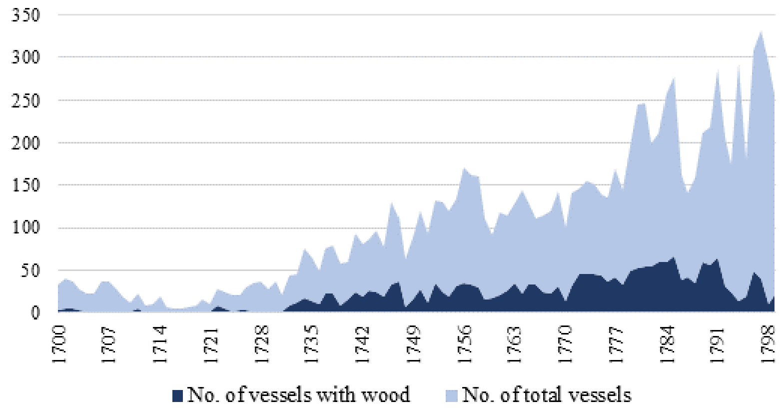

Figure 6. Shipping from the Baltic region to Portugal (harbour of destination: Lisbon, Oporto, Setúbal and "Portugal") in the XVIII century (SOURCE: STR online, accessed on 03.03.2018).

A more detailed quantitative examination of the timber trade between Portugal and the rest of Europe, especially England, France, Spain, and the Mediterranean region, as well as North America, provides interesting information. England was Portugal's primary supplier nation, accounting for 40% of total imports (Figure 7), with the main commodities being "woollen" (51%), "groceries" (28%), and "woods" accounting for only 0.5%. The Netherlands and Italy contributed 6.4% and 5.6% of overall imports, respectively (Figure 7), but the kind of commodities supplied varied: "groceries" (55%), "metals" (16%) and "linen products" (15%) came from the Netherlands, with minimal imports of wood products (0.4%). The major imports from the Mediterranean, restricted to Italy, from the ports of Liorne, Naples, Trieste and Venice were "silks" (62%), followed by "different goods" (18%), which included paper, fur, pearls, gloves, and books, and minimal imports of "wood" (1.6%).

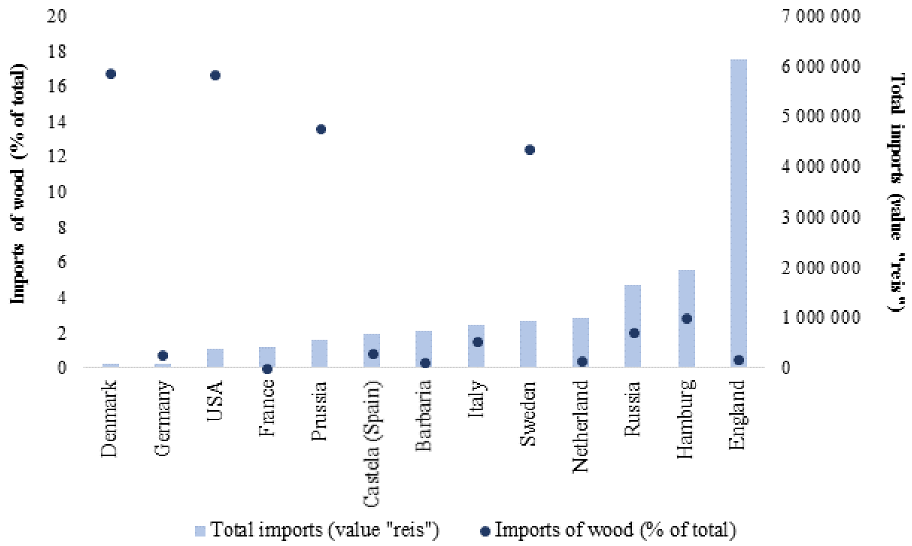

Figure 7. European imports to Portugal in 1796, 1797 and 1799 and their respective contribution from wood imports (SOURCE: JC, 1796, 1797, 1799).

Historical data on timber imports from Italy from the XVIII and XIX centuries is also gathered through 4 % donation customs payment records, which indicate numerous ports of origin and timber or planks as a commodity (Table 2). As shown in the section on Italian news in the Portuguese publication GAZETA DE LISBOA, exact information is occasionally provided.

"Veneza 30 de Junho ... O nosso Arsenal e os nossos Estaleiros se enchem de madeira, ferro e cânhamo (…)[4]"

(GAZETA DE LISBOA, 1816 August 3)

Table 2. Wood imported from Italy to Lisbon between 1771 and 1776 according to Customs payment records of 4% donation (SOURCE: PM, 1771, 1772, 1774-1776)).

YEAR	VESSEL NATION	ORIGIN	GOODS	
			PORTUGUESE	ENGLISH TRANSLATION
1771	London	Italy	*"taboado"*	planks
1771	Netherland	Liorne	*"estiva[5] de taboas"*	(…) planks
1772	England	Genoa	*"uma estiva de taboas a entregar a Ruseu (??) e Compª"*	(…) planks to be delivered to *Ruseu (??)* and Company
1772	England	Genoa	*uma estiva de taboas e pedaços*	Planks and wood pieces
1772	England	Genoa	*uma estiva de taboas e de trigo a entregar a Nicolau Joze Neco*	(…) planks and wheat to be delivered to *Nicolau Joze Neco*
1772	England	Palermo	*barrotes, taboas, páos … a entregar a Mad^as Brandeburgo*	beams, planks and wooden sticks … to be delivered to *Mad^as Brandeburgo*
1776	Sicily	Sicily	*200 duzias de tabuado*	200 dozens of planks

[4] Author's free translation: "*Venice 30 June ... Our Arsenal and our shipyards fill up with wood, iron and hemp*."
[5] *Estiva* means the weight or quantity of goods to be verified at the customs [in Dicionário infopédia da Língua Portuguesa. Porto: Porto Editora, 2003-2021. [Accessed on 2021-04-26]. Available on internet: https://www.infopedia.pt/dicionarios/lingua-portuguesa/estiva].

2. WOOD FOR SUPPORTS FOR PAINTINGS AND MUSICAL INSTRUMENTS IN EUROPE FROM THE XV TO XVIII CENTURIES

2.1. Wood panels from the XV and XVI centuries

2.1.1. Manufacture of wooden supports for Flemish and Portuguese panels

Flemish woodworking for art production was structured in a guild (or corporation) during the XV and XVI centuries, but the concept of tasks among the various crafts varied from city to city (WADUM, 1998; VEROUGSTRAETE, 2015). In general, most of the wooden supports for the panels were made by the joiners, while carpenters and woodcarvers were also authorized to do so (VEROUGSTRAETE, 2015). Usually, the joiners and carpenters purchased the wood themselves and chose it according to the particular qualities required by the final work. Whenever necessary, sawmills cut wood to size and, according to historical sources, timber trade recognized the feature of the boards "to be painted" (VEROUGSTRAETE, 2015). The wood for the panel and the frame, however, did not actually derive from the same source. For incorporation into the structure of the frame, the best performance of the painting panel involved a series of assembly rules to prevent the opening of the board joints and the cracking of the wood (VEROUGSTRAETE, 2015).

In the manuscript *Livro dos Regimentos dos offiçiaes mecanicos da mui excelente e Sempre leal Cidade de lixbona refromados per ordenança do Illustrissimo Senado della pello Licenciado Duarte nunez do liam Anno MDLxxij*, from Duarte Nunes de Leão, compiled in 1572 and edited by CORREIA (1926), the model of craftsmanship organization maintained in Portugal since the Middle Ages is presented. This document, which is a compilation of handwritten regulations from the sixteenth century that have been amended throughout the centuries, provides for the identification of mechanical crafts work in Portugal, as well as the principles that determined their procedures. The organizational culture of the craft corporations was characterized by the control of the workday, the number of apprentices, the opening of new workshops, the regulation of the quality and quantity of the works, and the specialization of production (MATTA, 2013). The career path was defined by each mechanical craft work community, beginning as an apprentice, followed by an official, until reaching the status of master caretaker of confidential information and holder of recognized knowledge and practices (MATTA, 2013). The performance of one or more specific tasks for the examination of each mechanical crafts work was generally determined by the *Livro dos Regimentos dos Oficiaes mecanicos* and detailed at the time of the examination by the judge. BRANDÃO (2016) presupposed the presence of a set of sketches that would have to be copied by the apprentice, since the manuscript explicitly references them even though they are not currently attached to the original in the Municipal Archive of Lisbon. The distinction between the regiments of painters, which included oil painters, and cabinet makers, which included assemblers, is evident in this historical record. The narrative of the exams to practise as an ensemble maker and painter is extremely helpful since it offers information about the field of specialty, as well as information about access to wood to produce a painting panel. BORGES and UCHA (2007) and OLIVEIRA (2007) also presented some specifics on the practices and materials used in the context of regional artistic production centres in northern Portugal from the last quarter of the XVI century to the end of the XVIII century. According to CASIMIRO (2007), the mobility of Portuguese or Portuguese-Flemish artists in the early XVI century was a process of creating and disseminating artistic and scientific knowledge, holding Portugal, despite its periphery, up to date with scientific knowledge occurring in civilised Europe.

The most traditional practices in the manufacturing of wooden supports can be examined during a dendrochronological analysis. The rules applied in Flemish and Portuguese panels concerning the choice of wooden boards, their width and thickness as well as the placement of the board are set out in detail below.

- ♦ Boards selection

In selecting oak boards for a panel, density and wood grain are essential quality parameters (FRAITURE, 2011; VEROUGSTRAETE, 2015). A slow and regularly grown wood (Figure 8A) is better for the support of the panel because the wood is less thick and more stable in response to changes in temperature and humidity and therefore less vulnerable to shrinkage (FRAITURE, 2011, 2012; VEROUGSTRAETE, 2015). The wood produced by a fast-growing oak is more likely to warp since it is much denser than that of a slow-growing oak (Figure 8B) (FRAITURE, 2012).

On a full radial (or full quarter) oak plank, the medullar rays are visible throughout the whole width, offering high-quality planks (WADUM, 1998). Some authors also consider them to be the highest performing boards because the chances of wood breaking under environmental conditions are reduced (FRAITURE, 2011; VEROUGSTRAETE, 2015). In the radial (or quarter) cut, the medullar rays are visualized with a slight slope at an angle of less than 45°. The cut is classified as semi-radial (or false quarter) if the angle of the medullar rays is greater than 45° (FRAITURE, 2011) (Figure 9).

Figure 8. Transverse section of oak boards from *Mater Misericordiae*, NMCPSMS, assigned to the Portuguese painter Gregório Lopes: **[A]** with slow and regular growth; **[B]** with fast and irregular growth; and **[C]** including the first growth rings near to the pith (SOURCE: CEF-ISA unpublished).

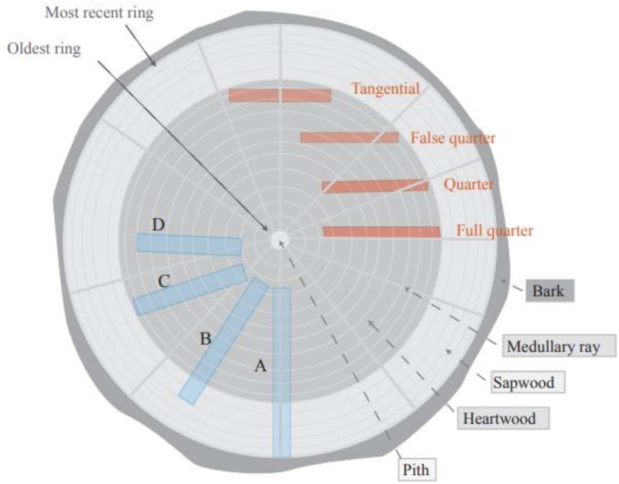

Figure 9. Transverse section diagram of an oak wood trunk. Red rectangles represent the different possible cutting directions of the boards. Blue rectangles represent the different cutting options of the boards according to/without sapwood and/or heartwood removal: **[A]** board with complete sapwood; **[B]** board with partial sapwood; **[C]** board without only sapwood; and **[D]** board without sapwood, as well as some heartwood rings (SOURCE: FRAITURE, 2011).

In the XVII century, the quality selection of wood for panel support shifted in the Flemish workshops. According to DUBOIS and FRAITURE (2011), an analysis focused on more than 350 panels from the mid-XV to mid-XVII century showed the felling of slightly poorer quality trees from the end of the XVI century onwards. Tangential cut boards were found in panels painted by renowned artists, including Rubens.

The pith and the sapwood are parts of the wood that are not ideal for quality support because they are vulnerable to deformation and rot (FRAITURE, 2011; VEROUGSTRAETE, 2015). For this reason, the regulations on their elimination have been well established (VANDEKERCHOVE *et al.*, 2009; VEROUGSTRAETE, 2015) (Figure 8C) in spite of exceptions found in many Flemish (FRAITURE, 2012) and Portuguese panels. Figure 9 also demonstrates the cutting options of the boards in relation to the addition or removal of sapwood and heartwood.

A lighter coloured region, not usually visible in the cross-section, can be visualized at the back of the panels. This may result from a wood growth phenomenon referred to as a *moonring*, consisting of a group of sapwood type light rings surrounding the central heartwood (CHARRIER *et al.*, 1995; WADUM, 1998). Although these rings are sometimes described as including sapwood, they have unique properties, notably better resistance to fungal attack, more like heartwood. This defect is believed to occur when the development of heartwood is disrupted by a tree trauma, such as extreme cold or frost (CHARRIER *et al.*, 1995; WADUM, 1998), and has been found in Central European oak trees (CHARRIER *et al.*, 1995). SANTOS (2012) reported *moonrings* on the back of the *Santa Clara* panel, attributed to Francisco João of Paço Episcopal de Évora, but studies on this type of anomaly in Portuguese panels are scarce.

- Boards' width and thickness

The width of the boards will necessarily depend on the diameter of the oak tree, and the removal of sapwood/heartwood carried out. The width of the boards was variable, but usually ranged between 25 and 29 cm, according to WADUM (1998). DUBOIS and FRAITURE (2011) showed that Baltic board widths have been progressively and steadily decreased, because of the felling of smaller trees.

Boards of various thicknesses were joined and flattened on the back, but there are instances where the thickness of the boards is not aligned (WADUM, 1998). The thickness of the boards ranges between 8 and 30 mm, according to the source, but there was a declining tendency from the XV and XVI centuries onwards. In the first half of the XVI century, boards with a thickness of more than 25 mm accounted for nearly 60% of the overall, which declined to almost 40% in the second half of the century. Conversely, boards with a thickness between 15 and 25 mm rose from 30% to nearly 45% over the same period of analysis.

Figures 10 and 11 summarize two research works on the XVI century Portuguese panel oak supports regarding the thickness and width of the boards, respectively. The average thickness and width of 26 and 27 panels from the same workshop were analysed by SANTOS (2012), respectively. The second research study was focused on dendrochronological studies produced in the last decade by CEF-ISA, out of a total of 156 panels examined in 73 Portuguese panels from distinct XVI century workshops. Even if it is not appropriate to carry out a comparative study of the two investigations since the initial assumptions vary, including the time scale and the sources of one or more workshops, it can be checked that the dimensions are in accordance with the reference values set out in the literature of the Flemish panels.

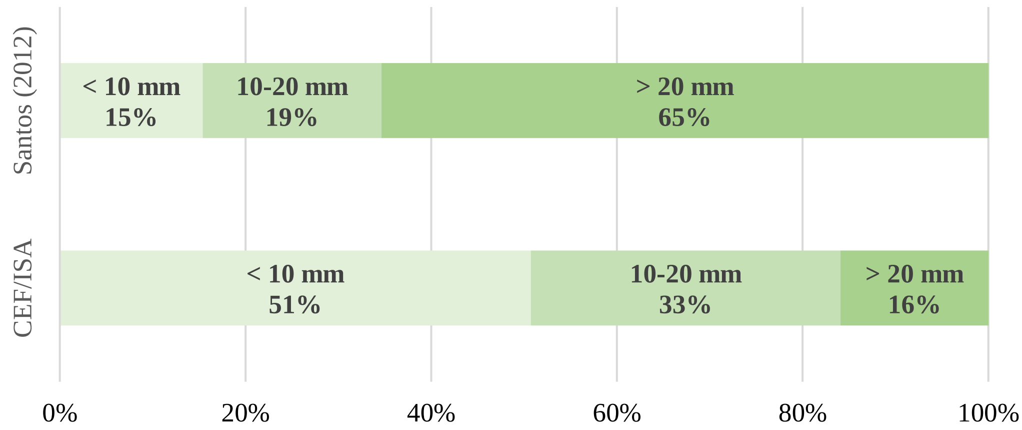

Figure 10. Thickness of boards from Portuguese panels of the XVI century according to two research works (SOURCES: CEF-ISA unpublished; SANTOS, 2012).

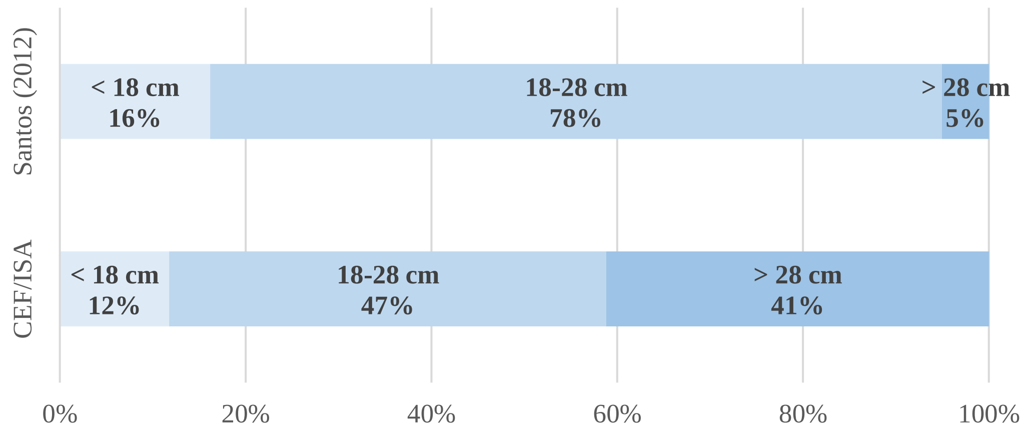

Figure 11. Width of boards from Portuguese panels of the XVI century according to two research works (SOURCES: CEF-ISA unpublished; SANTOS, 2012).

The research undertaken by CEF-ISA confirmed that some of the panels belonging to the *Paraíso* altarpiece, attributed to Gregório Lopes's workshop, had many boards wider than 30 cm, with a maximum of 38.5 cm on the *Natividade* painting. In several artworks, boards with widths greater than 30 cm wide were also found, namely in: **(1)** Frey Carlos's workshop, precisely *S. Francisco recebendo os estigmas, Assunção da Virgem and Ascensão de Cristo* painting (CEF-ISAunpublished); **(2)** in Giraldo do Prado's workshop, namely *Adoração dos Reis Magos* and *Circuncisão do Menino Jesus* belong to

Retábulo-Mor da Igreja da Misericórdia de Almada paintings (LAUW *et al.*, 2014); and **(3)** in João Francisco' workshop (SANTOS, 2012).

- Boards' positioning: width

In Flemish workshops, a narrow board was preferably placed in the center of the support. In this way, the panel makers avoided positioning the boards joints near to the frame, since the tension produced by it could be harmful (VEROUGSTRAETE, 2015). The ability to use larger panels in the panel's center region, on the other hand, was intended to avoid putting joints in the most essential area of artistic composition, reducing the risk of cracks in the panel's central area (WADUM, 1998; DUNKERTON *et al.*, 1999). CRUZ *et al.* (2020) described the implementation of this criteria for the assembly of the board in two panels attributed to Belchior de Matos's workshop. There are also a few individual cases in other panels of Portuguese workshops (ESTEVES and KLEIN, 1999; LAUW *et al.*, 2014), but it cannot be inferred that this is the rule of assembly of the supports.

- Boards' positioning: vertical *versus* horizontal

In Flemish workshops, several panels are arranged vertically, i.e., aligned on the long side. The goal of this method was to reduce the number of boards and to spread the pressure caused by the weight of the paint evenly over all boards, rather than concentrating it on the bottom boards if the structure was horizontal (DUNKERTON *et al.*, 1999).

Dendrochronological research carried out by IJF-DGPC and CEF-ISA during the last decades and conservation and preservation studies on Portuguese panels have verified that most panels are vertically placed. In general, the horizontal panels lead to the altarpieces' predellas (e.g., *Paraíso* altarpiece attributed to Gregório Lopes (CEF-ISA unpublished) and Francisco João workshops (SANTOS, 2012)). However, exceptions have been found in some Portuguese painters who have introduced both approaches: Gregório Lopes' workshop (ESTEVES and KLEIN, 1999; LAUW *et al.*, 2013; LAUW *et al.*, 2014; ANTUNES *et al.*, 2016) and Francisco João's workshop (SANTOS, 2012).

- Boards' positioning: grain

In Flemish workshops, several panels have grain parallel to their length and all panels have the same grain direction. However, certain panels in Rubens' studio exhibit grain boards running perpendicular to one other, resulting in an artwork that is very vulnerable to unpredictable environmental conditions (BAUCH *et al.*, 1978; WADUM, 1998).

Dendrochronological studies performed by IJF-DGPC and CEF-ISA have shown that Portuguese workshops have applied this rule although exceptions have been identified: **(1)** in the *Mater Misericordiae* panel, assigned to Gregório Lopes, on the exhibition at the Núcleo Museológico da Capela do Espírito Santo dos Mareantes de Sesimbra (Figure 12); and **(2)** in the *Assunção da Virgem* panel, attributed to Francisco João, from Igreja Matriz de Santo Estêvão, with eleven panels mounted vertically and two horizontally (SANTOS, 2012).

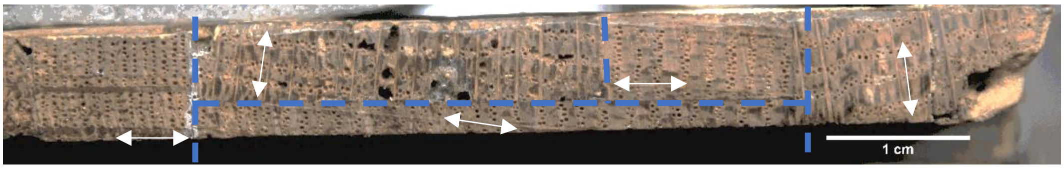

Figure 12. Transverse section of oak boards from *Mater Misericordiae*, NMCPSMS, assigned to Portuguese painter Gregório Lopes. White arrow indicates grain direction; dashed blue indicates the joining of boards in the panel (SOURCE: CEF-ISA unpublished).

- ♦ Boards' positioning: edge

In Flemish workshops, the traditional rule was to match the outer edges of the panel with the oldest rings, referring to the most stable and durable wood (WADUM, 1998; VANDEKERCHOVE *et al.*, 2009; VEROUGSTRAETE, 2015). Several dendrochronological studies performed by IJF-DGPC and CEF-ISA have found this technique in the Portuguese panels. There are exceptions, however, both in Flemish and Portuguese workshops (ESTEVES and KLEIN, 1999; LAUW *et al.*, 2014). Figure 13 shows compliance and non-compliance with the rule at two edges of the same panel.

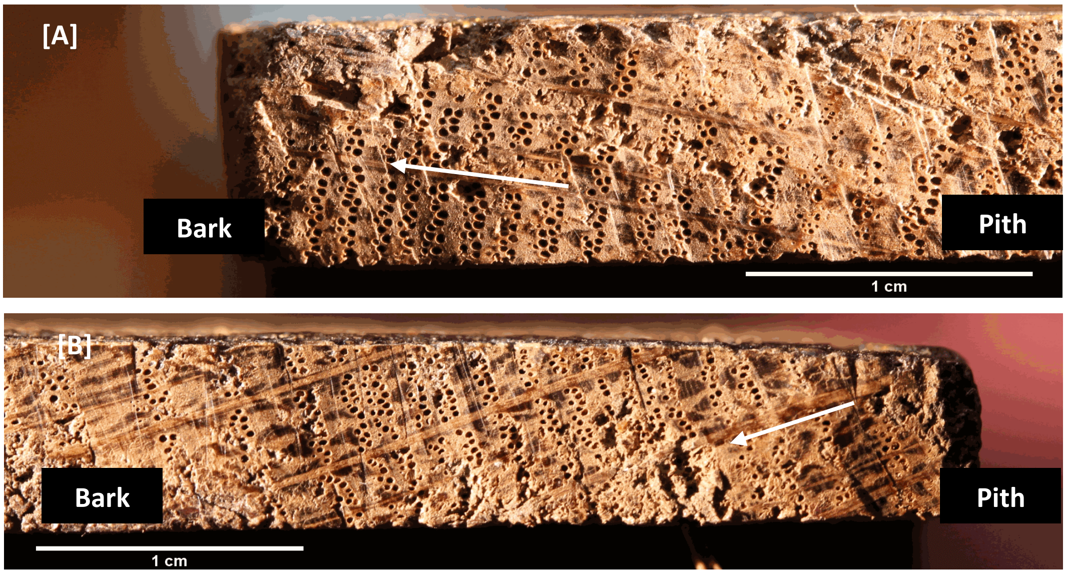

Figure 13. Transverse section of oak boards from the *Presépio* panel (inventory number MS-CJ3-PR3), attribute to the Portuguese painter Jorge Afonso: **[A]** non-compliance with the rule, with earlier tree-rings at the edge; and **[B]** compliance with the rule, with older tree-rings at the edge. White arrow indicates the direction of wood growth [The white arrow indicates the direction of growth] (SOURCE: CEF-ISA unpublished).

- Boards from the same tree

It was not rare in Flemish workshops to use boards of the same tree in the same or in many artworks (BAUCH, 1978; FRAITURE, 2011). The goal was to promote the composition of boards of the same size and to use wooden elements with similar behaviour to external influences (FRAITURE 2011, 2012; VEROUGSTRAETE, 2015). The use of these criteria for board assembly in Portuguese workshops has been demonstrated in various research workshops – António Nogueira (IJF-DGPC unpublished), Belchior de Matos (CRUZ *et al.*, 2020), Duarte Frisão (KLEIN and ESTEVES, 2001), Giraldo do Prado (LAUW *et al.*, 2014), Gregório Lopes (ESTEVES and KLEIN, 1999; KLEIN and ESTEVES, 2001; LAUW *et al.*, 2014), Jose de Escovar (KLEIN and ESTEVES, 2001), Mestres do Sardoal (CEF-ISA unpublished) and unknown attributions (LAUW *et al.*, 2014; CEF-ISA and IJF-DGPC unpublished).

In certain cases, a symmetry criterion can be found in triptychs with wing panels belonging to the same tree (VEROUGSTRAETE, 2015) and in panels with extreme side boards belonging to the same tree (KLEIN, 1996; 2007c; 2008a; 2010a; 2010c).

2.1.2. Wood boards in Flemish panels

Wood panels have been a traditional support for artistic panels over the centuries. The wood species used in panels from the XV and XVI centuries vary from one European school to another. The woods used by the painters corresponded primarily to their supply from local forests until the end of the XVI century (MARETTE, 1961), although some dendrochronological analyses have shown that imported wood was used by various schools (WADUM, 1998; VEROUGSTRAETE, 2015).

From the XV to XVII centuries, the support panels used by the Flemish school were mostly made of oak wooden boards (MARETTE, 1961; BAUCH and ECKSTEIN, 1970; BAUCH *et al.*, 1978; KLEIN, 1986, 1991, 1994a, 1994b, 1996, 1997, 1998a, 1998b, 2006, 2007b, 2008b, 2007c, 2010a, 2010b; CAMPBELL and FOISTER, 1997; WADUM 1998; FRAITURE, 2002, 2011, 2012; JASMAN *et al.*, 2004; LÄÄNELAID and NURKSE, 2006; HANECA *et al.*, 2009; VANDEKERCHOVE, *et al.*, 2009; WAZNY, 2011; VEROUGSTRAETE, 2015; HELAMA *et al.*, 2016), but exceptions were found in Flemish panels: fir (Abies sp.), a wood species used in the Netherlands for ship masts (KLEIN, 1994b), pear tree (KLEIN, 1998a), beech, poplar and walnut (BAUCH and ECKSTEIN, 1981). The Dutch and Flemish painters used Baltic oak wood until the first half of the XVII century (see subchapter 3.7.1. *Dendroprovenance: the oak panels*). As a result of the Second Swedish-Polish War (1655-1660), which resulted in a complete breakdown of the Hansa trade, Baltic wood was not identified in panels after 1650 (KLEIN, 1998b).

Alternatively, the choice returned to canvas (ECKSTEIN and WROBEL, 2007) or oak trees from western and southern Germany and the Netherlands (BAUCH and ECKSTEIN, 1981; KLEIN, 1998b; JANSMA *et al.*, 2004; ECKSTEIN and WROBEL, 2007; SLOTSGAARD, 2011), as well as to tropical timber (BAUCH and ECKSTEIN, 1981; KLEIN, 1998b). In panels from Rembrandt's studio, dated between 1633 and 1654, BAUCH *et al.* (1981) described different tropical species introduced from Central and South America.

The German School shows further variety in the choice of wood types, while most of the panels were made of oak (*Quercus* sp.) supports (CAMPBELL and FOISTER, 1997; WADUM, 1998; HANECA *et al.*, 2009). Beech (*Fagus* sp.), lime (*Tilia* sp.), spruce (*Picea* sp.) and other softwoods are also found (MARETTE, 1961; KLEIN and BAUCH, 1981; KLEIN, 1994b, 1998b, 1999, 2007a; CAMPBELL and FOISTER, 1997). Beech boards were identified almost exclusively in Lucas Cranach panels, the Elder's workshop for a brief period (1520-1535) (KLEIN, 1996; 1999). Interestingly, panels on woods other than oak were developed in Southern Germany and Austria (CAMPBELL and FOISTER, 1997).

The most common wood support for panels was poplar (*Populus* sp.) at the Italian School (MARETTE, 1961; CAMPBELL and FOISTER, 1997; BRUZZONE and GALASSI, 2011). However, several other species have been described in the Italian panels: chestnut (*Castanea sativa* Gaertn.), cypress (*Cupressus sempervirens* L.), lime (*Tilia* sp.), pine (*Pinus* sp.), Rosaceae family, spruce (*Picea abies* Karst.) and walnut (*Juglans regia* L.) (BERNABEI *et al.*, 2007; BRUZZONE and GALASSI, 2011). Other species have also been reported, such as alders (*Alnus* sp.), beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.), plane (*Platanus orientalis* L.), silver fir (*Abies alba* Mill.), yew (*Taxus baccata* L.) and willow (*Salix* sp.) (KLEIN, 2007b, 2010b ; BRUZZONE and GALASSI, 2011). Based on the wood anatomical identification from about 500 panels and on historical records, BRUZZONE and GALASSI (2011) hypothesized that the choice of a type of wood was not strictly linked to an artist, workshop, or school, or influenced by artistic standards, but was instead linked to the local availability of wood.

National wood types were used as supporting panels in the Spanish School, according to historical records: black pine (*Pinus nigra* L.) (GALÁN, 2006; LARROSA and MELER, 2015), cypress, elm (*Ulmus* sp.) and lime (*Tilia* sp.) (BUADES, 2006), poplar (*Populus* sp.) (MARETTE, 1961; HODGE *et al.*, 1998; BUADES, 2006), Scots pine (*Pinus sylvestris* L.) (MARETTE, 1961; HODGE *et al.*, 1998; BUADES, 2006, GALÁN, 2006; MANUEL, 2006; MARTÍN, 2010), walnut (*Juglans* sp.), chestnut (*Castanea* sp.), oak (*Quercus* sp.), and cedar (genus *Cedrus*) (GALÁN, 2006). In the middle of the XVI century, the use of imported wood began: Baltic and Swedish oak (GALÁN, 2006; RODRÍGUEZ-TROBAJO and

DOMÍNGUEZ-DELMÁS, 2015), Scandinavian pine, Cuban cedar (*Cedrela odorata* L.) and mahogany (*Swietenia macrophylla* King.)

2.1.3. Wood boards in Portuguese panels

The dendrochronological studies undertaken by IJF-DGPC on Portuguese panels from the XV and XVI centuries revealed the use of various species of wood for panel support (http://paineisnunogoncalves.org/downloads/ipcr.pdf). The Portuguese workshops in the north and centre of the country selected local species, including chestnut (*Castanea sativa* Mill.) (MARETTE, 1961; MOURA, 1974; CRUZ, 2005; LAMEIRA, 2007; LIVEIRA, 2007; SALGUEIRO, 2011; SOUSA and CRUZ, 2012; SOUSA *et al.*, 2014), walnut (*Juglans regia* L.) and, in occasional instances, thujas (*Thuja* sp.) (MARETTE, 1961). The historical XVII century document, entitled *Breve Tratado de Iluminação composto por um religioso da Ordem de Cristo*, on panel materials and techniques in Portugal, also listed cedar and cypress (MONTEIRO and CRUZ, 2010). The choice of wood relied on a variety of considerations, such as the status of the order, the master, and the contract work, as well as the availability of supplies and the geographical location of the workshop (LAMEIRA 2007; SALGUEIRO, 2012).

There are examples of panels from the same workshop with different wood species: **(1)** Gregório Lopes' workshop with pine (ESTEVES and KLEIN, 1999) and oak supports (ESTEVES and KLEIN, 1999; LAUW *et al.*, 2013; LAUW *et al.*, 2014; ANTUNES, *et al.* 2016); **(2)** Vasco Fernandes' workshop with chestnut and oak supports (SALGUEIRO, 2012); and **(3)** João Francisco' workshop with chestnut and oak supports (SANTOS, 2012).

The predominance of oak is confirmed in the Portuguese panels from the XV to XVII centuries, namely from the workshops of the Lisbon area (MARETTE, 1961; MOURA, 1974; SALGUEIRO, 2012). The fact that Portuguese forests include large areas with different *Quercus* species, such as deciduous species (*Quercus robur* L. and *Q. pyrenaica* Willd) in the north, persistent leaf species (*Q. suber* L. and *Q. ilex* L.) in the south, and *Q. faginea* Lam. with marcescent leaves in the transition between the two regions, supports the possibility of using local oak (MOURA, 1974; KLEIN and ESTEVES, 2001).

While MARETTE (1961) suggested the use of local wood by Portuguese workshops, dendrochronological studies conducted in recent decades have shown the use of imported hardwoods, especially from the Baltic region (ESTEVES and KLEIN, 1999; KLEIN and ESTEVES, 2001; CARVALHO, 2013; LAUW *et al.*, 2014; ANTUNES *et al.*, 2016; CRUZ *et al.*, 2020) (see subchapter 3.7.1.

Dendroprovenance: the oak panels). Other sources of evidence have corroborated the use of imported wood for the support of the Portuguese panels, such as historical records and the study of the incise marks on the reverse side of the wood panel supports, which will be illustrated below.

The manuscript *Livro dos Regimentos* (CORREIA, 1926) specifically mentions cabinetmakers' acquisition of imported and local timbers.

> *"36. – Item nenhũma pessoa de qualqur condição que seia atrauessaraa mdr.ª que de fora do rejno viera nem madeira do rejno que ao dito officio pertença (…);*
>
> […]
>
> *42. – E por o trabalho que os compradores leuão e por o tempo q̃ perdem nas cõpras da madeira dos bordos q̃ comprarem na maar hauerão dous reaes de cada hũ. e dos que comprarem na terra hũ real de cada hũ (…)*[6]*".*

Many artworks still survive in Portugal that demonstrate the importance of the foreign creative community in the XV and XVI centuries, notably the Flemish painters (BILOU, 2013). The *Sé Velha de Coimbra* altarpiece (attributed to the Flemish painters Olivério de Gand and João de Ypres), the *Políptico da Sé do Funchal* (of the unknown Portuguese-Flemish artist, known as *Mestre da Lourinhã*) and the *Políptico da Sé de Évora*, currently in Museu de Évora (attributed to Gerard David's workshop) demonstrate the scale of Flemish works in the region. According to CAETANO (2014), the trading and pilgrimage routes to Santiago de Compostela have facilitated the arrival of foreigners in the Iberian Peninsula. Historical sources also show that *feitors*[7] and traders are drawn to the recruiting of artists in Flanders to work in Portugal. The paucity of painters at workshops with royal contracts also explains why the Flemish painter Francisco Henriques, who lived in Portugal, travelled to Flanders by royal command to recruit artists (CAETANO, 2014). BILOU (2013) listed several foreign artists living in Portugal based on the complaint book of the Lisbon Inquisition, which identified painters, carpenters, and woodworkers of Flemish descent among a number of professions and nationalities (Figure 14). As suggested by CASIMIRO (2007), the transfer of knowledge of the techniques and materials used in Flanders to the Portuguese workshops is therefore expected.

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[6] Author's free translation: *"36. – Item no one, regardless of condition, will hoard wood from outside the kingdom or wood from within the kingdom that belongs to the referred craft (…); 42. – The buyers will be paid two 'reais' for the effort and the time they spend buying the wooden planks they buy at sea, and 1 'real' for the wooden planks they buy on land."*

[7] Author's free translation: "manager of a trading post [feitoria]"

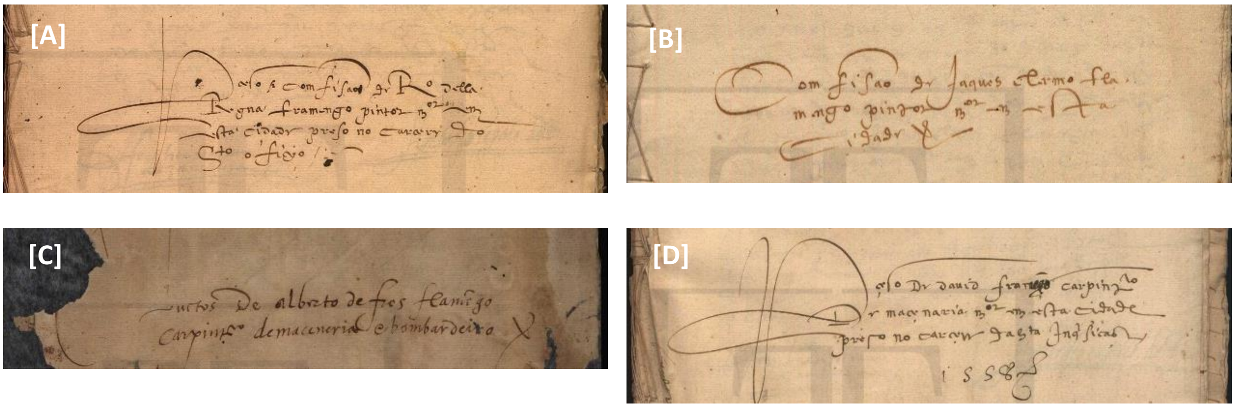

Figure 14. [A] "(…) *flamengo pintor* (…)" ("*Flemish painter*") - Processo de Rodrigo della Regna dated 1558 (SOURCE: ANTT, PT/TT/TSO-IL/028/01981); **[B]** "(…) *flamengo pintor* (…)" ("Flemish painter") - Processo de Jacques [Clerbo] dated 1559 (SOURCE: ANTT, PT/TT/TSO-IL/028/05618); **[C]** "(…) *flamengo carpinteiro de marcenaria* (…)" ("*Flemish woodworker*") - Processo de Alberto de [Fres] dated 1557 (SOURCE: ANTT, PT/TT/TSO-IL/028/06622); and **[D]** "(…) *flamengo carpinteiro de marcenaria* (…)" ("Flemish woodworker") - Processo de David dated 1557 (SOURCE: ANTT, PT/TT/TSO-IL/028/03573).

Imported wood was mentioned in some orders, but not always, and compliance with the agreed regulations was not always the case. For example: **(1)** contract for *Sé de Lamego* altarpiece construction, attributed to Vasco Fernandes, states "*toda a dita maconaria q emtrar na dita obra (…) será de boordo de frandes*[8]" but the wooden support is in chestnut (instead of oak). The failure to employ oak during construction might be owing to cost considerations or the availability of other choices in the region, resulting in the use of national timber (SALGUEIRO, 2012); and **(2)** contract for an altarpiece construction in church *Convento de São Paulo*, in Serpa, states "*retabolo para a Imagem de N. Sra das Sete Dores (…) entalhada e feita em madeira de Pinho da flandes (…)*[9]" (BORGES and UCHA, 2007).

The documents of expenses offer an additional source of historical information on imported timber. BRANCO (1988) gathered information from a historical record spanning the years 1542 to 1546, which outlines the expenses paid for the church building in *Convento do Bom Jesus de Valverde*, in Évora, reporting the amount of 90.000 *reais*[10] for wood and 8.670 *reais*[10] spent in "*bordos que vierão de*

[8] Author's free translation: *"(…) all woodwork used in the construction will be made of Flanders planks".*
[9] Author's free translation: *"(…) altarpiece for the picture of N. Sra das Sete Dores (...) carved and made of Flanders pine wood".*
[10] *Real* (plural *reais ou réis*) - O real (no plural réis ou reais) é uma antiga moeda nominal ou de conta que foi unidade do sistema monetário em Portugal desde o início da II Dinastia até à implantação da República (em 1910), sendo então substituído pelo escudo e este, a partir do ano 2002, pelo euro. [in Dicionário infopédia da Língua Portuguesa. Porto: Porto Editora, 2003-2021. [Accessed on 2021-04-2]. Available on internet: https://www.infopedia.pt/$real-(moeda)].

frandes[11]". SERRÃO (1998) also alluded to statements in *Santa Casa da Misericórdia de Viana*, referencing the transport of "*madeira de bordos de flandres pª forrar a egreja*[12]".

The use of imported oak in Portuguese orders for artworks intended for other nations is also documented. An example is the Cardinal of Portugal, a XV century altarpiece attributed to the Italian painters Antonio and Piero del Pollaiuolo, for the *Cappella del Cardinale del Portogallo* in Florence (currently at Uffizi Gallerie). Since it is an Italian panel, one may expect it to have a poplar support, however CECCHI *et al.* (1999) discovered an oak support. The authors proposed that the wood was chosen by the cardinal's Portuguese executors and referred to Flanders as the material's source, citing historical records dating back to 1466 setting "*16 pezi d'asse venuti di Fiandra per la cappella*[13]".

There were also orders for panels for religious institutions made specifically in Flanders in the XVI century. This is the case of the artworks commissioned by Infanta D. Maria in 1565 for the *Igreja do Convento de São Bento dos Apóstolos*, in Santarém, who stated the desire for altarpieces to be painted in Flanders (Figure 15) (SERRÃO, 1983).

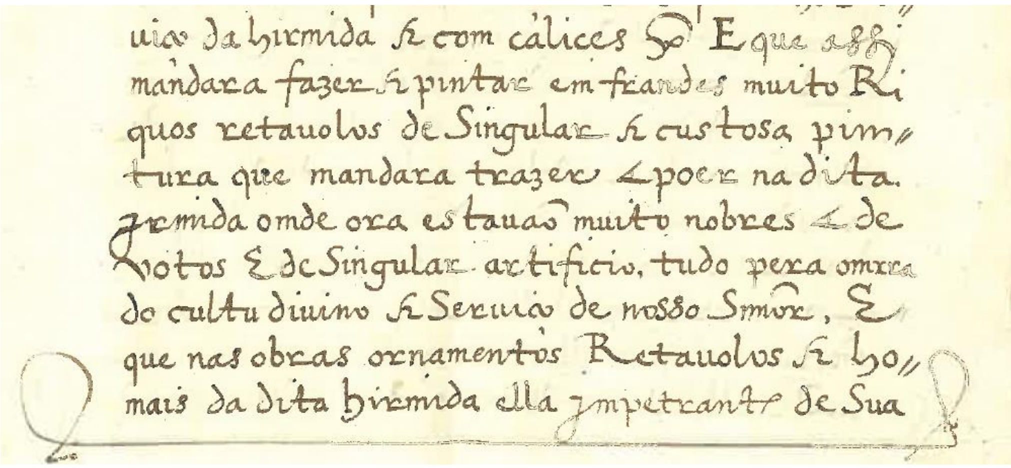
uios da hirmida e com calices &c E que assi
mandara fazer e pintar em frandes muito Ri
quos retauolos de Singular e custosa pim
tura que mandara trazer e poer na dita
ermida omde ora estauão muito nobres e de
votos E de Singular artificio, tudo pera ornar
do cultu diuino e Seruiço de nosso Snõr, E
que nas obras ornamentos Retauolos e ho
mais da dita hirmida ella impetrante de Sua

Figure 15. Order of altarpieces painted in Flanders by Infanta D. Maria in 1565, for the Igreja do Convento de São Bento dos Apóstolos in Santarém "(…) *E que assi mandara fazer e pintar em frandes muito Riquos retavolos de Singular e custosa pimtura* (…)" ((…) "*had ordered a very expensive and exclusive altarpiece to be made and painted in Flanders* (…)") (SOURCE: Fundo Reservado Biblioteca Camões, Biblioteca Municipal de Santarém).

[11] Author's free translation: *"(…) planks that came from Flanders".*
[12] Author's free translation: *"(…) Flanders planks wood for lining the church".*
[13] Author's free translation: *"(…) 16 pieces of board from Flanders for the chapel".*

MELO and CRUZ (2017) provided the significance of incised marks on the back side of the wooden supports of Portuguese panels of the XV and XVI centuries by a bibliographical analysis of many theories established in the last decades. The authors referred to three types of symbols based on historical and archaeological sources: **(1)** marks indicating the quality of the wood fitted on arrival at the port by the quality inspectors of the City of Danzig; **(2)** marks indicating the owner of the wood; and **(3)** commercial marks fitted to distinguish the merchant and/or addressee on the shipped wood. There is, however, a fourth description of "lumberjacks marks" by some researchers. OSSOWSKI (2014) identified a number of merchant marks on barrel staves and heads in the context of an investigation conducted on the timber cargo from the Copper ship of the XV century found in Gdansk Bay in 1969. MELO and CRUZ (2017) investigated a set of 26 incised marks on the reverse side of 25 Portuguese panels and found that they are marks connected to felling practices and the structure of the Hanseatic commerce in timber in the Baltic region, as already verified in the Flemish panel studies (WADUM, 1998). As a result, the authors disproved the widely held belief in the Portuguese literature that the incised markings related to the workshop in charge of panel manufacturing or board quality monitoring.

2.2. Musical instruments from XVII to XIX centuries

2.2.1. Violins and cellos

The luthier or violin maker is an artist who creates all musical instruments played with a bow, such as violin, cello, viola, bass, as well as finger-pinched instruments such as lute, harp, guitar, mandolin and psaltery (MACQUER, 1767). Under this family of instruments, the present study is limited to violins and cellos and deals only with their construction and materials. The cellos have the structure and purpose of the violins, with a larger body and a distinct playing style, and are not singled out in the following definitions.

2.2.1.1. Violin´s components

The violin's arrangement comprises of around 70 parts, nearly entirely of wood, of various types and origins, depending on their specific purpose in the instrument. The number of total pieces varies (MAUGIN, 1834; DAVIDSON, 1871; HERON-ALLEN, 1884). DAVIDSON (1871) pointed out that many of the Cremona instruments had fewer than 70 elements, quite an exception to the common rule. Figure 16 describes a portion of the components in the front, side and back sections of the violin.

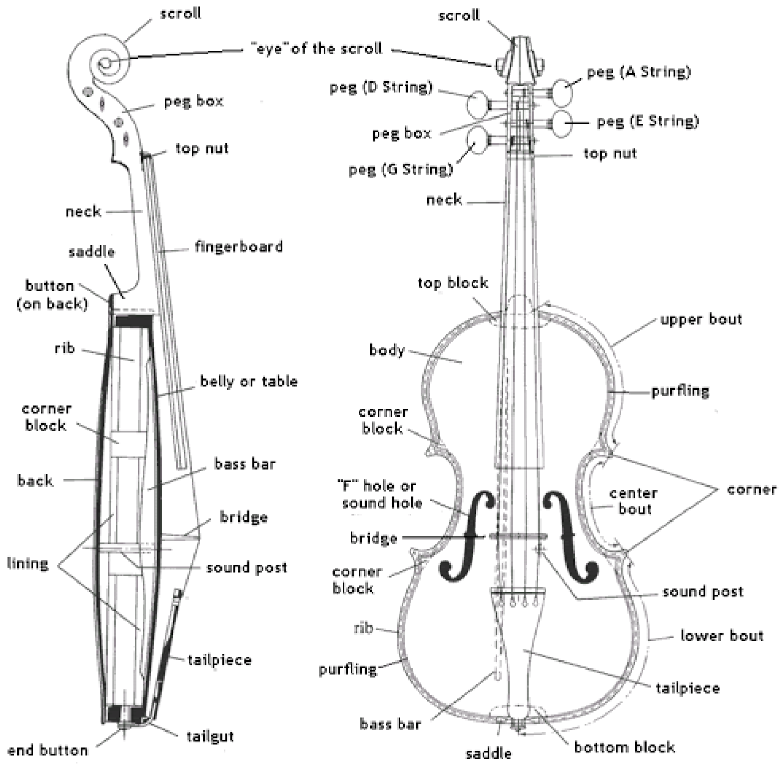

Figure 16. Interior and exterior structure of the violin (SOURCE: NELSON, 2003).

2.2.1.2. Manufacture of the violin´s belly and wood applied

In view of the scope of the present dendrochronological analysis, this study is confined to the front section of the violin - the *belly*. The number of components that comprise the violin's belly might vary. In his luthier manual, MAUGIN (1834) described "*Le violon, quand le fond et la table sont chacun d'une seule pièce, est composé de soixante-neuf parties, et de soixante-onze, quand le fond et la table sont chacun de deux pièces*"[14]. In Figure 17, the arrangement of two wood components from the same stem according to the standard procedure is schematically represented. According to KOLNEDER (2003), the two wedge-shaped segments are normally cut about 50 mm longer than needed for the finished instrument and at least 40 mm thick at the edge of the instrument. The violin top plate corresponds to the radial section of the wooden boards in which the growth rings regularity

[14] Author's free translation: *"The violin is made up of 69 parts when the back and top are both one piece, and 71 parts when the back and top are both two pieces."*

is visible. The two pieces are not cut parallel to the grain but in such a way that they form a slightly acute angle towards the top, providing an increased tension for the top and better friction for the glue (KOLNEDER, 2003).

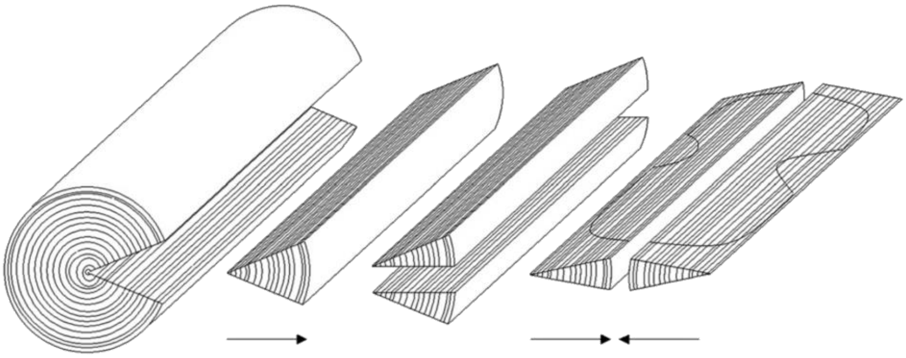

Figure 17. Illustrative representation of the violin belly manufacture according to standard method (SOURCE: BERNABEI and BONTADI, 2011).

The wedges are glued in one of two ways to obtain a symmetrical tree ring pattern in relation to a center joint (a mirror image): **(1)** cambium-cambium, the most common way in which the youngest part of the wood is centre-oriented; **(2)** heart-heart, a more unusual option in which the oldest part of the wood is in the centre of the instrument (NELSON, 2003; BUCUR, 2016; BERNABEI and ČUFAR, 2018); and **(3)** cambium-heart of gluing adjacent pieces, which gives an asymmetrical pattern of the tree ring, a very rare situation found primarily in old instruments (BUCUR, 2016). In other situations, however, asymmetry may exist, such as: (**1**) on larger instruments (e.g., cello, viola, and double bass) with more than two pieces (NELSON, 2003); **(2)** although the belly consists of two adjacent wedges, the original width of the plank is large enough to allow the cutting areas to be selected; and **(3)** only a single piece of wood forms the belly. In the latter example, KOLNEDER (2003) proposed that, owing to the position and pressure of the lower and higher strings, the widest rings should be on the left and the narrowest on the right.

According to the current opinion of the luthiers, only certain rings near the bark are removed in the traditional violin construction. If the board is larger than required, which inevitably ensures that certain parts of wood are removed, the luthier intends to cut the innermost section nearest to the pith (BERNABEI *et al.*, 2017).

The hypothesis of building the hollow box with a single wood piece to simplify the method of constructing the musical instrument was rejected by HERON-ALLEN (1884). In terms of acoustic quality, the author believed that having two excellent quality pieces (belly and back) was desirable; however, finding suitably large planks in significant quantities was problematic.

In historical luthier manuals, there are guidelines and material selection criteria for making the violins' belly. In the section "*Des bois employés pour la lutherie*", MAUGIN (1834) suggested that the regularity of the rings, as well as the absence of knots and defects, were very important for the construction of a good musical instrument:

> "(…) *ses veines doivent être régulièrement séparées entre elles d'une ligne environ; elles doivent tomber perpendiculairement du dessus de la table au dessous, et ne pas être disposées en biais ; elles doivent être en ligne droite dans la longueur du violon, et ne pas décrire de lignes courbes. Le moindre noeud, le moindre défaut doivent faire rejeter la table qui en est tachée."*[15].

MACQUER (1767) referred to Tyrol for the specific source of the best woods ("*Le point principal pour la bonté de l'inftrument, eft de trouver de beau fapin vieux & fonore pour la table: on en fait venir du Tyrol, qui eft cenfé être le meilleur"*[16]) and MAUGIN (1834) explicitly listed some Swiss cantons ("*C'est en Suisse et principalement dans les cantons de Schwytz et de Lucerne que l'on trouve à se procurer le plus beau plane*"[17]).

The historical descriptions on the wood used for the violins' belly refer different types e.g., "sapin" (DIDEROT, 1765; MACQUER, 1767; MAUGIN, 1834); Swiss pine (DAVIDSON, 1871); "azarole" (MAUGIN, 1834; DAVIDSON, 1871); an Italian word referring to "epicea" (HERON-ALLEN, 1884); "white pine" (HERON-ALLEN, 1884); "pine and fir" (ABELE and ALWYN, 1905); in Spain "pinovete" (NASSARRE, 1723-1724; MARTÍNEZ GONZÁLEZ, 2016) and "*ciprés*"[18] (MARTÍNEZ GONZÁLEZ, 2016). The term "pine" is used to describe the wood of various species, but Norway spruce (*Picea abies* (L.) H. Karst), is the first to be considered for the violins' belly (NELSON, 2003; BUCUR, 2006). *Picea abies* (L.) H. belongs to the family Pinaceae, nowadays predominantly in the Northern Hemisphere, and includes several widespread taxa, such as *Abies* (firs), *Picea* (spruce), *Tsuga* (hemlock), and *Pinus* (pines). The characteristics of Norway spruce wood make it a valuable source of wood for musical instruments. The wood is almost white, often with a light-yellow color, with an annual ring very easily evident, with distinct boundaries due to the cellular variations between earlywood and latewood

[15] Author's free translation: *"(…) its grain must be regularly separated from each other by about one line; it must run perpendicularly from the top of the soundboard to the bottom, and not be set at an angle; it must run in a straight line along the length of the violin, with no curved lines. The soundboard must be rejected if it has the slightest knot and the slightest defect".*
[16] Author's free translation: *"The main point for the goodness of the instrument is to find beautiful old & resonant 'sapin' for the soundboard: it comes from Tyrol, which is said to be the best".*
[17] Author's free translation: *"The most beautiful planes can be found in Switzerland, especially in the cantons of Schwyz and Lucerne".* The term 'planes' most likely applies to boards.
[18] Genus *Cupressus* L.

(TJOELKER *et al.*, 2007). However, identifying wood species in the soundboards of the historical bowed stringed instruments through the classical microscopic examination is nearly impossible due to the high value of such instruments and the inability to prepare samples for microscopy. Through the observation of the upper and lower tops of two dismantled French guitars (*vihuelas de mano*), VAIEDELICH (2004) concluded that the bellies were made of wood of the genus *Abies* Mill. given the absence of resin ducts in the cross-section, as commonly identified in the genus *Picea* Mill. (the most expected for the soundboards in this kind of musical instruments). FIORAVANTI *et al.* (2017) identified several wood species through a non-invasive methodology carried out in situ with portable digital microscopes with high magnification as well as reflected light and polarizing filters. *Picea abies* (L.) H. was found on more than 80% of the soundboards of bowed stringed instruments evaluated by the authors. BORYSIUK *et al.* (2016) proved the potential of the X-ray computed tomography (CT) in wood identification, suggesting a promising approach in the field of musical instruments. HAAG *et al.* (2018) described two technical approaches and practical applications of non-destructive microscopic investigation methods in eleven musical instruments from the XVI to XX centuries – 3D-Reflected-Light Microscopy and High-Resolution µ-X-ray CT. They were able to determine that the soundboards of five Spanish guitars from the XIX and XX centuries were constructed of *Picea abies* L.

Over time, manufacturers have demonstrated a preference for wood with neither too wide nor too narrow rings, to achieve a texture that is neither too rough nor too soft (SAVART, 1819; GALLAY, 1869; HERON-ALLEN, 1884; SCHELLENG, 1982). This leads to empirical rules granting priority to the southern slopes for the cutting sites and the southern side of the tree stem to the ideal tree ring pattern (MAUGIN, 1834; DAVIDSON, 1871; SCHELLENG, 1982). The bottom stem section was discarded to avoid compression of wood as well as asymmetry in the growth ring pattern (HUTCHINS, 1978). The straight grain from top to bottom of the belly of the violin was a consensual norm (SAVART, 1819; MAUGIN, 1834; HERON-ALLEN, 1884; HUTCHINS, 1978; SCHELLENG, 1982).

The wood selection for the violin’s belly was also related to tree growing conditions and harvesting. The first variable to be considered in ensuring the wood quality was the moment when it should be cut. Traditionally, the selection was made on trees cut in winter (GUÉLARD, 1743; MAUGIN, 1834; DAVIDSON, 1871; HERON-ALLEN, 1884; SCHELLENG, 1982; BUCUR, 2016). The theory was based on two variables: (1) determining the season in which the tree's physiological activity was at its lowest; and (2) the moment when the sap was closest to the ground, allowing it to be removed more readily after falling. In the first century BC, the Roman architect, artist, engineer, and treatise writer VITRUVIO POLIN mentioned in *De architectura*, nowadays known as *Los Diez Libros de Arquitectura*[19],

> "*La madera debe cortarse desde principios de otoño, hasta antes i que empiece á correr el favonio: porque en la primavera todos los arboles abundan de savia, y echan su natural vigor en hojas y anuales frutos; y estando, por motivo de la estación, anchos de poros y cargados de humor, vienen á ser leves y de poca fuerza. (…) por el otoño las plantas, suelta ya la hoja por la madurez del fruto, chupando los arboles por la raiz el suco de la tierra, se recobran y restituyen á su primera firmeza. Entonces la fuerza del viento ibernal que les sobreviene, las consolida durante dicho tiempo: luego la madera cortada en él será buena.*"[20]

In fact, during the cold seasons, trees slow down their sap production and, therefore, the wood hardens (NISTAL, 2015). The influence of lunar cycles had on the organic activity of trees was recognised in ancient times. In the quest for the greatest inner dryness of the tree, preference was always given to the last quarter moon when sap quantity is lowest (NISTAL, 2015), as explained by ZAMORANO (1594):

> "*La luna, quando es creciente, ayuda a henchir de fuftancia y virtud todas las Plantas: y quando mengua las vazias, y enxuga; y por effo los experimentados, en el cortar de la madera para fabricar naos y otros edificios, fiempre aguardan a cortalla fiendo la Luna bien menguante, y tambien en menguante del dia, por que entonces los arboles no tienen tanto humor como en las crecientes.*"[21]

Throughout the centuries, this principle has been shared by the most different fields of study. In a medical treatise from the XIV century, the French doctor Bernard de Gordon compared the negative effect of excess humidity in the treatment of snoring, with the defects of violas made of wood cut at full moon (" (…) *y por effo la gayta, ò vihuela, cuyo palo fue cortado en Luna llena, nunca fonarà bien, por la mucha humedad que cobrò (…)*"[22]) (GONZÁLEZ DE REYES, 1697). The Spanish military man Luys

[19] Note: Translated from Latin and commented by Don Joseph Ortiz y Sanz in the XVIII century but referred to as VITRUVIO POLIN (1787).

[20] Author's free translation: *"The wood should be cut from the beginning of autumn just before the beginning of 'favonio': since all trees are full of sap in the spring and produce their natural vigour in leaves and annual fruits; as a result of the season, the wood became lightweight and fragile due to wide porous and high moisture content. (…) Since their leaves had already been loosened by the ripening of the fruit, the trees had recovered and restored themselves to their original robustness by autumn, absorbing nutrients from the soil through their roots. Then the power of the winter wind that happens during that period consolidates them: the wood cut in it will be good". Favonio* is a westerly wind that blows since 8th February (NISTAL, 2015).

[21] Author's free translation: *"When the moon is waxing, it helps to fill all plants with substance and vigour; when it wanes, it makes them empty and dry; and for this reason, those who are experienced in cutting wood to make ships and other buildings always wait to cut it when the moon is waning, as well as when the day is waning, because the trees do not have as much moisture as when the moon is waxing."*

[22] Author's free translation: "*and for this reason, the gayta, or vihuela, whose wood was cut during the full moon would never sound good due to the high humidity it got".*

Collado cited a similar theory in an artillery manual from the XVI century in an allusion to Roman knowledge (COLLADO, 1592):

> *"(…) la perfecta madera ha de fer cortada en el menguante de la Luna, y la razon que dan para ello, cierto quadra a qualquier buen juzio, Y es que en el menguante de la Luna vna gran parte del humor terreftre, que es aquel que da virtud ala planta, (…), fube, y abaxa en ella, con la modança de la Luna (…). Entonces la madera fera bien cortada quando haura dias quel arbol defpidio fu fructo, y hoja, y la Luna fera vieja."*[23]

2.2.1.3. Manufacture of the violin´s belly and wood applied in Portuguese workshops

The manuscript *Livro dos Regimentos dos offiçiaes mecanicos da mui excelente e Sempre leal Cidade de lixbona refromados per ordenança do Illustrissimo Senado della pello Licenciado Duarte nunez do liam Anno MDLxxij*, compiled in 1572 and edited by CORREIA (1926), presents the model of craftsmanship organization maintained in Portugal since the Middle Ages. This document, seen as a collection of the XVI century handwritten laws and modified in the following centuries, allows certain artistic professions operating in Portugal to be identified, as well as the principles that determined their procedures. The organizational culture of the craft corporations was characterized by the control of the workday, the number of apprentices, the opening of new workshops, the regulation of the quality and quantity of the works, and the specialization of production (MATTA, 2013). The career path was defined by each professional community, beginning as an apprentice, followed by an official, until reaching the status of master caretaker of confidential information and holder of recognized knowledge and practices (MATTA, 2013). After studying as an apprentice, the aspiring craftsman could present himself for the examination corresponding to the career he was training for. The performance of one or more specific tasks for the examination of each profession was generally determined by the *Livro dos Regimentos dos Oficiaes mecanicos* and detailed at the time of the examination by the judge. BRANDÃO (2016) presupposed the presence of a set of sketches that would have to be copied by the apprentice, since the manuscript *Livro dos Regimentos dos Oficiaes mecanicos* explicitly references them even though they are not currently attached to the original in the Municipal Archive of Lisbon. Beyond this historical document, the *Acrescentamento do regimento*

[23] Author's free translation: "*The perfect wood must be cut in the waning of the moon, and the explanation they provide for it is certain to any good judgement, and it is that in the waning of the moon, a great part of the earthly moisture, which is what gives vigour to the plant (...) rises and descends in it with the change of the moon* (...). *Then the wood will be well-cut when the tree has no fruit and leaves, and the moon will be old*."

do ofício de violeiro (1719), transcribed by MORAIS (2006), is the main source with the most complete rules on *viola's* construction in Portugal in the XVI to XVIII centuries.

Bandeira corresponded to an aggregation of various occupations around the dedication to the patron, depicted by a single banner (later called *flag*) with the image of the saint. The main role was to engage in civic-religious rituals and processions through the streets and alleys of the city. Under each banner there was a distinction between the leading corporations and the "attachments," which often led to disagreements between the different members of the corporation. Bandeira could or could not bring together professions with affinities in their field of activity (MATTA, 2013). The *Bandeira de S. José* was led by the masons and carpenters' corporations, which integrated the *violas* makers ("*violeiros*" or "*violeros*"), and other stringed instruments (MATTA, 2013). *Violeiro* is therefore known as the Portuguese word equivalent to the French luthier. In Portugal, the word "*viola"* (also written as "*violla*" or "*viula"*) was used as a common name for a family of stringed instruments, including violins and cellos, from the XV to the early XIX centuries (MORAIS, 2006). Considering the current study, the following historical references addressing the regulations of viola construction are confined to the belly and the corresponding woods employed. The first historical reference on *viola's* construction is given in 1572 in the examination rules for *violeiros*, mandatory for Portuguese and foreign candidates (CORREIA, 1926).

> *"4. - (…) faraa huma viola de seis ordens de costilhas de pao preto ou vermelho laurada de fogo muito bem moldada e laurada tampaõ e fundo de duas metades (…)"*[24]

Literature on the specification of the sort of wood used in the Portuguese string instruments is scarce. The term for the wood used in the front piece of the violin – *pinhavete*, *Pino avete* or *pinavete* – is mentioned in the partial transcript presented by CARVALHO (1943) concerning *Regimento para o Ofício de Violeiro em 1719,*

> "(…) *Não levarão mais por (…) Um tampo de pinhavete, de hua violla de marca, sendo lizo 480 reis. (…). Um tampo de meia violla de pinhavete 240 reis (…)"*[25]

According to MORAIS (2006), a publication on the instructions for the manufacture of *violas* stated by the Portuguese prestigious writer João Vaz Barradas Muito Pão e Morato (1689-1748) mentioned

[24] Author's free translation: *"(…) will make a six-stringed viola, with black or redwood ribs, very well moulded and with a top and bottom in two halves*". The term *pao preto* probably corresponds to *Caesalpinia echinata* Lam*.*

[25] Author's free translation: "(...) *They will not take more for (...) A belly of pinhavete* [pinewood]*, of a good viola, being 480 reis. (...). A belly of a half-pinhavete* [pinewood] *viola 240 reis.*". *Reis* was an ancient monetary unit of Portugal and Brazil [in Dicionário infopédia da Língua Portuguesa. Porto: Porto Editora, 2003-2021. [Accessed on 2021-04-26]. Available on internet: https://www.infopedia.pt/dicionarios/lingua-portuguesa/mil-réis]

the same wood, as well as Scots pine[26]. The author believed that this text was based on a piece released late by the Spanish composer Pablo Nassarre (ca. 1655 - ca. 1730) in which he used the word *Pino avete*, which according to HUBBARD (1967) and LEN (2016) related to spruce.

> "(…) *Primeyramente se escolherá madeyra forte e liza*; *o tampo sobre que carregaõ as cordas há de ser de madeyra poroza, e segundo a experiencia he melhor a de Pinho avete ou de Flandes"*[27]
>
> (João Vaz Barradas Muito Pão e Morato (1762) described by MORAIS (2006))

> "(...) *Las tapas de los inftrumentos, fobre quienes cargan las cuerdas, há de fer una madera porofa , y fegun la experiencia enfeña , la mas al cafo es el Pino avete, importa que fea delgada , para que fea nas refonante en el concavo el fonido (…)"*[28]
>
> (NASSARRE, 1723-1724)

Two plausible hypotheses should be considered: the use of local or imported wood for the belly's violins. It is unknown since when the Portuguese workshops used imported wood for the front piece of the violins. Italy is even mentioned in some historical texts. In *Acrescentamento do regimento do ofício de violeiro* from 1712 (described by MORAIS (2006)) and in compendium *Estudo de Guitarra* (LEITE, 1796), considered the first compendium on the study of a musical instrument published in Portugal, the wood used in the belly's violins and Portuguese guitars comes from Venice.

> "(...) *Dizem os juizes do offiçio de violeiro e os mais oficiais (...) quantidades de tampos em caixões de Veneza e Amburgo (...)"*[29]
>
> (*Liuro primeiro dos acrecentamentos dos Regimentos dos offiçiais mecanicos desta muito sempre nobre e sempre leal cidade de Lisboa tresladado no anno de 1712* transcribed by MORAIS (2006))

> "(...) *PAra que a Guitarra feja boa, requerem- fe tres coufas , a faber: boa madeira na fua conftrucçaõ; proporçaõ nas fuas partes (...). A madeira da fua conftrucçaõ deve fer de Platano muito fecca, ifto fe entende, naõ o tampo, porque efte deve fer de Veneza, por fer madeira mais leve; e fendo ella de vêa fina, e rija, muito melhor, porque o fom das Cordas reflecte mais, e faz hum excellente efeito (…)"*[30]
>
> (LEITE, 1796)

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[26] Note: Probably, *Pinus sylvestris* L., also known as Scots pine, Scotch pine, European red pine, or Baltic pine (in Portuguese: pinho-de-riga, pinheiro-silvestre, pinheiro-da-escócia, pinho-nórdico, casquinha-nórdica ou casquinha).

[27] Author's free translation: "*First of all, choose a strong and smooth wood; the belly on which the strings are supported must be made of porous wood, and, according to experience, the best is Pinho avete or Flanders pine*."

[28] Author's free translation: "*The tops of the instruments, on which the strings are loaded, must be made of a porous wood, and the most suitable one according to experience is 'Pino avete'; it is important that it be thin so that the sound is more resonant*."

[29] Author's free translation: "*The judges of the viola manufacture and other officials say (...) quantities of soundboards in boxes from Venice and Hamburg*".

[30] Author's free translation: "*For a good guitar, three things are required, namely: good wood in its construction; proportion in its parts (...). The wood used in its construction should be very dry sycamore, this is understood, not the soundboard, because this should be of Venice, for it is lighter wood; and being thin-grained and hard, much better, so the tone of the strings reflects more, creating an excellent effect*".

The type and components of wood, strings, and equipment used in workshops are also revealed in wills and inventories for musical instrument makers' asset-sharing processes. In the inventory of the Portuguese *violeiro* workshop from 1807, there are two brief passages which confirm the use of different woods – "*serrar madeira de fora*. (…) *Onze bocados de vinhático de vários tamanhos, vinte e oito bocados de paus diversos e pequenos e dois bocados de folha de Casquinha*[31]" (FEITOS FINDOS, 1807). CASTAGNA *et al.* (2012) transcribed the types of wood used from the will and corresponding inventory of a Portuguese *violeiro* located in Brazil in the XVIII century.

> "(…) *tampos de Veneza para violas e meias violas* (…) *pares de Tampos de Veneza que Se gastarão nas Viollas, e meyas viollas a ¼*", (…) *Devo q' pagarej a Joze Pera. Carnro. Corenta outavas e doze vinteis de ouro porcedidas desde cajxois de pinho de flandes (…)"*[32]

Resumos de Importação e Exportação de Portugal para o Brasil, Ilhas, América, África, Ásia e Nações Estrangeiras (JC, 1797; 1799-1831) and *Mappas Geraes do Commercio de Portugal* (DGACI, 1852, 1866, 1867, 1869, 1873) also recorded the import of wooden parts for musical instruments. The accessible statistical collection, which spans the years 1796 to 1870, lists products for the restoration or construction of string musical instruments, such as the import of pieces of instruments, including bellies and bottom boards for viola and strings for four instruments, namely sitar strings, guitar, clavichord and viola. Italy was the largest country of origin of bellies and wood for violas, with a single registration from England to Oporto in 1827 (Table 3). Correspondence from the Portuguese consulates in Trieste backs up the issues, indicating that wood pieces for violas were imported from Trieste and Venice to Lisbon (Table 4). Customs payment records for the 4% donation are also a source of historical knowledge, detailing the import of wood parts for musical instruments from Venice and Sicily – "*800 tampos de violas a entregar a quem pertencer"*[33] (PM, 1774), "*cenco e quarente e um massos de tampos pª viollas"*[34] (PM, 1175), "*200 maços de tampos de violla a entregar a quem pertence"*[35] and "*3000 fundos de violas a entregar a quem pertencer"*[36] (PM, 1776). Portugal

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[31] Author's free translation: "*saw foreign timber (…). Eleven pieces of 'vinhático'* [known as Madeira-Mahagoni (*Persea indica (L.) C.K.Spreng.*)] *of several sizes, twenty-eight pieces of various small sticks and two pieces of 'folha de Casquinha*[26]*'"*.

[32] Author's free translation: "(…) b*ellies from Venice for violas and half-violas (…) pairs of bellies from Venice used in violas, and half viollas to ¼ (…) I owe and I will pay to Joze Pera. Carnro. forty octaves and twelve gold 'vinteis'* ['vinténs'] *from boxes containing pine of Flanders (…)". Vintém* (plural *vinténs*) was an ancient Portuguese coin with the effigy of the king, equivalent to two cents [in Dicionário infopédia da Língua Portuguesa. Porto: Porto Editora, 2003-2021. [Accessed at 2021-04-26]. Available on internet: https://www.infopedia.pt/dicionarios/lingua-portuguesa/vintém]

[33] Author's free translation: "*800 bellies of violas to be given to whom it belongs"*

[34] Author's free translation: "*one hundred and forty-one packs of bellies of violas"*

[35] Author's free translation: "*200 packs of bellies of violas to be given to whom it belongs*"

[36] Author's free translation: "*3000 back of violas to be given to whom it belongs*"

was not the only country that imported this sort of product into the Iberian Peninsula. Spain also imported wood for *tapas de instrumentos musicales* from Italy (WESTBROOK, 2005), specifically in the XVII century from Florence (CHERRY, 2003).

Table 3. Wood pieces for guitars/violas imported to Portugal between 1796 and 1831 according to the records of JUNTA DO COMÉRCIO (SOURCE: JC, 1797, 1799-1831).

YEAR	DEPAR TURE	DESTINA TION	CATEGORY	GOODS		AMOUNT	VALUE
				PORTUGUESE	ENGLISH TRANSLATION		
1796	Italy[37]	Lisbon	Several goods	Tampos de viollas	Soundboards for violas	9 boxes	36$000
1819	Italy	Lisbon	Several goods	Madeira pª violeiros	Wood for *violeiros*	33 boxes	132$000
1819	Italy	Lisbon	Several goods	Madeira pª violeiros	Wood for *violeiros*	52 packs	156$000
1825	Italy	Lisbon	Several goods	Madeira pª viollas	Wood for violas	14 boxes	84$000
1825	Italy	Lisbon	Several goods	Madeira pª viollas	Wood for violas	5 boxes	40$000
1826	Trieste and Venice	Lisbon	Several goods	Tampos de viollas	Soundboards for violas	11 boxes	-
1827	England	Oporto	Woods	Ilhargas	Ribs	100	30$000
1827	England	Oporto	Woods	Tampos de viollas	Soundboards for violas	200	6$000
1827	Trieste and Venice	Lisbon	Woods	Tampos de viollas	Soundboards for violas	11 boxes	66$000
1828	Trieste and Venice	Lisbon	Woods	Tampos e ilhargas	Soundboards and ribs	-	422$400
1829	Italy	Lisbon	Woods	Ilhargas	Ribs	1000	50$000
1829	Trieste and Venice	Lisbon	Woods	Ilhargas	Ribs	1000	50$000
1829	Italy	Lisbon	Woods	Tampos de viollas	Soundboards for violas	1000	50$000
1829	Trieste and Venice	Lisbon	Woods	Tampos de viollas	Soundboards for violas	1000	50$000
1829	Trieste and Venice	Lisbon	Woods	Tampos de viollas	Soundboards for violas	6 boxes	36$000
1830	Italy	Lisbon	Woods	Tampos de viollas	Soundboards for violas	4000	320$000
1830	Italy	Lisbon	Several goods	Ilhargas	Ribds	4000 units	200$000
1831	Austria[38]	Lisbon	Woods	Madeira pª viollas	Woods for violas	6 boxes	72$000

Table 4. Wood pieces for guitars/violas imported from Trieste and Venice to Lisbon between 1813 and 1832 according to the diplomatic correspondence [*Caixas de Fundos de Guitarra* – boxes of soundboards for guitars; *Caixas de Fundos e Faixas pª Ghitaras* - boxes of soundboards and ribs for guitars] (SOURCE: MP, 1815, 1817, 1825, 1826, 1827, 1830-1832).

	VESSEL NAME	NATION	PORTS WHERE THEY LOADED	GOODS	QTY
1813-1815	Maria	English	Trieste	*Caixas de Fundos de Guitarra*	4
1813-1815	Mercurius	Swedish	Trieste	*Caixas de Fundos de Guitarra*	9
1817	Titania	Danish	Trieste	*Caixas de Fundos pª Guitarra*	5
1825	Arpocrate	Austrian	Trieste	*Caixas de Fundos para Guitarras*	1

[37] "*Com as differentes praças de Itália – Veneza*" [Author's free translation: "*With the different squares of Italy – Venice*". The word 'praças' ['*squares'*] most likely applies to harbours].
[38] "*pelos Portos de Trieste e Veneza*" [Author's free translation: "*by the harbours of Trieste and Venice*"].

	VESSEL NAME	NATION	PORTS WHERE THEY LOADED	GOODS	QTY
1825	Bershite	Swedish	Venice	*Caixas de Fundos para Guitarras*	7
1825	Espirito	Austrian	Venice	*Caixas de Fundos para Guitarras*	7
1826	Regenerado	Austrian	Venice	*Caixas de Fundos para Guitarras*	7
1826	Humildade	Austrian	Venice	*Caixas de Fundos para Guitarras*	4
1827	Regenerado	Austrian	Trieste	*Caixas de Fundos e Faixas pª Ghitaras*	8
1827	Amatissimo	Austrian	Trieste	*Caixas de Fundos e Faixas pª Ghitaras*	3
1827	Anna Dorothea	Swedish	Venice	*Caixas de Fundos e Faixas pª Ghitaras*	7
1827	Anna Maria	Swedish	Venice	*Caixas de Fundos e Faixas pª Ghitaras*	16
1830	Furiozo	Neapolitan	Venice	*Caixas de Fundos para Guitarras*	3
1831	Harlequin	Austrian	Trieste	*Fundos para Guitarras Caixas*	4
1831	Henriqueta	Austrian	Trieste	*Fundos para Guitarras Caixas*	8
1832	Cesar Augusto	Austrian	Trieste	*Caixas de Fundos para Guitarras*	16

2.2.2. Harpsichords

Before modern times, there were no books on the making of harpsichords, and the literature on the subject was disseminated in relatively short chapters and occasional notes in works covering a wide range of subjects, such as encyclopaedias, treatises on musical theory and history, newspapers, musical periodicals, notary records, almanacs, among other sources (HUBBARD, 1967). According to RIGALI (2016), the limitation of written sources is partly justified by socio-professional issues arising from the Middle Ages, namely the competencies assigned to the various protagonists of the musical field. The "music theorist" and the "musician" were opposed, being the first to be seen as the true musician who knew the principles of musical science, while the "musician" was, on the other hand, regarded merely as a skilled instrument player. The third players, the makers of musical instruments, still had a very humble status in a lower position. RIGALI (2016) considered from this perspective that theorists did not really intend to report deeply on practical questions about the manufacture of instruments. In the other hand, there is the idea that the manufacturers of instruments were rather "reserved" persons. In fact, until the late XVIII century, the arts and crafts were organized within the traditional guild structure, and practical expertise was retained within the workshop. The absence of treaties written by the instrument's makers can be explained in part by their reluctance to share knowledge and, possibly, by the fact that they were illiterate.

2.2.2.1. Principal harpsichord´s components

The term “harpsichord” means any stringed keyboard instrument that uses jack movement to produce plucked sounds. The earlier term for harpsichord – *clavicembalum* - is mentioned in a letter dated 1397 from Padua. The first document to offer details on the construction of a harpsichord dates from about 1440 by Henri Arnaut, physician, astronomer, and organist to Philip III of Burgundy the Good. The harpsichord design by Henri Arnaut has enough information to build the instruments, but it omits the type of wood used in the various constituent sections (KOTTICK, 2003).

The harpsichord is the ancient predecessor of the piano. The harpsichord's history is defined by the instrument's style, the century in which it was produced and played, and the national school. The main schools were French, Italian, German, Flemish and English. The most common version today is the wing-shaped one (Figure 18), but there is also the *clavicytherium* (in upright form), the *virginal* (in polygonal or rectangular form with the bass strings in the front) and the *spinet* (in rectangular, trapezoidal, or bent side configuration with its bass strings at the rear of the case) (KOTTICK, 2003).

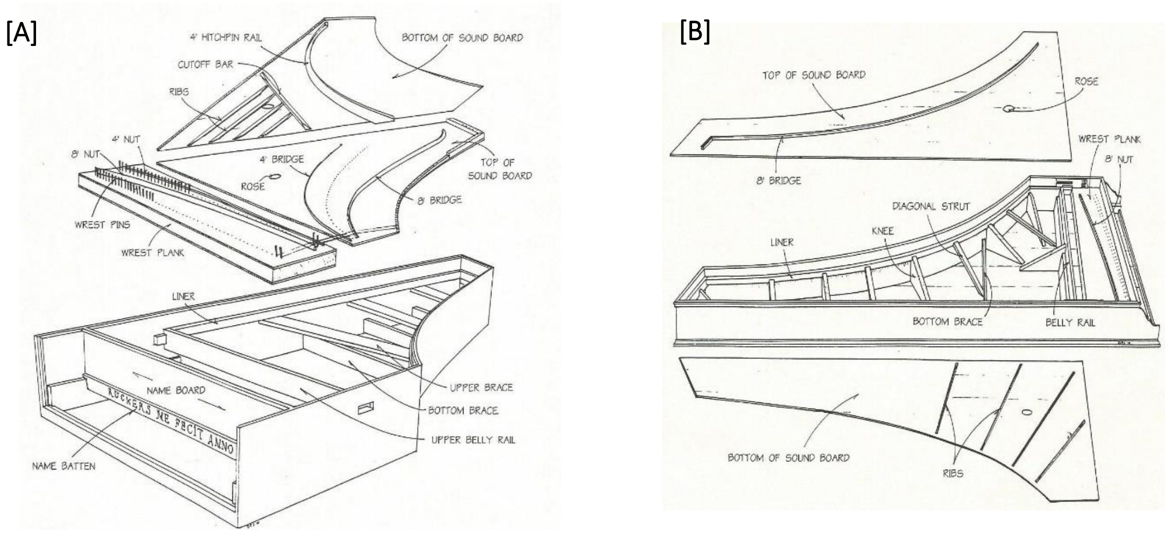


Figure 18. Exploded view of: **[A]** a Flemish harpsicord; and **[B]** Italian harpsicord (SOURCE: KOTTICK, 2003).

2.2.2.2. Harpsichord's soundboard manufacture and wood applied

Since historical records are too complex and difficult to obtain, knowledge becomes more scarcer when the research concentrates on one of the components of the musical instrument. The study of the manufacturing of harpsichord soundboards in historical instruments can thus be fruitless. It is possible to preserve accurate details about soundboard preparation by consulting the relevant and available historical records from the XVIII century.

In the first edition of the French *Encyclopédie*, DIDEROT (1765) defined the following criteria: **(1)** use boards without knots and cracks with a thickness approximately 2 lines (5 mm); **(2)** individual boards of wood shall not exceed 0,5 ft (approximately 15 cm) in diameter, because larger parts are more subject to warping; and **(3)** once the boards have been glued, the final thickness of one line should be flattened (2.5 mm). In a German collection of lessons on the structure, usage, and repair of many keyboard instruments, ADLUNG (1768) proposed that the boards should be boiled beforehand, as the wood for the soundboard should not be greasy. After that, the wooden boards should be properly glued to ensure that the top can be shifted more quickly and vibrate, and the wooden boards should not be more than 1/16 inch thick (*circa* 16 mm).

HUBBARD (1967) and BRAUCHLI (1998) referred to many other brief citations from historical documents. After cutting into boards, the harpsichord manufacturers were recommended to use wood with long-term stabilization and heartwood should not be used. A set of features is often referred to as the selection criterion for the highest quality material in the manufacture of soundboards: preference for the oldest wood, fine-grained, clear from knots and blemishes, non-resinous and very dry.

Soundboard wood was usually quarter sawed (i.e., radially), a configuration that minimizes shrinkage and warping. However, there are several examples of soundboards with tangentially cut woods in Italian and a few early German instruments (KOSTER, 2007).

The right choice of wood is an important aspect of the construction of the harpsichord. The wood used by harpsichord makers differed according on period and place. Over the centuries, certain woods have historically been selected based on certain purposes such as acoustic, mechanical, surface texture, and colour (HUBBARD, 1967; KOSTER, 2007). However, there were two other major factors to consider before making the decision: availability and price (KOSTER, 2007). According to the author, ancient builders intended to use local wood wherever feasible, but expanding global trade has given them with unique raw materials. A wide variety of woods has been identified for the different components of the instrument: beech (genus *Fagus* L.), boxwood (genus *Buxus* L.), chestnut (genus *Castanea* Mill.), cypress (genus *Cupressus* L.), ebony (genus *Diospyrus* L.), European popular (genus *Populus* L.), European walnut (*Juglans regia* L.), fir (genus *Abies* Mill.), lime (genus *Tilia* L.), holly (genus *Ilex* L.); mahogany (genus *Swietenia* Jacq.), maple (*Acer campestre* L.), Norway spruce (*Picea abies* (L.) H. Karst.), oak (genus *Quercus* L.), pine (genus *Pinus* L.), rosewood (genus *Dalbergia* L. F.), satinwood (*Chloroxylon swietenia* DC.), tulip (genus *Tulipa* L.) and several fruitwoods (RORIMER, 1930; HUBBARD, 1967; ODELL, 1972; O'BRIEN, 1983; SCHOTT *et al.*, 1984; POLLENS, 1997; BRAUCHLI, 1998; KOTTICK, 2003; DODERER and VAN DER MEER, 2005; KOSTER, 2007; MARTIN *et al.*, 2010; ESTROMPA, 2012; KOSTER, 2019).

In view of the focus on dendrochronological analysis, this analysis is restricted to the soundboard. Soundboards are often made of softwood with appropriate physical properties, including relatively high elastic modules, low density, and internal damping (KOSTER, 2007). In Italy, the soundboards have historically been made of cypress (HUBBARD, 1967; BRAUCHLI, 1998; KOSTER, 2007; MARTIN *et al.*, 2010), as well as fir, spruce and very rarely maple (KOSTER, 2007). Invariably, Norway spruce was used in Flanders (HUBBARD, 1967; KOSTER, 2007) and England (ODELL, 1972; KOSTER, 2007; MARTIN *et al.*, 2010). In Germany, there was a distinction between north and south, with spruce commonly used in northern regions (KOSTER, 2007) and spruce and fir in southern regions (BRAUCHLI, 1998; KOSTER, 2007). Different species were identified in the soundboards of French instruments: pine (HUBBARD, 1967), "*sapin de Hollande*" (DIDEROT, 1765), and spruce and fir (KOSTER, 2007). The literature on Spanish instruments also mentions different wood species on the soundboard – "*pino abeto*" (BORDAS IBÁÑEZ, 1984; MARTÍNEZ GONZÁLEZ, 2016) and "*ciprés*"[18] (MARTÍNEZ GONZÁLEZ, 2016).

Some of the treaties of the XVIII and XIX centuries can be a source of knowledge on the manufacture and components used in the soundboards of the keyboard's instruments. BRAUCHLI (1998) outlined some of the treaties from which very specific information is taken on chosen materials, such as: **(1)** Peter Nathanael Sprengel (1737-1814) specified in the encyclopaedia *Handwerke und Künste in Tabellen* (published in 1773) that the soundboard should be made of Bohemian or Black Forest fir (*Tannenholz*) as it is specially resin-proof and elastic wood and low resin content. For the manufacturing, the wooden boards should be narrow, cut in the middle of the tree as the fibers are less rough and flattened to a thickness of around 3 mm; **(2)** David Tannenberg (1728–1804) claimed in *Drawings and Instructions* (published *c.* 1780) that the soundboard had to be made of "*spruce pine*" and planed to ⅛ inch; **(3)** Carl Wihelm Lemme (1474-1808) noted in *Anweisung und Regeln zeu einer zweckmässigen Behandlung englischer und teutscher Piannoforte's und Klaviere* (published in 1802) that the instruments should be made of pine ("t*annenholz"*), with special focus on the climatic conditions most appropriate for the maintenance of musical instruments, in particular with regard to temperature and humidity variations; and **(4)** Christian Friedrich Gottlieb Thon (1773-1844) underlined in "*Ueber Klavierinstrumente* (published in 1817), that the soundboard is the most important element of the instrument so it should be made in pine ("*tannenholz"*).

However, the classification of the soundboard woods offers significant challenges due to the difficulty of doing so with the naked eye, under millennia's accumulation of dirt and wax, without removing a sample for laboratory analysis (HUBBARD, 1967; KOTTICK, 2003). ODELL (1972) stated that a simple workshop terminology for soundboard woods is used as a "*pine*" in a number of works on musical instrument history. The German word *"tannenholz"* (or *"tanne"*) is translated as *Abies* (HUBBARD, 1967), as well as pine or fir (BRAUCHLI, 1998). HUBBARD (1967) recognized the problem of wood classification, even considering it to be a linguistic and guessing exercise. However, he believed that, given the difficulty in identifying wood species, there are four possible genera utilized in soundboards: spruces (genus *Picea* Mill.), pines (genus *Pinus* L.), firs (genus *Abies* Mill.) and cypress (genus *Cupressus* L.). FIORAVANTI *et al.* (2017) evaluated the feasibility and reliability of identifying the wood of historical musical instruments using microscopes with high magnification and reflected light together with polarized light filters, which included keyboard instruments. Through several microscopic anatomical features necessary for the wood species identification in the soundboards of virginals, harpsichords, and pianofortes, they identified four species – *Cupressus sempervirens* L. (in over 40% of cases), *Picea abies* L. (H.), *Swietenia* sp. and *Abies alba* Mill.

The sound quality differs according to the wood employed in the soundboard (HUBBARD, 1967). A harpsichord with cypress soundboard sounds less well than the one with a spruce soundboard, namely a lesser volume of sound, quicker attenuation, and a higher number of false notes.

The soundboard timbers come from a variety of sources, such as Bohemia or the Black Forest, Saxony, Lorraine, Switzerland, and the Netherlands, based on historical records (HUBBARD, 1967; BRAUCHLI, 1998; KOSTER, 2007). DES BRUSLONS (1750) mentioned as the main French "*sapin*" forests the regions of Lorraine, Bayonne, Dauphiné, Auvergne and France-Comté[39].

2.2.2.3. Harpsichord´s soundboard manufacture in Portuguese workshops

Not all specialist professions in Portugal were able to discover the denomination that best suited them in their native language in the XVIII century. In the case of the harpsichord makers (in Portuguese, "*construtores de cravos*"), the word used was "harpsichord carpenter" ("*carpinteiro de cravos*"), a direct connection to its technical background as one of the specialties of carpentry. Throughout the second half of the century, this term was replaced by "master, officer or apprentice of harpsichord's maker" ("*mestre, oficial ou aprendiz de fazer cravos*"), "master or officer of

[39] Franche-Comté, historical region and former région of France. As a région, it encompassed the eastern départements of Jura, Doubs, Haute-Saône, and the Territoire de Belfort. In 2016 the Franche-Comté région was joined with the neighbouring région of Burgundy to form the new administrative entity of Bourgogne–Franche-Comté [in Britannica, T. Editors of Encyclopaedia (2017, September 22). Franche-Comté. Encyclopedia Britannica. https://www.britannica.com/place/Franche-Comte].

harpsichords" (*“mestre ou oficial de cravos”*) and simply by "harpsichord’s maker" (*“cravista”*). The word *“cravista”*, however, was also used by musicians who played the harpsichord. For this cause, a modern word "harpsichord's maker of manufacture" ("*cravista de manufactura*") emerged in the first quarter of the XIX century. From the 1830s until the end of the XIX century, the terms "piano maker" ("*fabricante de pianos*") and "pianist" ("*pianista*") emerged in a time of apparent mastery of piano and pre-industrial processes (TUDELA, 2009).

A substantial royal investment in the national musical instrument industry created the circumstances for the rise of Portuguese craftsmen and their innovative talent during the reigns of D. João V (1706-1750) and D. José I (1750-1777). However, the Portuguese corporate model, which focused primarily on domestic demand, was unable to compete with European industrial countries' production. At the beginning of the XIX century, the progressive introduction of foreign fortepianos and pianos into Portugal, notably from England, France, and Germany, led to a decline in the construction of Portuguese instruments (TUDELA, 2019). Documentary historical evidence on the importation of these types of instruments can be found in *Resumos de Importação e Exportação de Portugal para o Brasil, Ilhas, América, África, Ásia e Nações Estrangeiras* from 1819 to 1831, which also indicates their origin, quantity and importance (Table 5). The organological features of the instruments are not explicit since they favor to quantitative and non-qualitative data on the items mentioned.

Table 5. Import list of musical instruments to Portugal from 1819 to 1831 (SOURCE: JC, 1755/1834).

YEAR	DEPARTURE	DESTINATION	SPECIMEN (PORTUGUESE / ENGLISH)	VOLUME	VALUE	TOTAL
1819	France	Lisbon	Orgao de 3 cilindros / 3-cylinder organ	-	20$000	420$000
1819	France	Lisbon	Orgao de 4 cilindros / 4-cylinder organ	7	20000	
1819	France	Lisbon	Orgao de 6 cilindros / 6-cylinder organ	1	20000	
1819	France	Lisbon	Orgao pequeno / Small organ	25	4$000	100$000
1819	France	Lisbon	Piannoforte / Pianoforte	2	150$000	300$000
1819	Hamburg	Lisbon	Grandes piannos / Big pianos	3	4000	44$000
1819	England	Lisbon	Piannoforte / Pianoforte	83	-	9899$560
1819	Italy	Lisbon	Piannoforte / Pianoforte	4	-	570$000
1821	France	Lisbon	Orgao pequeno / Small organ	10	8$000	80$000
1821	France	Lisbon	Orgão grande de 4 selindros / 4-cylinder organ	22	20$000	440$000
1821	Hamburg	Lisbon	Orgao / Organ	2	6$000	12$000
1821	England	Lisbon	Pianno / Piano	46	-	5901$735
1821	England	Lisbon	Pianno / Piano	8	120$000	960$000
1823	Hamburg	Lisbon	Piannoforte / Pianoforte	2	-	260$000
1823	England	Lisbon	Piannoforte / Pianoforte	22	-	2866$753
1823	Italy	Lisbon	Piannoforte / Pianoforte	3	6310	310$000
1824	France	Oporto	Orgao / Organ	4	9000	36$000
1824	France	Oporto	Orgao / Organ	1	120	120$000

YEAR	DEPARTURE	DESTINATION	SPECIMEN (PORTUGUESE / ENGLISH)	VOLUME	VALUE	TOTAL
1824	Hamburg	Lisbon	Piannoforte / Pianoforte	4	-	500$000
1824	Hamburg	Oporto	Orgao / Organ	1	6000	6$000
1824	Italy	Lisbon	Piannoforte / Pianoforte	2	80000	160$000
1825	Hamburg	Lisbon	Pianno / Piano	9	-	1206$000
1825	England	Algarve	Piannoforte / Pianoforte	1	200$000	200$000
1825	England	Lisbon	Piannoforte / Pianoforte	28	-	4009$364
1825	Italy	Lisbon	Pianno / Piano	3	-	672$000
1826	France	Lisbon	Orgao de 3 selindros / 3-cylinder organ	1	-	-
1826	France	Lisbon	Orgãos pequenos / Small organ	4	-	-
1826	France	Lisbon	Orgãos grandes / Big pianos	4	-	-
1826	France	Lisbon	Piannoforte / Pianoforte	1	-	100$000
1826	England	Lisbon	Piannoforte / Pianoforte	39	-	6699$129
1826	Italy	Lisbon	Piannoforte / Pianoforte	4	-	768$000
1827	France	Lisbon	Orgãos de 3 selindros / 3-cylinder organs	6	8000	48$000
1827	Hamburg	Lisbon	Piannoforte / Pianoforte	13	-	2150$000
1827	Netherlands	Lisbon	Piannoforte / Pianoforte	12	-	5473$000
1827	Italy	Lisbon	Piannoforte / Pianoforte	9	-	1180$000
1828	France	Lisbon	Orgão / Organ	2	12000	24$000
1828	Hamburg	Lisbon	Piannoforte / Pianoforte	-	-	-
1828	Hamburg	Oporto	Piannoforte / Pianoforte	2	130$000	260$000
1828	England	Lisbon	Piannoforte / Pianoforte	3	-	380$000
1828	England	Lisbon	Piannoforte / Pianoforte	6	-	667$234
1828	Italy	Lisbon	Piannoforte / Pianoforte	-	-	2408$000
1829	Hamburg	Lisbon	Piannoforte / Pianoforte	11	-	1468$000
1829	Italy	Lisbon	Piannoforte / Pianoforte	13	-	1800$000
1830	France	Lisbon	Orgãos com selindros / Organ with cylinder	1	12000	12$000
1830	France	Lisbon	Piannoforte / Pianoforte	1	-	700$000
1830	Hamburg	Lisbon	Piannoforte / Pianoforte	9	-	1092$000
1830	England	Lisbon	Piannoforte / Pianoforte	21	-	3124$561
1830	Italy	Lisbon	Piannoforte / Pianoforte	-	-	192$000
1830	Italy	Lisbon	Piannoforte / Pianoforte	-	-	700$000
1831	Hamburg	Lisbon	Piannoforte / Pianoforte	17	-	2840$400
1831	Hamburg	Oporto	Manicórdio / Monochord	2	8000	16$000
1831	Hamburg	Oporto	Piannoforte / Pianoforte	5	100$000	500$000
1831	England	Lisbon	Piannoforte / Pianoforte	24	-	-
1831	England	Oporto	Piannoforte / Pianoforte	15	130$000	1950$000
1831	Italy	Lisbon	Piannoforte / Pianoforte	2	100$000	200$000

The information available on harpsichords manufacture in Portugal is very scarce. According to BRAUCHLI (1998), most materials used in Portuguese keyboards instruments from the XVIII century were locally accessible: several wood species (including spruce or pine for the soundboard), iron for the tuning pins from the Basque provinces and Catalonia, brass strings from Toledo, Alcaraz, Seville or Lisbon, iron strings from the Asturias and Minho province. However, the import records reveal that some types of keyboard instrument accessories were imported from Hamburg, England, and the Netherlands (Table 6).

Given that Portugal imported a considerable amount of wood from Europe, two plausible hypotheses should be considered: the use of local and imported wood for soundboards. Historical records mention the use of local woods in the Iberian Peninsula, particularly in Spain. MARTNEZ GONZLEZ

(2016) mentioned the employment of Cuenca Mountain pine wood (referred to as "*madera de Cuenca*" or "*pino de Cuenca*") in the soundboard organ from the XVIII century located in *Monasterio San Lorenzo de El Escorial* (Madrid, Spain).

Table 6. Import list of keyboard musical instrument accessories to Portugal from 1819 to 1831 (SOURCE: JC, 1755/1834).

YEAR	DEPARTURE	DESTINATION	SPECIMEN (Portuguese / English)	VOLUME	UNITY	VALUE	TOTAL
1797	Hamburg	Oporto	Fio de manicórdio / Wire for monochord	1132	*Arrateis*[40]		444$876
1819	Hamburgo	Lisbon		944		$600	566$400
1821	França	Oporto		88		$600	52$800
1821	Hamburgo	Oporto		1400		$300	421$800
1823	Hamburgo	Lisbon		1357		$300	407$100
1824	Hollanda	Oporto		36		$240	160$000
1824	Inglaterra	Oporto		8		$240	1$920
1825	França	Lisbon	Pennas de corvo pª cravo / Crow feathers for harpsichords	1	1.000	$600	$600
1825	Hamburgo	Lisbon	Fio de manicórdio / Wire for monochord	1234	Dozen	$300	370$200
1825	Hollanda	Lisbon		94	Dozen	$300	28$200
1825	Inglaterra	Lisbon	Martelo pª cravo / Hammer for harpsichords	1/2	Dozen	$600	$300
1826	Hamburgo	Lisbon	Fio de manicórdio / Wire for monochord	2737			
1827	Hamburgo	Lisbon		1824		$300	547$200
1827	Hamburgo	Oporto		639		$300	191$700
1827	Hollanda	Lisbon		55		$300	16$500
1827	Hollanda	Oporto		275		$300	82$500
1828	Hamburgo	Lisbon		744		$300	223$200
1828	Hamburgo	Oporto		1004		$300	301$200
1828	Hollanda	Oporto		98		$240 $300	29$400
1829	Hamburgo	Lisbon		1368		$300	410$400
1830	Hamburgo	Lisbon		909		$300	272$700
1830	Inglaterra	Lisbon		50		$350	17$500
1831	França	Lisbon		18		$400	7$200
1831	Hollanda	Oporto		16		$240 $400	6$400

[40] *Arrátel* (plural, *arráteis*) was an ancient unit of measurement of weight corresponding to 459 grams [in Dicionário infopédia da Língua Portuguesa. Porto: Porto Editora, 2003-2021. [Accessed on 2021-04-2]. Available on internet: https://www.infopedia.pt/dicionarios/lingua-portuguesa/arrátel].

3. DENDROCHRONOLOGY IN TECNHICAL ART HISTORY

3.1. Concept and general principles of dendrochronology

In a broad sense, dendrochronology - from the Greek *dendron* (tree), *kronos* (time) and *logus* (study) - is the science that dates the annual tree growth rings. In other words, it is a set of methods aimed at defining the annual tree growth rings (or growth layers) and at assigning each one, in a particular and unequivocal manner, to a unique year in the Gregorian calendar.

The conceptual origins of dendrochronology date back to the sixteenth century with Leonardo da Vinci in *Trattato della pittura* – *"(...) I circoli de' rami degli alberi segati mostrano il numero de' loro anni, e quali furono piú umidi o piú secchi, secondo la maggiore o minore loro grossezza (...)*"[41]. However, the development of dendrochronology, as known today, is credited to the American astronomer Andrew Ellicott Douglass (1867-1962). In the first decades of the XX century, in the South of the United States of America, when searching for a way to collect climatic records to research the relationship between sunspots and the Earth's climate over time, Douglass noted how climate changes had influenced the width of tree rings. On his journey through the forests of northern Arizona, Douglass started to establish hypotheses: **(1)** tree growth would be influenced mainly by the supply of water and secondary light and competition between individuals; and **(2)** narrower growth rings would lead to dry years.

In Europe, dendrochronology experiments started successfully and consistently in the 1930s. The method developed by Douglass started to be used in Germany as an application to solve the issue of medieval oak dating (*Quercus robur* L.). A notable difference with the USA is the type of species used and their different sensitivity due to the European temperate climate. The reference species in Europe are the oak trees, used since prehistoric times in the construction of diverse and artistic applications. The differential response of oaks to climatic conditions has contributed to a number of adaptations in the Douglass method: while the arid climate in the south of the United States has induced drastic reactions in trees that have expressed themselves in the size of a single ring (in a given year), the European climate (more temperate) has produced variations that could be observed in the trend of a series of rings. As dendrochronology handles tree rings to extract information about different temporal and spatial processes, its methods can be used in many fields of research and may be made up of many sub-disciplines, such as dendroarchaeology, dendrochemistry,

[41] Author's free translation: "(…) *The circles on branches of sawn trees show the number of years, and which were wetter or drier, according to their larger or smaller thickness*. (…)".

dendroclimatology, dendroecology, dendroentomology, dendrogeomorphology, dendroglaciology, dendrohydrology and dendropyrochronology. Curiously, dendrochronology has also been used for the study of financial and human activity (MONTERO and VILLALBA, 2005; BOLLE and LÉOTARD, 2011), the temporal spread of famines, plagues, and epidemics (BAILLIE, 1995; BÜNTGEN *et al.*, 2011), and for predicting the consistency of past vintage wines (BOURQUIN-MIGNOT and GIRARDCLOS, 2001).

Dendrochronology is regulated by a series of principles or "scientific rules" on which all study in this area must be focused, with the possibility that accurate results will not be obtained if none of the standards is followed (FRITTS, 1976):

- PRINCIPLE OF UNIFORMITARIANISM

The physical and biological mechanisms that are currently influencing tree growth patterns from the point of view of growth rings have already been recorded by trees in the past.

- PRINCIPLE OF LIMITING FACTORS

The growth of tree rings is constrained by the most restrictive environmental variable.

- PRINCIPLE OF AGGREGATE TREE GROWTH

The basis of variance seen in any sequence of tree growth rings may be "broken down" by a number of environmental, human and natural influences that have influenced the tree's growth pattern over time.

- PRINCIPLE OF ECOLOGICAL AMPLITUDE

The ecological range refers to the range of habitats in which a species can grow and reproduce. Species are more sensitive to climate change (temperature and precipitation) at the latitude and altitude limits of their habitat area.

- PRINCIPLE OF SITE AND TREE SELECTION

The most favourable sites for dendrochronology can be identified and chosen on the basis of parameters that will yield a set of growth rings that are sensitive to the environmental variable under analysis.

- PRINCIPLE OF CROSSDATING

Matching of ring width patterns or other ring features (e.g., density patterns) between different ring series enables the detection of the exact year in which each tree ring was formed.

- **PRINCIPLE OF REPLICATION**

The sign of the environmental factor to be investigated can be maximised and the amount of "noise" minimised, through extensive sampling, with more than one trunk radius per tree, and more than one tree per site.

3.2.Terminology

A *tree ring* is a layer of wood that, in terms of anatomy corresponds to concentric layers of cells in the cross-section of the stem. In temperate climate regions, each tree ring is typically the result of a single annual growth flow that occurs in the spring (earlywood) and finishes in the summer or early autumn (latewood), so that one layer is formed per year (FRITTS, 1976) (Figure 19). There are many species, geographical areas, and cases where dendrochronology cannot and should not be applied because tree ring patterns cannot be dated. Many woody species, particularly those growing in the tropics or semitropics, can produce several growth layers every year, and the number and features of the growth layers are often not coincident from tree to tree or on opposing sides of the stem from the same tree.

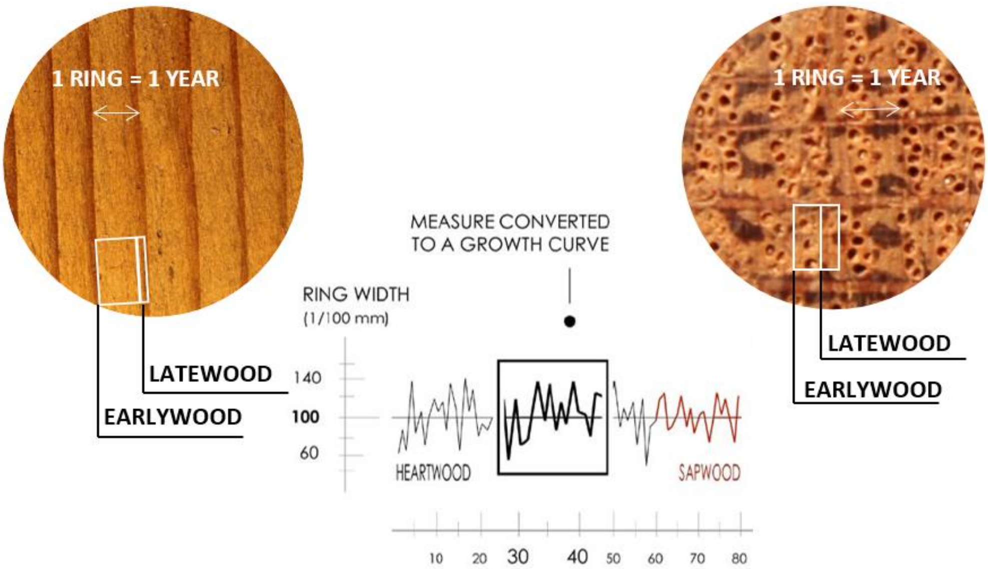


Figure 19. Identifying a tree-ring in conifer (left side) and oak (right side) woods and schematizing the measurements to obtain a growth pattern (SOURCE: Readapted from HEGINBOTHAM and POUSSET (2006)).

The distance from one *tree ring* boundary to the next, almost always expressed in hundredths of millimetres, is referred to as *ring width*. The sequence of growth ring width measurements is known as a *tree ring pattern*, resulting in a *tree ring measurement series* that can be plotted as a *tree ring curve* or *growth curve* (Figure 19).

The growth response of a tree to different forms of environmental influences is reflected in the tree ring pattern, with an abrupt or gradual change in the tree ring widths. A tree ring curve is regarded as an aggregation of various responses, or *signals* (COOK, 1990). Growth signals cover the variability of ring width related to: **(1)** tree's age; **(2)** "local endogenous factors" (for example, competition between neighbouring trees); **(3)** "stand-related exogenous factors" (for example, fire, snow avalanche, insect attack); and **(4)** climate (JANSMA, 1995). Trees can be highly susceptible to climatic and environmental conditions, depending on the species. The recording of these components in the growth rings is indisputable and shows a data collection used for different purposes. Thus, tree rings represent natural archives of environmental information. The topic of the dendrochronological analysis decides which signal is being tested. For dating purposes, the most important is the climate signal represented in the tree ring curve by the difference of tree ring widths from year to year (JANSMA, 1995).

Detrending involves removing growth signals that mask the studied signal from the tree ring measurement series. A detrended measurement series is known as the *growth-index series* (hereafter designated as *index series* or *dendrochronological sequence*). The common signal of the cross dated growth-index series is the fraction of the growth signals that the series has in common. The common signal is determined by the coefficients of correlation between the series.

BAILLIE (1995) considered *cross-dating* as the art of dendrochronology. The measurements data presented as tree ring curve must be aligned against other tree ring curves (SCHWEINGRUBER, 1988; BAILLIE, 1995), which means identifying the right match. This method results in *dendrochronological dating* if the tree ring curve is undated and would match with dated tree ring curves. The average chronologies have a higher dating success rate than the individual series, since the average decreases part of the non-climatic variability in the individual measurements (BAILLIE, 1995; JANSMA, 1995). This means that the average chronologies have the advantage of reducing much of the "noise" associated with individual samples and focusing the associated "signal" (BAILLIE, 1995). *Replication* is known to be a dendrochronological date obtained by a multi-match process.

The early averages of cross-dated growth-index series create an *average chronology*. There is no precise description of each type of chronology in the literature. Owing to the type of samples under analysis and the scale at the geographical level, JANSMA (1995) suggested a classification of five categories of chronologies (Table 7).

Table 7. Classification of tree-ring chronologies [n.a.=not applied; FS=Forest stand; AHO=archaeological/ historical object; * in well-defined geographical regional] (SOURCE: JANSMA (1995)).

CHRONOLOGY TYPE	LIVING TRESS	DEAD WOOD	OBSERVATION VALID FOR	GEOGRAPHICAL SCALE
Tree curve	1 tree	1 tree	1 tree	Point
Site chronology	1 FS	1 bog oak site	1 FS	Micro-scale
Object chronology	n.a.	1 AHO	1 FS?	
Local chronology	2 – 5 FS	2 – 5 AHO	1 FS in 1 forest?	Local scale
Regional chronology	≥ 6 FS*	≥ 6 AHO and bog oak sites*	> 1 FS in >1 forest	Regional scale

3.3. Dendroarchaeology: panels and musical instruments

Dendroarchaeology is a broad term that encompasses all types of dendrochronology applications in archaeology, as well as building and art history (SASS-KLAASSEN, 2002). DOMÍNGUEZ-DELMÁS (2020) described the research objects in detail, including archaeological artefacts, barrels, furniture, historical buildings, musical instruments, panels, ships, and trunks. Sources of ancient history are often considered to be fragmentary, heterogeneous, and sometimes unclear. The date of the artifact corresponds to the year, but it may be referred to the season in more special situations (BERNABEI *et al.*, 2019). In the circumstance that the timber artifact retains bark and only the early wood is visible, it can be confirmed that the tree was felled after the spring.

The scientific study of panels that have emerged over the past century has fundamentally altered the way an artwork is evaluated. Using a broad variety of analytical instruments, researchers in the fields of art history, conservation and computer science, chemistry, physics, and biology highlight the successfully performed of interdisciplinary work. Initially referred to as "*technical studies*", interdisciplinary collaboration has proven to be a growing area of research called "*technical art history*" (AINSWORTH, 2005). In addition to infrared reflectography, X-radiography and pigment analysis, dendrochronology applied to panels is now considered one of the standard techniques, while innovative methodologies have appeared in many areas, such as X-Ray microanalysis – X-Ray fluorescence (XRF), particle-induced X-Ray emission (PIXE), X-Ray diffraction, scanning electron microscopy–energy-dispersive X-Ray analysis, confocal microscopy – 3D micro-XRF and 3D micro-

PIXE (HAHN, 2012), as well as in image processing via wavelet analysis for automatic image characterization and classification.

Main testimonies of the significance and validity of dendrochronology are the various studies that have been developed worldwide and published over the last decades. They began in Europe in 1970 (BAUCH 1968 cited by BAUCH and ECKSTEIN, 1981; BAUCH and ECKSTEIN, 1970), which some researchers subsequently developed (FLETCHER, 1976; BAUCH, 1978; BAUCH *et al.*, 1978; BAUCH and ECKSTEIN, 1981; KLEIN and BAUCH, 1981; KLEIN, 1984, 1986a, 1986b, 1994a, 1994b, 1996, 1997, 1998a, 1998b; KLEIN *et al.*, 1987; BONDE, 1990; KLEIN and WAZNY, 1991; WADUM, 1998). Dendrochronological studies have been especially numerous and with varied authorships over the last two decades (KLEIN, 1999, 2007a, 2007b, 2008a, 2008b, 2010a, 2010b, 2010c; BAUCH, 2002; KUNIHOLM, 2000; FRAITURE, 2002, 2009, 2011, 2012; JANSMA *et al.*, 2004; GRISSINO-MAYER, 2006; LÄÄNELAID and NURKSE, 2006; LEEFANG and KLEIN, 2006; BERNABEI *et al.*, 2007; KRĄPIEC and BARNIAK, 2007; SLOTSGAARD, 2011; WAZNY, 2011; RODRÍGUEZ-TROBAJO and DOMÍNGUEZ-DELMÁS, 2015; HELAMA *et al.*, 2016). Publications referencing the dendrochronological analysis related to Portuguese works of art are scarcer (ESTEVES and KLEIN, 1999; ALMEIDA and ALBUQUERQUE, 2000; KLEIN and ESTEVES, 2001; MNAA, 2013; LAUW *et al.*, 2014; ANTUNES *et al.*, 2016; ANTUNES *et al.*, 2018; CRUZ *et al.*, 2020), as are panels of foreign authorship belonging to Portuguese collections (KLEIN *et al.*, 1999; LEEFLANG *et al.*, 2006). The main output in these studies focus on wood species identification and its provenance, the determination of the *terminus post quem* of the panel or altarpiece, the artistic attribution, and the panel manufacturing technology.

A multidisciplinary approach to the study of wooden musical instruments has also been carried out, with particular focus on: **(1)** dendrochronology; **(2)** varnish and glues characterization by X-Ray Fluorescence (EDXRF), Scanning Electron Microscopy with Energy dispersive X-Ray spectroscopy (SEM-EDX) microanalyses and Micro-Infrared Spectroscopy (µFT-IR) techniques; **(3)** vibro-acoustic characterization; and **(4)** tomographic analysis of ancient instruments used to study internal architecture.

Over the last three decades, numerous dendrochronological studies have been extended to musical instruments, primarily violins and cellos, and reported to the scientific community (CORONA, 1981; KLEIN *et al.*, 1984; KLEIN *et al.*, 1986; TOPHAM and MCCORMICK, 1998; GRISSINO-MAYER *et al.*, 2005; WESTBROOK, 2005; BEUTING, 2009, 2011, 2015; BEUTING and KLEIN, 2003, 2020; BERNABEI *et al.*, 2010; ČUFAR *et al.*, 2010, 2017; BERNABEI and BONTADI, 2011; RATCLIFF, 2012, 2014a, 2014b; BERNABE, *et al.*, 2017; POLLENS, 2017). The wooden belly of several violins, cellos, violas and guitars from several museums and private collections was examined. The study of violins and cellos made in Italy, Germany, England, and France has become a main priority for historical and cultural reasons. RATCLIFF (2014a) mentioned the development of five instrument clusters based on time and origin, assigning local growth trends to each cluster. Emphasis was given to Antonio Stradivari instruments, due to their recognized musical quality and high value, sparking some controversy (KLEIN, 1998C; TOPHAM and MCCORMICK, 2000; TOPHAM, 2002, 2003; BURCKLE *et al.*, 2003; GRISSINO-MAYER *et al.*, 2004; GRISSINO-MAYER *et al.*, 2010). Curiously, Antonio Stradivari's extensive instrument research found that 16 violins were made from a single log wood (RATCLIFF, 2014a). There is an almost complete lack of dendrochronological research on Portuguese building string musical instruments, even though workshops were active in the country in the XVIII and XIX centuries. According to existing literature, only three instruments assigned to Portuguese luthiers belonging to foreign collections have been dendrochronologically dated, namely: **(1)** XVII century guitar, attributed to António dos Santos Vieyra and belonging to the Ashmolean Museum, Oxford (TOPHAM, 2002); **(2)** a small five-course Renaissance guitar attributed to Belchior Dias and belonging to the Royal College of Music, London, dated 1581 (label) (TOPHAM, 2003); and **(3)** a violin from 1929 (handwriting in ink on the bottom) attributed to Augusto Ernesto Pinheiro and belonging to the Theatre Museum Carlo Schmidl, Trieste (BERNABEI *et al.*, 2017). The first-string instrument in a national collection belonging to the National Museum of Music (Lisbon) to be studied dendrochronologically relates to the Neapolitan mandolin assigned to Vincentius Vinaccia, historically dated 1794 (in handwritten label "*Vincentius Vinaccia Fecit Neapoli/Sito Nella Calata dello [S]pitaletto/AD.1794*"). Peter Klein of the University of Hamburg (Germany) successfully dated by x-ray examination, with reference chronologies from the Alpine region to 1756 upwards (TORRES, 2001).

Scientific studies on keyboard instruments have been also limited. POLLENS (1997) reported the dendrochronological research done by Peter Klein in the two Flemish harpsichords of the Metropolitan Museum of Art. The contribution of the dendrochronological analysis to a pianoforte attributed to Gabriel Anton Walter was stated by MAUNDER (2000) in the sense of a controversy about whether it was played by Mozart. A Belgian investigation presents a detailed approach to 34 string keyboard instruments in most of the known authorship, examining technological issues such as soundboard construction, dates, and wood origins (HOUBRECHTS, 2004; 2006). BEUTING (2007) illustrated the dendrochronological studies in musical instruments in an Austrian and a German pianoforte of the Kunsthistorisches Museum Wien. BERNABEI *et al.* (2014) conducted an Italian study on 15 string keyboard instruments from the *Conservatory Luigi Cherubini* collection.

Dendrochronology applied to artwork may provide an important contribution to answering to such geographical, technological and cultural issues Dendrochronology applied to artwork may provide an important contribution to answering to such geographical, technological and cultural issues that cannot be addressed by historical and philological methods alone. This technique can be used for the following purposes:

I. To sustain authentication

If the artwork itself is dated, any dendrochronological estimate should help to authenticate it (BAILLIE, 1982).

II. To supply a date "*terminus post quem*"

Dendrochronological studies allow authorship assignments and/or dates of art objects to be checked in complementarity with other research techniques in some cases. Certain erroneous assignments and dates, defined by one or more scientific methods, do not have wilful wrongdoing at their origin (CORONA, 1992), as seen in the following examples:

(1) *Christ appearing to his Mother*, a panel from The Metropolitan Museum of Art, originally attributed to Rogier van der Weyden, was convincingly re-evaluated, and is considered nowadays a slightly smaller reproduction after Rogier's own version of his artwork found in the Gemäldegalerie, Berlin (AINSWORTH, 1992).

(2) During the conservation-restoration treatment, the *Leuven Trinity* panel of the M-Museum Leuven, Belgium, originally credited to Robert Campin's workshop or Jacques Daret, was re-evaluated. According to art historical appraisal, stylistic analysis and material analytical methods, the result was that the panel should be assigned to Rogier van der Weyden's workshop (VANDEKERCHOVE *et al.*, 2009).

(3) Often, with the presence of various versions of the same scene credited to the same painter, the original panel is debated. Four similar panels originally attributed to Hieronymus Bosch are a simple example: *Christ Mocked* (or *The Crowning with Thorns*) at the National Gallery of London, *Christ Crowned with Thorns* at the Museo de Belles Artes in Valencia (Spain), *The Crowning with Thorns* at the *Monasterio San Lorenzo de El Escorial* (Madrid, Spain) and *The Mocking of Christ* at the Art Museum of Philadelphia (USA). It was obvious that the version in the National Gallery of London should be the original, based on the dendrochronological dates obtained in the four panels (KLEIN, 1996; KLEIN, 2010b).

(4) For the *St. John* altarpiece attributed to Rogier van der Weyden, in the Städel Museum, Frankfurt am Main, the dendrochronological date was 50 years after the death of the painter (KLEIN, 1986).

(5) The attribution date of 1614 to an Italian guitar assigned by Matteo Sellas (active in Venice between 1625 and 1645) had to be revised since the youngest tree-ring measured was 1630 (TOPHAM, 2003).

(6) The date of the outermost tree-ring of the Karr-Koussevitzky double bass (1761) did not support the original date and thus did not support the assignment (1611, Amati Brothers) (GRISSINO-MAYER *et al.*, 2005).

The six Portuguese panels traditionally designated by *Painéis de São Vicente de Fora* (or *Políptico da Veneração a São Vicente*) attributed to the royal painter of the Portuguese king D. Afonso V, Nuno Gonçalves, in exhibition at the National Museum of Ancient Art, Lisbon, are an excellent example of the contribution of the dendrochronological analysis in multidisciplinary research carried out in the field of ancient art (ALMEIDA and ALBUQUERQUE, 2000; PEREIRA, 2010). Without related historical documentation, a great controversy has arisen between historians, art critics, heralds, and artists over the last century around the six panels, regarding the dating, attribution, and iconographic identification of the figures. Different dating criteria were applied (dress, wardrobe, hairstyle), but with a wider timeline. Peter Klein performed dendrochronological analysis in 2001 and established the year 1431 as the *post quem terminus*, with the most possible panel date after 1442. However, this finding has been viewed in a discordant manner, conforming to various modes of thought. According to ALMEIDA and ALBUQUERQUE (2000), the dendrochronological findings give credibility to the year 1445, allegedly painted on the boot strap of the figure of one of the six panels, as the year of completion of the work. PEREIRA (2010), on the other hand, refuted the existence of a date written on the panel and its interpretation, arguing that an artwork of this scale is difficult to create in less than two years.

III. To date, more specifically, a collection of art objects from the workshop of a certain artist

If there is no established date for the art piece, as is often the case, a dendrochronological estimate may be useful in establishing the cycles of an artist's style or distinguishing the artist's works from those of "his school" (BAILLIE, 1982). Many gallery catalogues and art bulletins provide numerous dendrochronological investigations that have shown to be quite useful in determining the estimated age of the panel (HAND and WOLFF, 1986; AINSWORTH and MARTENS, 1994; URBACH *et al.*, 2015).

IV. To provide evidence of the initial relationship between the scattered wood pieces

A particular case of this type of contribution happens when wooden boards of the same tree are detected in the work of various artists or the same artist (KLEIN 1980; TOPHAM, 2003; KLEIN, 2010b). Two possibilities are raised: **(1)** wood panels may have been usable concurrently in an artist's workshop and could be used for various artworks on identical production dates; or **(2)** different artists could have bought wood boards from the same joinery that are then used later in different studios. It could not, though, be ruled out that the panels may have been in the studio for an indefinite time before their use. Therefore, the date of manufacturing cannot be the same for art objects using wooden parts of the same tree. Dendrochronology does not provide a solution in this situation, but it does add to the debate.

An additional example is the dendrochronological research conducted by FLETCHER (1976). He referred that a bunch of English portraits from the XVI century were made in the primary English workshop that endeavour to deliver duplicates of Henry VIII image, in more modest measurements, to offer to sovereigns and other significant people.

TOPHAM (2003) displayed a number of instances of wooden components from the same tree that constitute the front of several stringed musical instruments created by different artists, such as: **(1)** one of the front parts (dated 1682) of German luthier Joachim Tielke's bass guitar (1641-1719) belongs to the same tree as one of the front pieces (dated 1685) of an instrument made by Thomas Urquhart, an English luthier (*c.* 1629 - *c.* 1698); and **(2)** the two tree-rings series obtained (dated 1899 and 1904) in an Italian viola, historically dated 1923 and attributed to Giovanni Maria Ceruti, are cross-matched, in particular, with the French violin by Emile Miquel (1851-1911) and the English violin Alfred Vincent (1877-1902) tree ring series.

V. To identify possible fakes

Dendrochronology is recognized as one of the scientific methods to accuracy, if not a precise date reflected in calendar years, at least an indicative of whether the study item is likely to have the age ascribed stylistically or historically (CRADDOCK, 2009). In the organological domain, false dating and attributions are quite common because they are frequently associated with great economic or cultural interests. Nevertheless, it must be recalled that it was not unusual in the past to put false labels with the names of distinguished luthiers, as well as to produce exquisite instruments as a tribute to the great masters of the period (CORONA, 1992; CRADDOCK, 2009). There are some dendrochronological examples that explicitly illustrate the falsehood of an artwork, such as originals and copies of several Stradivari violins from private collections (KLEIN, 1998c).

The level of knowledge obtained from the study of a large selection of a single artist or a collective of similar artists from a dendrochronological point of view is greater than the extended study of individual artwork by different authors (KLEIN, 1986a). The high number of tree-ring series obtained by wood boards analysis of several artworks from the same workshop or region can enable the creation of master-chronologies. In addition to this great contribution, the possibility of comparing the same tree-ring sequence on multiple occasions can be an especially useful tool for assigning such artworks. Statistically, wood boards come from the same tree can be determined. If the wooden boards of separate panels come from the same oak, it may be appropriate to redefine the *terminus post quem* in one or more artworks. A clear example of this case is the dendrochronological study of three panels attributed to Petrus Christus (*Portrait of a Female Donor* and *Portrait of a Male Donor* belonging to the National Gallery of Art collection, Washington, and *Madonna Enthroned with Saints Jerome and Francis* belonging to the Städel Museum collection, Frankfurt am Main). KLEIN (1994a) determined as *terminus post quem* the years 1391, 1412 and 1421, respectively, but in the case of Washington donor portraits the year 1421 should be reconsidered as the three boards on which the most recent rings were identified in the three panels belong to the same tree.

An art object's interpretation in the sense of a dendrochronological study should be intimately related to its manufacturing analysis and future reconstruction. The following case studies provide insight on the risks involved with dendrochronological dating in the absence of multidisciplinary collaboration on the same artwork to offer art historians with more precise answers.

I. Panel study can prove more challenging in response to uncomplicated dendrochronological dating. WAZNY (2011) analysed the *Still life of dead game* panel attributed to the School of Rembrandt van Rijn belonging to the Herbert F. Johnson Museum of Art, Ithaca, New York. He discovered that the initial support of the XVII century had been reinforced by six oak boards of higher quality during the reconstruction at an uncertain date. Four of the six boards are nearly 200 years older than the original panel. It indicates the older panels have been divided into parts and used to reinforce the original panel. In comparison, the author of the study states that Rembrandt used a wooden board from the same tree in *The Landscape with the Good Samaritan* panel, belonging to the Princes Czartorysky Museum in Krakow. In the light of the recent observations, WAZNY (2011) posed additional concerns for art historians, which, in his view, could not be addressed by dendrochronology at risk of conjecture.

II. BAUCH and ECKSTEIN (1981) dated the *A warrior* panel, with a 1638 signature, inside a larger dendrochronological analysis of eighteen panels of Rembrandt, but it was not recognised as an authentic panel of Rembrandt. A female portrait was observed under the surface panel by x-ray analysis conducted at the same time. Thereby, the *terminus post quem* (1612±5) had been naturally associated to just this female portrait. The investigators found that the difference between the two dates was substantial and suggested the possibility of a re-use panel. However, they proposed that dendrochronology should limit interpretations and should be reserved for art historians.

III. The contribution of dendrochronology was deemed significant by art historians as part of an investigation into the relationship between the *St. Thomas* panel, assigned to Rembrandt van Rijn, belonging to the Pushkin Museum of Fine Arts, Moscow, and a very similar panel of the same name belonging to a private American collector. In the first approach, BAUCH (2002) did not date the first panel at all, although the central board had 249 measurable tree rings. However, by analysing the central board with 300 tree-rings, he was able to partly date the second one. In a second phase, the author compared the only dated series with chronological series obtained from other works of the same painter. It seemed that the wood was of the same tree as one of the three boards of the *Portrait of man in oriental costume* panel, belonging to the Alte Pinakothek, Munich. Dendrochronology thus accomplished the time frame of the Chicago panel and confirmed the assignment to Rembrandt. However, BAUCH (2002) proposed an X-ray review of the two dated panels to determine which version was the first to be produced.

IV. The Italian violin dendrochronological dating (1931) attributed to Pietro Ranta (active between 1729 and 1733), belonging to the collection of the Civico Museo Theatrale Carlo Schmidl, Trieste, historically dated 1733 by its label, initially posed some doubts and restrictions. The existence of a violin kept by its previous owner was demonstrated by the existence of a 1917 photograph. An in-depth historical analysis found that given the loss of its front, the musical instrument had been restored in the 1950s. The use of newer woods in the reconstruction was validated by dendrochronological evidence initially established by the research team (BERNABEI *et al.*, 2017). This example shows the need for a critical spirit when conducting an interpretation of dendrochronological data collected during the investigation.

V. Dendrochronological observations can also be found to be inconclusive if there is a disparity between dating methods. The case-study *The King Arthur Round Table* is a prime example (CRADDOCK, 2009). Two historical scenarios were suggested for the date of its creation: **(1)** in 1290 by King Edward I; or **(2)** at the end of the first half of the XIV century, when King Edward III issued the Order of the Round Table and ordered the construction of a special room at Windsor Castle to house the Order. Dendrochronology provided a period between 1260 and 1280, with radiocarbons dating back to the early XIV century.

One of the fundamental rules of dendrochronology is that the tree ring should date one and only one position in time. This means that if a growth ring has been properly dated, it cannot have multiple dates. Nonetheless, there are a few case-studies on dendrochronological data re-evaluations by different researchers with the same "object of study" (VANDEKERCHOVE *et al.*, 2009; GRISSINO-MAYER *et al.*, 2010). Unfortunately, there is not always an attempt to explain the discrepancy of evidence. VANDEKERCHOVE *et al.* (2009) presented the year 1411 for the last measured tree-ring in the analysis of the materials and techniques applied to the *Leuven Trinity* panel from the M-Museum Leuven, Belgium, which is a result different from the one originally presented by Peter Klein as 1369 (ASPEREN DE BOER *et al.*, 1990). The first calculations could not be accessed by VANDEKERCHOVE and her research team, thus failing to improve the analysis and explain the contradictions. Such lack of clarity as to the difference of results contributes to a "negative" image of dendrochronology. Fortunately, there was a different response in the controversial case concerning the re-dating of the *Messiah* violin attributed to Antonio Stradivari, belonging to the Ashmolean Museum, Oxford (TOPHAM, 2000; GRISSINO-MAYER *et al.*, 2010). The scientific community was confronted with some disagreement (TOPHAM, 2000; GRISSINO-MAYER *et al.*, 2010) since the research team created by Angelo Mondino and Matteo Avalle identified the years 1832 and 1844, respectively, using SynchroSearch Software, based on the raw measurements collected (as well as the dendrochronological dates of 1682 and 1687) and made available by H. D. Grissino-Mayer, P. Sheppard, and M. K. Cleaveland at the ITRDB (BRIT050[42]). In the light of this new investigation, the *Messiah* violin could not be attributed to Antonio Stradivari and was attributed to Jean-Baptiste Vuillaume. To explain the divergent findings of the two researchs based on the same raw measurements, the Violin Society of America team headed by Henri Grissino-Mayer identified and

[42] Grissino-Mayer, H.D.; Sheppard, P.; Cleaveland, M.K. (2003-01-27): NOAA/WDS Paleoclimatology - Grissino-Mayer - Messiah Violin - PCAB - ITRDB BRIT050. NOAA National Centers for Environmental Information. https://doi.org/10.25921/8se2-5715. Accessed [21.11.2015].

counteracted the erroneous statistical problems related to the re-dating of the violin (GRISSINO-MAYER *et al.*, 2010). TOPHAM (2000) has shown that the date of the *Messiah* violin's belly is fully consistent with its attributed date of production.

3.4. Requirements for tree-ring dating

BERNABEI *et al.* (2010) referred the three requirements which must be strictly followed for a precise, high-precision, and efficient dendrochronological date, based on the Italian standard UNI Standard 11141, entitled *'Wood dendrochronological dating guidelines'*:

1. The wood piece must contain an adequate number of unambiguously, observable, and measurable tree rings (see subchapter 3.6.2.2. *Short tree-ring series*). Since dendrochronology is a scientific discipline focused on statistical analysis, the reliability of the results increases in relation to the length of the data series to be compared.
2. The object must be made of a tree species suitable for dendrochronology. GRISSINO-MAYER (1993) presented a list of 573 wood species in tree-ring research, with information on species known to cross date, as well as information on species with measurement and/or chronology data in the International Tree Ring Data Bank (ITRDB). The author suggested a basic index, *Crossdating Index* (CDI) as follows: **(1)** CDI=0 means species that are actually not known to cross date and are thus of little or no value in dendrochronology; **(2)** CDI=1 means the ability of a particular species to cross date between trees at any one site, *i.e.*, a wood species of minor importance in dendrochronology but which may be able to provide information on a site-by-site basis; and **(3)** CDI=2 signifies the ability of a particular species to cross-date between sites in either area, i.e. species that cross-date between sites in a region and thus have the greatest potential for dendrochronological analyses on a regional basis. BERNABEI *et al.* (2007) referred that riverine species (for example, poplar (*Populus* spp.), willow (*Salix* spp.), and alder (*Alnus* spp.), or those subject to severe human disturbance like fruit trees (e.g., *Rosaceae*), chestnut (*Castanea sativa* Mill.), or walnut (*Juglans regia* L.) are usually less appropriate for dendrochronological studies as the climate signal in tree patterns is reduced by more factors impacting tree growth. In accordance with GRISSINO-MAYER (1993), these wood species have a CDI equal to 0 or to 1. Table 8 presents the main tree genera used in dendrochronology. The most studied genus is Pinus, since the pine species are among the most widely distributed botanical species in the world with a remarkably high ecological range.

Table 8. Thirteen major tree genera applied in dendrochronological research (SOURCE: GRISSINO-MAYER, 1993).

RANK	GENUS	NUMBER OF SPECIES INVESTIGATED	NUMBER OF SPECIES THAT CROSSDATE
1	*Pinus*	63	54
2	*Quercus*	44	27
3	*Abies*	34	21
4	*Picea*	21	19
5	*Juniperus*	21	15
6	*Larix*	9	9
7	*Populus*	10	7
8	*Nothofagus*	12	7
9	*Acer*	10	6
10	*Dacrydium*	5	5
11	*Betula*	13	5
12	*Tsuga*	7	5
13	*Cedrus*	4	4

3. A reference chronology for the species and the geographical area must be available. BRIDGE (2012) backed the idea that chronologies give the best match with sites of closer geographical origin has been oversimplified. In two dendrochronological experiments of live oak sites, the author has shown that there are better matches with trees growing under comparable conditions (even farther away) than with even closer sites.

According to the wood species selection, the most common method is the distinction of chronologies of the same species (known as *teleconnection*). Instead, once chronologies of the same species are not available to date the artifact, master curves of various species can be adopted (BERNABEI *et al.*, 2019). This scenario, known as *heteroconnection*, makes it possible to span distinct geographical regions or to stretch over a longer period. Two interesting examples of *heteroconnection* can be found in the literature: **(1)** the establishment of the first beech chronology through a comparative analysis based on oak chronologies. The mean beech and oak chronologies from the same site have been shown to be well-matched with the required degree of statistical confidence, considering the variations in the structure and physiological behaviour of the two species (KLEINE and BAUCH, 1981); and **(2)** BERNABEI and BONTADI (2011) obtained remarkable dendrochronological statistical findings in the dating of six stringed instruments against the Italian silver fir reference chronology, while the anatomical study verified that all the bellies were made from Norway spruce. The authors believed that in areas where spruce chronologies are not available, silver fir chronologies indicate comparable growth wherever silver fir and spruce exist in similar ecological environments or in mixed forests.

3.5. Types of dendrochronological dating in dendroarchaeology

A dendrochronological date is obtained for the last whole ring preserved and identified (*i.e.,* the outer growth ring) on the wooden artifact. The absolute or partial absence of sapwood rings in artefacts, however, is quite common (see subchapter 3.6.1.2. *Sapwood number*) (HANECA *et al.*, 2005; VEROUGSTRAETE, 2015), leading to less useful dendrochronological details (SCHWEINGRUBER, 1988). Three cases that can occur: **(1)** part of the sapwood is present; **(2)** none of the sapwood is present, but the sapwood-heartwood transition may be identified with certainty; and **(3)** both the sapwood and part of the heartwood are missing. In the first two cases, an average felling date for the tree can be estimated by adding the estimated number of sapwood rings to the date of the last known heartwood ring. The third scenario is the most complicated because the number of heartwood rings that could already have been extracted is a new unknown (BAILLIE, 1982). According to VEROUGSTRAETE (2015), it was difficult for woodcutters to discern the line between sapwood and heartwood on freshly cut oaks. Therefore, they would presumably prefer to cut any heartwood rings to ensure the complete absence of sapwood, to conform with the stipulated rules. Any of these cases had one of two causes: the sapwood rings have been trimmed off by users, or the wood has been damaged by microorganisms and wood-boring insects.

Depending on the type of artefact under study and the wood species, the criteria for the removal of sapwood vary:

1. In the case of oak panels, the most common technique was the removal of sapwood rings in each board to protect against potential biological decay (BAILLIE, 1982; FRAITURE, 2002; HANECA *et al.*, 2005; BERNABEI *et al.*, 2007; WAZNY, 2011).
2. In the case of buildings, normally the carpenter carved wood, removing an uncertain number of rings (KUNIHOLM and STRIKER, 1987).
3. In the case of beech, silver fir and Norway spruce, it is believed that the standard procedure was to use the whole tree, except the bark (KLEIN, 1998c). It is impossible to estimate accurately the felling year based on the younger tree-ring identified in Norway spruce artwork (KLEIN *et al.*, 1986; RATCLIFF, 2014b). Any approximation of the felling date by extrapolating the estimated number of sapwood rings is not considered realistic since these species do not develop a perceptibly sapwood (KLEIN, 1986; 1998b). TOPHAM (2000) suggested that there was no standardised method for the removal of a certain quantity of sapwood by Cremona's luthiers. KLEIN *et al.* (1986) argued that it is possible to make a general explanation of the use of sapwood for instruments only after further in-depth studies on violin makers from different

schools. As reported by RATCLIFF (2014b), if there is a short period of time between the dendrochronological and the manufacture date of the musical instrument, it can be concluded that this corresponds to "*expedient wood transportation and minimal seasoning*" (see subchapter 3.6.3.2. *Time span after tree felling*).

Bearing in mind the risk associated with misinterpretation of wooden outer ring dating, BAILLIE (1982) suggested a scheme to classify the relative quality of dating (Table 9).

Table 9. Dating qualities according to the identification of the outer growth ring (SOURCE: BAILLIE, 1982).

Type A (***precise***)	The final growth ring is present and unmistakably with the presence of the bark.
Type B (***close estimate***)	Sapwood is mainly complete, but the outer portion is absent or damaged. The felling date is derived by adding an estimate sapwood rings to the date of sapwood-heartwood transition.
Type C (***reasonable estimate***)	A trace of sapwood remains, or an evident sapwood-heartwood transition can be inferred from the curvature of the surface. The felling date is likely by adding a sapwood estimate to the date of the sapwood-heartwood transition.
Type D (***suspect***)	No evidence of sapwood exists nor proof for the curved sapwood-heartwood transition. It is impossible to be sure of how many heartwoods rings are missing. The felling date will be at least the estimate sapwood rings after the outermost remaining ring but *may be much later*. Type D dating provides only a *terminus post quem* for felling.

Due to this uncertain number of trimmed sapwood rings, the sapwood should be treated as an estimate (BAILLIE, 1982; FRAITURE, 2002; HANECA *et al.*, 2005). The sum of the last ring measured with the approximate number of sapwood rings (see subchapter 3.6.1.2. Sapwood number) indicates the date of the *terminus post quem* (or the date of *the terminus post quem* for tree felling), i.e., the date on which the tree must have been felled and the wood consequently used. Regardless of the criterion selected for the estimated number of sapwood rings, if the minimum value is assumed, it is obtained "*terminus post quem* for the earliest possible tree felling"; if one chooses the average/median value of sapwood rings, it results in "*terminus post quem* for the estimated tree felling" date.

Numerous dendrochronological studies on oak panels often suggest adding the factor "expedient wood transportation and minimal seasoning" (see subchapter 3.6.3.1. *Time span after tree feeling*), thus considering "*terminus post quem* for the support manufacture" (or "presumed dendrochronological date"). However, FRAITURE (2002) provided dendrochronological findings based on the "*terminus post quem* for tree felling" and thus dismissed the second subjective factor.

From more than 440 oak panels used by nearly 75 artists analysed in 26 galleries from several countries, BAUCH (1978) concluded that the approximate date for the panels of the XIV and XV centuries is more difficult to estimate than that for later centuries. In the XVI century, the period between the tree feeling and its use for a board panel was more significant in the Netherlands and Germany than in the XVII century. Wood boards were scarce in the second half of the XVII century and an improvement in the reuse of boards was thus a choice. In the dendrochronological analysis of the panels of this time, this fact added another potential problem.

3.6. Limitations in dendroarchaeology

Dendrochronology, like all fields of study, has some drawbacks. SPEER (2010) described four general limitations: young trees, calibration data sets, lack of tree ring formation in the tropics and some deficit of physiological knowledge of how tree rings are produced. For each of them, he provided a collection of generic solutions undergoing continuous scientific research in several areas. Tree ring dating cannot always provide the desired and concrete response. In the case of artefacts, there are a few possible sources of inaccuracy that must be considered when estimating a date.

3.6.1. Biological restrictions

3.6.1.1. Ring-growth anomalies

Tree-rings are particularly hard to recognise in many situations. Only cases in which a single artefact (for example, an altarpiece) consists of many pieces of wood may theoretically allow a comparative study of measurements and the detection of possible irregularities. Certain instances, such as the "impossible" band of oak rings with indistinct lines of vessels, cannot be solved with any degree of certainty (BAILLIE, 1982). The mere counting of growth rings is insufficient, may prevent cross-dating and lead to errors in the assignment of dates due to many ring-growing irregularities, i.e., micro rings, false rings, missing rings, pinching rings, frost rings, diffuse ring borders and offset of wood growth through rays.

False rings, or intra-annual growth lines, are associated with a temporary suspension of apical growth, induced by limiting factors and accompanied by a resumption of growth in the same year. The forming of such rings can be caused by droughts, insect defoliation, fire, storm, tree crown removal, as well as frost damage (BAILLIE, 1982; BIONDI *et al.*, 2003; SCHWEINGRUBER, 2007; SPEER, 2010). Locally inactive cambium induces discontinuous tree rings and, as a result, dissimilarity of the growth ring circuit in the cross section. Both genetic predispositions and environmental influences contribute to this phenomenon, which can be seen over the entire thickness of the ring or either in latewood or earlywood. For example, in ring-porous species with minimal resources, particularly under poor light conditions or with reduced assimilation capability of the crown, early wood pore rows are discontinuous or missing altogether. This phenomenon of discontinuous or locally absent tree rings (also known as **missing rings**, **wedging rings,** or **pinching rings**) makes it hard to determine the exact number of rings and requires a comparative visual analysis of several directions of the same section in order to obtain a representative tree growth pattern (SCHWEINGRUBER, 2007; SPEER, 2010). In the case of oak, one of the plants most used in works of art in Europe, it is extremely rare see a missing growth ring or two distinct rings in a single year (BAILLIE, 1982; HANECA *et al.*, 2009). This phenomenon can be readily detected in a wider cross-section, but not necessarily in panels and furniture research, with only a narrow cross-section band available (HANECA *et al.*, 2009).

In certain species, the **offset of wood growth across rays** is not unusual (e.g., in oak). In situations where cell division does not occur at the same rate over the entire trunk diameter, the same growth ring on both sides of the ray can be misaligned (BAILLIE, 1982; SPEER, 2010) as seen in Figure 20.

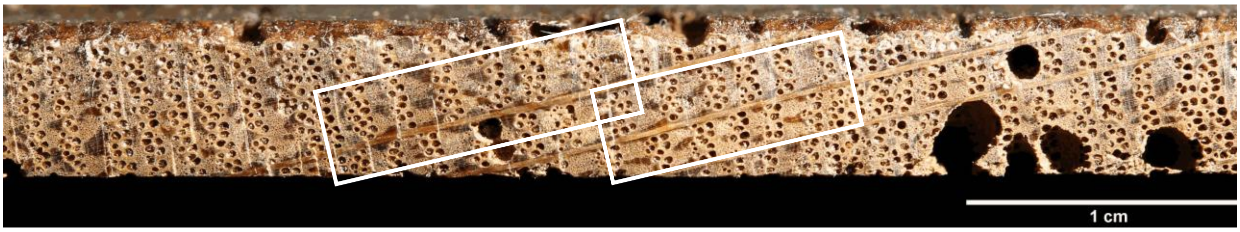


Figure 20. Offset of wood growth across rays in the transverse section of oak board from the *Aparição do Anjo a Sta. Clara, Sta. Inês e Sta. Coleta* panel (MS-CJ1-PR1, CJ-MS), attribute to Flemish painter Quentin de Metsys (SOURCE: CEF-ISA unpublished).

Frost rings form in the mid to high latitudes as the air temperature falls well below zero during the growing season. The cold temperature causes the spreading of water in the lumen of the cell, destroying the cell walls' integrity (SPEER, 2010). The frost rings are typically not present in the whole cross section of the stem and most frequently appear further up to the stem than close to the ground. In deciduous and coniferous species, they show a similar anatomy (SCHWEINGRUBER, 2007).

Micro rings can be generated by a tree, which means incredibly narrow rings just a few cells wide (e.g., beech) (SPEER, 2010).

3.6.1.2. Sapwood number

In the interpretation of tree-ring dates, many authors say that the sapwood ring number is the biggest single problem (HUGHES *et al.*, 1981; BAILLIE, 1982; VEROUGSTRAETE, 2015). Sapwood and heartwood depend on the wood species because their proportion and distinction vary greatly between species and under various growing conditions (BAILLIE, 1982). The transformation from sapwood to heartwood involves the accrustation and saturation of cell walls with excretions, as well as deposits in cell lumina and intercellular spaces. These mechanisms are attributed to physiological and biochemical activities caused by the environment, as well as chemical reactions in living and felled trees (SCHWEINGRUBER, 2007). According to SCHWEINGRUBER (1993), it is possible to discriminate between three specific types of heartwood formation: dark-coloured heartwood (high protective effect), light-dry heartwood (moderate protective effect) and no detectable heartwood (low protective effects). In spruce, one of the wood species identified in artworks, the heartwood is described as light-dry, and the sapwood and the heartwood are optically indistinguishable (SCHWEINGRUBER, 1993). The number of sapwood rings varies considerably between trees of different locations, even when comparing trees of the same age class (KLEIN *et al.*, 1986; SELLIN, 1996; LONGUETAUD *et al.*, 2005; RATCLIFF, 2014b), and may even include more than 60 sapwood rings (KLEIN *et al.*, 1986).

Beech and fir do not have detectable heartwood (for this reason KLEIN (1998b) often referred them as "all-sapwood species") and light-dry heartwood, respectively (SCHWEINGRUBER, 1993).

Oak, one of the most used species in Europe for art objects, namely panel and sculpture, is a dark-coloured species of heartwood. The sapwood is lighter in colour, the large earlywood vessels of the sapwood are hollow, while those of the heartwood are blocked by tyloses (HUGHES *et al.*, 1981; BAILLIE, 1982; SCHWEINGRUBER, 1993; SOHAR *et al.*, 2012). Therefore, SOHAR *et al.* (2012) established two distinct criteria for the identification of sapwood: lighter colour and absence of tyloses in the earlywood vessels, despite sapwood-heartwood boundary seldom follows the same ring in the same tree (HUGHES *et al.*, 1981; SCHWEINGRUBER, 2007).

The number of sapwood rings varies greatly, depending on tree's age, with old trees tending to have more sapwood rings than younger trees (KLEIN, 1994b; HANECA *et al.*, 2009; SOHAR *et al.*, 2012), position in the tree (HUGHES *et al.*, 1981; HANECA, 2005; SOHAR *et al.*, 2012) and various conditions of growth (BAILLIE, 1982; SOHAR *et al.*, 2012). However, LONGUETAUD *et al.* (2005) concluded that the number of heartwood and sapwood rings is strongly associated with the cambial age of and is practically independent of growth conditions. The authors suggested that the width of the sapwood in the stem at any level can be derived from the cambial age of the stem at that height and the respective radial growth rate. Table 10 provides a list of several studies on the sapwood estimate in Europe. In view of the spectrum of sapwood ring criteria, a fruitful discussion with art historians should complement the analysis of the dendrochronological study for each panel examined. KLEIN (2010b) provided a good example of the need for a multidisciplinary approach to draw a decision. Among several dendrochronologically dated panels attributed to Jan van Eyeck, he highlighted the panel *Virgin of Chancellor Rolin* (Musée du Louvre, Paris) with an historical date of *c.* 1435/36, for which the assignment of a median value of 15 sapwood rings to the last measured ring culminated in 1442, bringing into question the attribution of the panel after the death of Jan van Eyeck in 1442. The author argued that the median value of the sapwood rings should not always be considered.

Table 10. European sapwood rings estimate for oak [n.s.=not specified].

Region	Wood species	Material	Sapwood rings number		Absolute range	Confidence interval	Reference
			Median	Mean ± SD			
Aegean (Greece)	Wood samples	Living forests, standing buildings and archaeological sites	-	25.6±9.0	-	-	KUNIHOLM and STRIKER (1987)
Easter Baltic (Estonia, Finland, Latvia, Lithuania)	*Quercus pedunculate* L.	Living oaks	12	-	2-26	-	SOHAR *et al.* (2012)
			11.5	-	1-23	-	
Easter Baltic (Finland)	*Quercus robur* L.	Living oaks >120 years		13.9±3.2	7-24	-	BAILLIE *et al.* (1985)
Germany	Oaks < 100 years		-	16.0±4.5	-	-	HOLLSTEIN (1965), cited by HUGHES *et al.* (1981)
	Oaks 100-200 years		-	20.4±6.2	-	-	
	Oaks > 200 years		-	25.9±7.5	-	-	
	n.s.		-	25.0	-	-	HUBER (1967), cited by HUGHES *et al.* (1981)
Germany (North)	Oaks 150-160 year		-	20	max 27	-	HOLSTEIN (1980, cited by WAZNY (2011)
Germany (West & NL)	n.s.		17	-	7-23	-	KLEIN (2007c)
Irland	n.s.		-	31.8±9.0	-	-	BAILLIE (1973), cited by HUGHES *et al.* (1981)
North Wales	n.s.		-	27.2±4.9	-	-	LEGGETT *et al.* (1978), cited by HUGHES *et al.* (1981)
	n.s.		-	34.0±7.0	-	-	MILSOM (1979), cited by HUGHES *et al.* (1981)
NW England & North Wales	*Quercus pedunculate* L.	Living oaks	30	-	19-50		HUGHES *et al.* (1981)
Poland	*Quercus* spp.	Historical timbers	15	-	9-23	90%	WAZNY (1990)
	Oaks < 100 years		-	13±3	6-22	-	
	Oaks 100-200 years		-	17±4	9-31	-	
	Oaks > 200 years		-	18±5	9-30	-	
	Oaks > 300 years		-	-	min 13	-	BAUCH (2002)
Poland (Greater)	n.s.		13	-	6-21	90%	KRĄPIEC and KRĄPIEC (2014)

Region	Wood species	Material	Sapwood rings number		Absolute range	Confidence interval	Reference
			Median	Mean ± SD			
Poland (North)	*Quercus* spp.	Living oaks	15	-	9-36	-	ECKSTEIN *et al.* (1986)
Poland (Western Pomerania)	Oaks > 100 years		17	-	10 – 26	90%	WAZNY (2001)
Poland (South)			13	-	7 – 22	90%	
Western Europe	n.s.		17	-	7-50	-	KLEIN (2007b)

3.6.2. Methodological restrictions

3.6.2.1. Unavailable reference chronologies

The lack of a chronological reference for a given site/time span/wood species at the time of the investigation might justify the difficulty of dating a tree-ring series from an artefact (HANECA *et al.*, 2005). However, given the ongoing development of reference chronology databases for many tree species, a scenario that is now difficult to date may be addressed in the future.

The "growth type" may be an additional explanation for lower correlation values between individual tree ring series and site chronologies. A tree with a complete or partial erratic growth, as well as a tree growing in a complacent environment, cannot be accurately dated, regardless of the number of rings measured. Indeed, the growth conditions for a given region cannot be well represented by the existing site chronologies (KUNIHOLM, 2000; HANECA *et al.*, 2005).

Undated tree ring series have been confirmed in many panels of prominent and unknown artists, e.g.: **(1)** *Annunciation and Nativity* attributed to Petrus Christus, in the Staatliche Museen, Berlin (KLEIN, 1994a); **(2)** *The Virgin with the Infant Christ Holding an Apple*, made with fir wood, assigned to Master of the Magdalen Legend, in the Museum Boijmans Van Beuningen, Rotterdam (KLEIN, 1994b); and **(3)** the finest masterpieces of Italian Renaissance artists (such as Leonardo da Vinci, Michelangelo, Raphael or Giovanni Bellini) were painted on poplar wood, therefore dendrochronology may be ineffective due to a scarcity of accurate reference chronologies (BERNABEI *et al.*, 2019).

3.6.2.2. Short tree-ring series

The minimum number of tree rings is not yet defined by the science community (KLEIN, 1998b, 2010a; BERNABEI *et al.*, 2019). In the case of oak wood, a minimum of 70-80 tree-rings is considered necessary to obtain a valid date (VANDEKERCHOVE *et al.*, 2009). MUNRO (1984) defined that a minimum of 60 rings might to be considered suitable for analysis. According to the hundreds of dendrochronological data reported in the panels, instances of oak boards with less than 50 rings are uncommon and are only likely because smaller boards derived from the same trees as wider boards from the same or another panel(s). For example: **(1**) in the *Annunciation* painting attributed to Petrus Christus, belonging to the Metropolitan Museum of Art, New York, an oak board with 25 rings was dated from the four other boards of the same panel (KLEIN, 1994a); and **(2)** three oak boards with 37, 46 and 48 rings may be dated in three Flemish panels from the Rijksmuseum collections, as they come from the same tree as other boards from separate panels (KLEIN, 2007c). KLEIN (2007a) dated fir wood panels based on chronological series of almost 50 rings.

Several experiments have demonstrated that it is possible to date artefacts made from other types of wood, including beech, fir, pine and spruce, with a reduced number of rings. TOPHAM and MCCORMICK (1998) excluded sequences with 60 or fewer rings for dating musical instruments as they were considered too short to provide reliable statistical results. However, the minimum limit of 50 rings is considered by other authors for the same category of instruments (BERNABEI *et al.*, 2010; 2019). In other categories of artefacts, it was feasible to date wood pieces using a brief chronological sequence: **(1)** SASS-KLAASSEN *et al.* (2008) dated chronological series of 40-50 rings obtained in pine base piles while not having a solid but significant statistical significance; and **(2)** HANECA (2005) dated several chronological series of 30 to 60 growth rings from archaeological collected in Flanders. Even though the statistical metrics were relatively low, the author concluded that they were acceptable since the same matching positions existed on various reference chronologies.

3.6.2.3. Structural condition of the sample

Difficulties with the very thin thickness of the wooden boards, the thick medullary rays, and the tangential orientation of the growth rings may render tree-ring measurements incorrect. BAUCH (2002) cited these reasons for the difficulty of dating *The Incredulity of the St Thomas* panel assigned to Rembrandt van Rijn at the Pushkin Museum of Fine Arts, Moscow.

3.6.3. Historical restrictions

3.6.3.1. Old or reused wood

The artist can choose wood to support his painting, which has been cut and/or used many years before. If there is a considerable difference between the date of the latest measured ring and the date assigned to the panel, an X-ray scan should be performed to rule out the possibility of underpainting (KUNIHOLM, 2000). The Saint Anne altarpiece, attributed to Gerard David's studio from the National Art Gallery in Washington, DC, is one of the examples that demonstrates a substantial discrepancy between the dendrochronological data of the three center panels of the polyptych. Half of the 10 boards are dated to the second half of the XIV century (1353–1387), while the remaining four datable planks dated to the fourth quarter of the XV century (1477–1481) (KLEIN, 1998a).

A caveat is in order: boards with a significant gap between the date of the youngest heartwood ring in the same panel can be explained by the location of the board in relation to the pit. Normally, in this situation, the boards that have the oldest ring are narrower, have fewer rings and are positioned closest to the stem pith. Several examples of various painters can be given: **(1)** in the *The pedlar* panel assigned to Hieronymus Bosch, in the Museum Boijmans Van Beuningen, Rotterdam, four oak boards from the same tree have 86, 91, 222 and 225 tree-rings and the date of the youngest heartwood ring is 1367, 1476, 1473 and 1476, respectively (KLEIN, 1994b); **(2)** in the *The last judgment* triptych attributed to Hieronymus Bosch and his followers, belonging to the Academy of Fine Arts, Vienna, one of eleven oak boards presents the youngest ring at the beginning of the XIV century, compared to the remaining ten from the second quartile of the XV century (KLEIN, 1996); **(3)** in the *Christ and the adulteress* panel credited to Lucas Cranach the Elder studio, belonging to the Prague National Museum, three beech boards have 62, 105 and 113 rings and the date of the youngest heartwood rings 1476, 1527 and 1520, respectively (KLEIN, 2007a); **(4)** in the *Annunciation Virgin* panel from the *Cervana* altarpiece attributed to Gerard David, belonging to the Metropolitan Museum of Art, New York, three oak boards display 84, 155 and 167 rings and the date of the youngest heartwood ring 1232, 1320 and 1309, respectively (KLEIN, 2007a); and **(5)** in the *Jean Carondelet* panel attributed to Jan Gossart Group, belonging to The Nelson-Atkins Museum of Art, Kansas City, both oak boards have 67 and 181 rings and the dates of the youngest heartwood ring 1433 and 1489, respectively (KLEIN, 2010c).

3.6.3.2. Time span after tree felling

It is necessary to consider the time span between cutting down the tree in the forest and the conception of the artwork. Considering the type of artwork, this period covers several standard procedures. The wood transformation and transport process included a set of procedures from the forest to the workshop until the conception of an artwork: squaring the trunk, cutting it into quarters, floating to the harbours, shipping to distribution centres, cutting wood into planks, seasoning and possibly storage (FRAITURE, 2002, 2011; VEROUGSTRAETE, 2015). The wood used for the panels should be well seasoned for stability purposes, according to the main Flemish workshop procedures, as wood panels could be deformed or warped with incomplete seasoning (WADUM, 1998). Historical records offer additional detail, considering only the time of timber stabilisation: **(1)** at least six years (VIOLLET-LE-DUC, 1863); **(2)** at least eight years (ROUBO, 1769); and **(3)** 20 years, according to historical records from the XV century (VEROUGSTRAETE, 2015). Given the complexity that exist for these elements, the literature on dendrochronological study gives multiple criteria, representing the period following tree felling according to the century (Table 11).

Table 11. Time span between felling the tree and the use of the oak wood as a panel support according to dendrochronological research.

MATERIAL (CENTURY)	TIME SPAN (YEARS)	REFERENCE
Panels (XV century)	10 – 15	KLEIN (1982)
Panels attributed to Petrus Christus (XV century)	18 (minimum)	KLEIN (1994a)
Panels (XV and XVI centuries)	10 (approximately)	KLEIN (1994b)
Dutch and Flemish panels (XVI and XVII centuries)	2 – 8	BAUCH and ECKSTEIN (1981); KLEIN (1981)
Panels (XVI and XVII centuries)	4 – 12	BAUCH *et al.* (1974)
Art and furniture	4	JANSMA *et al.* (2004)

Drying wood in the open air, while shielding it from rain and heat, has long been the favoured approach over any less natural process (KOLNEDER, 2003). Norway spruce wood dries relatively quickly with minimal shrinkage, although it is susceptible to cracking (TJOELKER *et al.*, 2007). Through the guidelines described in the historical luthier manual, MAUGIN (1834) proposed in the chapter "*Des bois employés pour la lutherie*" the time of wood stability of five to six years from cutting to use in the production of a good musical instrument (“*cependant le bois a cinq à six ans de coupe (…) est très propre à faire de bons instrumens*”[43]). However, the period of the wood seasoning process in the construction of violins varies according to literature: **(1)** a minimum of 5 years (HERON-ALLEN, 1884; GRISSINO-MAYER *et al.*, 2005); **(2)** a limit of 3 years, based on 34 violins from the Italian Guarneri family (BEUTING, 2009); **(3)** 5 to 25 years for Italian and German masters from 1563 to 1892 (KLEIN *et al.*, 1986); and **(4)** a minimum of 45 years for Italian and German masters from 1563 to 1892 (HUTCHINS, 1978).

[43] Author's free translation: “however the wood has been cut for five to six years (...) is very appropriate for making good instruments”.

3.7. Dendroarchaeology beyond date: dendroprovenance

The goal of *'Dendroarchaeology beyond date'* is to contribute to different areas of study, such as climate, forest management by humans (even in the Neolithic period), history, landscape, medieval civil and religious architecture, reconstruction of timber supply networks of a city, timber quality and trade (HOUBRECHTS and FRAITURE, 2011). Several studies could exemplify this topic, as briefly reported below, but its further development would be beyond the scope of the present thesis. BILLAMBOZ (1992) showed a local settlement event and a chrono-cultural creation with a tree-ring study of pile-dwellings from an archaeological context in southwest Germany. Precise information provided for the relationship between human groups and their primary economic source and main raw material (forest and wood, respectively). HANECA (2005) and ROZAS (2005) have shown the potential of dendrochronology to the history of long-term management systems with radial-growth analysis in many pollard woodlands in Europe. Abrupt and sustained growth depressions were found in the oak ring-width pattern following pollarding, with unaltered earlywood width in the following first year, but with substantially reduced latewood. The result could be seen in the anatomy of several successive growth rings (HANECA, 2005; ROZAS, 2005), as exemplified in Figure 21 with five very narrow consecutive rings on the oak panel examined as part of the dendrochronological details of the Portuguese panel.

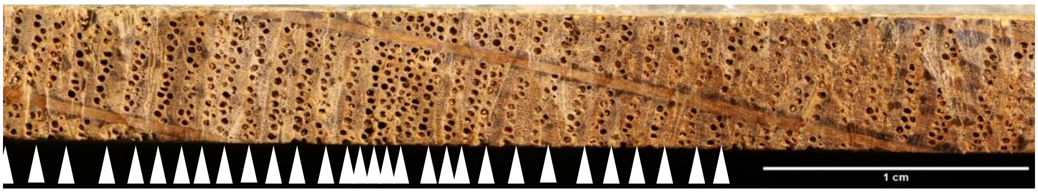


Figure 21. Abrupt growth reduction might be induced by pollarding, observed on a cross-section from the board II of the *Pregação de São João Baptista* panel (49 Pint), MNNA, of unknown attribution [The white arrows indicate the beginning of each growth ring] (SOURCE: CEF-ISA unpublished).

Knowledge about the growth sites of trees used in archaeological or historical structures and artefacts (e.g., buildings, panels, sculptures, and ships) provides valuable information on timber trade routes, the origin and authenticity of historical art objects, or the estimation of factors forcing tree growth (GUT, 2018). The importance of the sources of materials used in archaeological or historical structures and artefacts has increased to such a degree that it has contributed to the creation of a new branch in the study of tree ring growth patterns - *dendroprovenance*. Three assumptions are the basis for dendroprovenance, but some debate has arisen over the last few years: **(1)** within the study field, tree growth differs sufficiently, causing the development of regional or locally typical ring-width patterns; **(2)** the (dis)similarity of tree growth can be quantified by statistical measures of proximity; and **(3)** highest statistical proximity indicates closest geographical neighbours (GUT, 2018). The area of provenance is usually defined as the area represented by the chronology that provides the best statistical match (normally expressed by Student's t value) (BAILLIE and PILCHER, 1973; HOLLSTEIN, 1980; BAILLIE, 1982).

Dendroprovenance continues to be popular and broadly applied, despite the controversy. In some instances, by a visual and statistical comparison of the individual tree-rings sequence with reference chronologies representing the average growth conditions for a particular location, it has been possible to classify the most probable (or potential) geographical region of the wood provenance supply (HANECA *et al.*, 2009; GUT, 2018). The spatial distribution of the strongest crossmatch is mapped, thereby reducing the region of origin. *Dendroprovenance* is expressed in a wide-ranging comparative analysis of dendrochronological sequences derived from different classes of objects- archaeological artefacts, barrels, furniture, historic buildings, musical instruments, panels, ships, trunks, etc. This showed the mobility of items and materials between countries. LIESE and BAUCH (1965) were identified by HANECA *et al.* (2009) as the authors of the first *dendroprovenance* study, in which a Hanseatic Cog ship, excavated in the port of Bremen was dated dendrochronologically to 1378-1379 with a master chronology from Weserbergland, Germany. More recently, ECKSTEIN and WROBEL (2007) established the earliest dendrochronologically proven long-distance timber transport in Central Europe from the Viking trading site of trade Hedeby in Northern Germany to the early medieval settlement of Dorestad (Netherlands) and the Slavonic settlement Wolin in Poland in the estuary of the river Odra. Numerous dendrochronological studies have shown that wood and artworks have been transported across Europe on a large scale for many centuries. For instance: **(1)** oak coffins from archaeological excavations in the Netherlands came from trees grown in different regions of Germany and France (ANDRADE, 2011); **(2)** RODRÍGUEZ-TROBAJO and DOMÍNGUEZ-DELMÁS (2015) illustrated the use of Swedish oak wood in a XVI century altarpiece at Seville Cathedral, Spain; **(3)** English buildings and wood structures with Baltic oak (GROVES, 1992, 2002a; TYERS, 2014a, 2014b, 2014c) and Scandinavian conifer timber (GROVES, 2002b); **(4)** English chests and fittings made of oak wood from Germany (MILES and BRIDGE, 2008); **(5)** Baltic oak used in the XV and XVI centuries Portuguese panels (ESTEVES and KLEIN, 1999; CARVALHO, 2013; LAUW *et al.*, 2014; ANTUNES *et al.*, 2016; ANTUNES *et al.*, 2020; CRUZ *et al.*, 2020); **(6)** Norway Alpine spruce used in British stringed instruments from the XVII and XVIII centuries (TOPHAM and MCCORMICK, 1998);

and **(7)** Norway Alpine spruce used in Portuguese guitars from the XVI and XVII centuries (TOPHAM and MCCORMICK, 1998; TOPHAM, 2003).

The question is … *Where did grow the trees from which the artwork was?* There is no reason for the country in which an artwork exists should be related to the place of the wood origin. MACHADO (2007) gave several examples of the mobility of artworks in the sense of XVII century European diplomacy. In certain instances, paintings were regarded as diplomatic presents, intended to secure a favour, facilitate an agreement, or commemorate a solemn occasion. Hundreds, if not thousands, of examples of dendrochronology studies may be given, but the following are only for Portuguese artworks: **(1)** the Metropolitan Museum of Art, New York, has a panel attributed to the Portuguese painter Frey Carlos (*S. Vicente*) from the XVI century whose wooden support comes from the Baltic (CARVALHO, 2013); and **(2)** the Ashmolean Museum, Oxford, holds a guitar from the XVII century, attributed to the Portuguese maker António dos Santos Vyeira, with an Alpine wood's belly (TOPHAM, 2002). According to BAILLIE (1982), the nationality of an artist or his established area of practise may be a more useful source of knowledge for wood origin, but the question still remains as to where the artist obtained the wood material. The author questions - *would an artist from one country carrying out a commission in another bring with him a stock of prepared boards or acquired locally*? Another issue can also arise - *could the wood material origin be established by the commissioner of the artwork*? The subchapter 2.1.3. *Wood panels in Portuguese panels* includes two concrete examples of Portuguese orders, proposing the source of the wood material.

Several caveats have been raised about the study of wood provenance through a dendrochronological approach (BRIDGE, 2012; GUT, 2018; DOMÍNGUEZ-DELMÁS, 2020). DOMÍNGUEZ-DELMÁS (2020) demonstrated that the highest t-value does not always represent the region of origin, and that common sense must sometimes take precedence over statistics. BRIDGE (2012) offered an indication of the relevance of reassessing and upgrading the initial hypotheses when he examined oak stands in eastern England and compared the chronological sequences of intra- and inter-sites. Chronological sequences of more remote sites (approximately 270 km) demonstrated greater statistical proximity compared to a set of closer sites, within a radius of 100 km. The supposed paradox was justified by the fact that the most remote positions were situated on steep, well-drained hills. This indicates that, despite a wide geographical range, two locations were ecologically very close. In fact, the author noticed that most of the previous dendroprovenance investigations were carried out in regions with an Atlantic climate and low topographical complexity, such as the Polish, Belgian and Baltic coasts, and their hinterlands. DOMÍNGUEZ-DELMÁS (2020) described the fundaments, successes, and limitations of new methods and multivariant approaches being researched in recent years to study the provenance of wood from (pre)historical contexts, namely chemical fingerprints, genetic markers and isotopic signatures.

3.7.1. Dendroprovenance: the oak panels

Until the mid-XVII century, oak (*Quercus* sp.) was the preferred species for panels, altars, furniture, and, in some circumstances, architectural constructions. Early *dendroprovenance* studies using tree ring pattern analysis were performed on panel panels with oak supports (BAUCH and ECKSTEIN, 1970). In fact, the tree-ring curves from several Flemish, English, and French oak panels did not crossmatch with local chronologies, while these countries were covered by areas of natural distribution of the main species used as wood support (*Quercus petreae* (Matt.) Liebl. and *Quercus robur* L.) (Figure 22). It was possible to distinguish at least two clusters of timber by the study of growth patterns in these panels, which indicated two provenances with quite different characteristics (ECKSTEIN and WROBEL, 2007). The panels were dated with a Polish chronology (ECKSTEIN *et al.*, 1986) and concluded that oak trees had grown in the south-eastern Baltic countries. Unlike panels, no evidence of mediaeval Baltic timber construction has been discovered in Western European nations, but post-medieval dendrochronological studies imply their usage (BRIDGE, 2012).

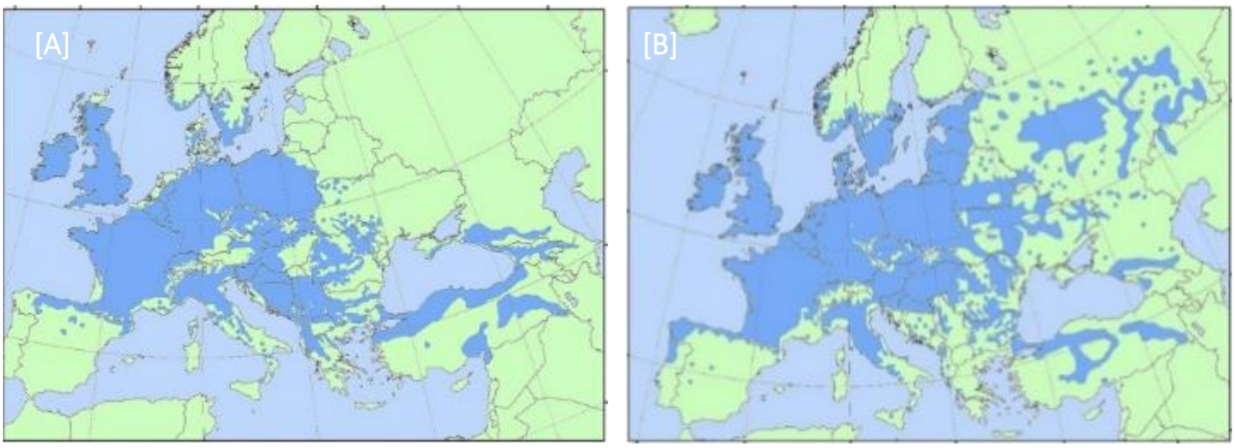


Figure 22. Distribution range of: **[A]** *Quercus petreae* (Matt.), Liebl.; and **[B]** *Quercus robur* L. (SOURCE: www.euforgen.org, consulted on 10.01.2020).

Over the past decades, the study of oak tree ring patterns from ancient artefacts has always established the Baltic region as the original source of timber, as supported by historical documents and trade records (HANECA *et al.*, 2005). Western countries in mediaeval Europe started importing large and straight stems suitable for building from the Baltic States as their traditional sources began to decline. The first centres of timber trade have been in Central Eastern Europe, along the Baltic Sea coast, carrying timber from the hinterland for more than 300 km across the river system. The easiest and not expensive mode of transport was to bind logs onto rafts and float them downriver (Figure 23) or take planks down inland waterways by boats (WAZNY, 2005; OSSOWSKI, 2014). High water levels and strong river flows would have provided favourable conditions for this mode of transport in late autumn and winter, from September to December. The rafts were presumably disassembled and taken to a storage yard to be classified after arrival at Gdansk, before being picked up by merchants and loaded on board seagoing ships (OSSOWSKI, 2014). The ports were often spread to the estuary of large navigable rivers from the Central European plains, such as Vistula, Nemunas and Daugava (Figure 24). The Vistula River assumed a dominant role in the timber trade (HANECA *et al.*, 2005), reaching into today's west Ukraine and making the large Polish forests accessible for exploitation (ECKSTEIN and WROBEL, 2007). Situated on the Daugava River, Riga later became a vital trade route, connecting Eastern and Western Europe. In the XVI century, the wood exported via Riga was cut to ever greater distances over time, with an exploration area covering Eastern Belarus nowadays. In the XVIII century, the easternmost point was almost 1800 km from Riga, well beyond Moscow (ECKSTEIN and WROBEL, 2007).

Figure 23. Older images known of the wood transportation in rivers by raft, around 1600 AD (SOURCE: *Holz im FlussFlößerei im Oberen Kinzigtal*, Naturpark Schwarzwald Mitte/Nord, Deustchland).

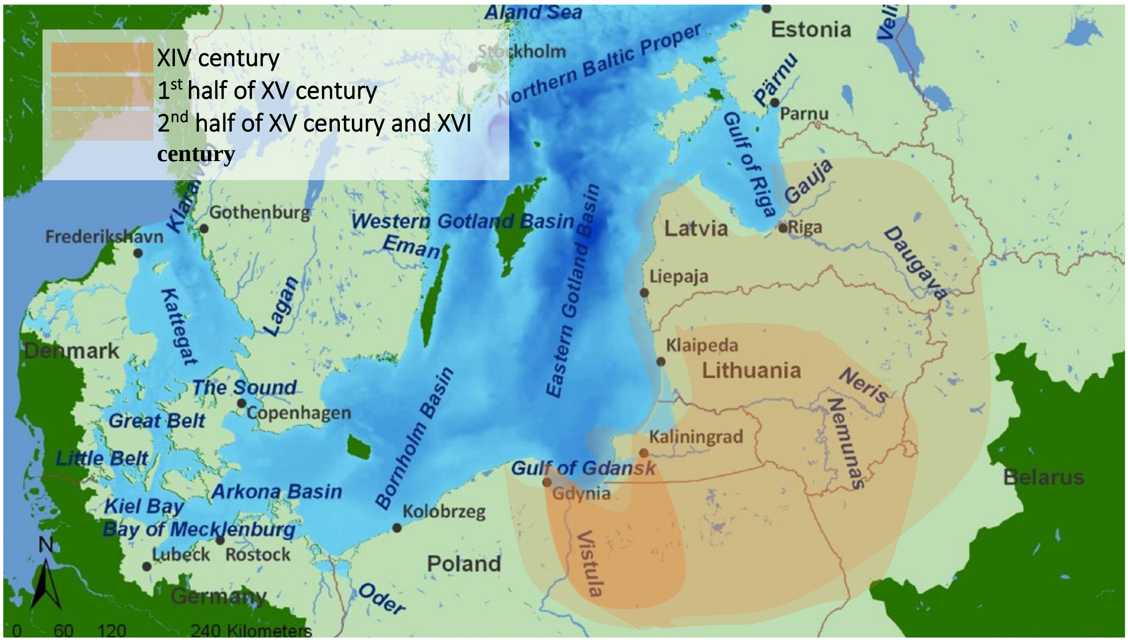


Figure 24. Area of influence of the Baltic Sea representing the potential supply areas of oak wood to Western European countries in the XIV to XVI centuries (SOURCE: Adapted from WAZNY (2005)).

WAZNY (2005) took the opinion that the catchment of the three major rivers should be understood as the Baltic region. HANECA *et al.* (2005) and BRIDGE (2012) agreed that this vast region undoubtedly included regions farther east, such as present-day Belarus and Russia, as well as Estonia, Latvia, and Lithuania to the north.

During the Middle Ages, this area was densely covered with primary forests, with a low human presence (ECKSTEIN *et al.*, 1986; WAZNY, 2005; 2010). The climate was cooler than in other parts of Europe, resulting in a shorter growing season and, as a result, the oak forests produced fine-grained, slow-grown timber. For this reason, the large tree trunks of the Baltic oak have provided the perfect raw material for the manufacture of robust and durable planks with little propensity to warp (GLATIGNY, 2010).

An excellent case-study for the export of Baltic wood in the XV century is the discovery of Copper Ship's wrecks, carried out between 1969 and 1981, with a multidisciplinary study of its construction and cargo. The Copper Ship's final trip was to bring wood commodities and metals from Gdansk to Western Europe, including copper (extracted from mines in modern-day Slovakia), iron bundles, oak (wainscot and staves), packed plant material, wax, wood tar, and potash. The shipwreck was caused by either a fire on board or an attack by a foreign warship. The dendrochronological research aimed to date the wood cargo, namely the long planks (so-called *wainscots*; *wańczos* in Polish) (Figure 25A) and the short oak staves (Figure 25B). Similarity trends with Polish chronologies suggested that

Gdansk Pomerania and the north-eastern part of Poland were the most likely areas of origin of the oakwood from which wainscots and staves were made (KRĄPIEC and KRĄPIEC, 2014; OSSOWSKI, 2014).

Figure 25. [A] Wainscot; and **[B]** staves that constituted part of the cargo of the Copper Ship, after preservation treatment (SOURCE: JAGIELSKA and URBAŃSKI, 2014).

For countries across the Baltic Sea, the network of site and regional chronologies has expanded substantially since the 1990s. Many historical site chronologies have been documented in many publications in northern and central Poland (VAN DAALEN and VAN DER BEEK, 2004; HANECA *et al.*, 2005), but the most of them remain inaccessible to the science community.

The Gdansk-Pomerania chronology is considered the first regional chronology from Baltic and is available from ITRDBB (POLA006[44]). It covers the period from 996 to 1985 and is built with approximately 300 tree-rings series of buildings and archaeological sites in northern Poland, especially in the region around Gdansk (ECKSTEIN *et al.*, 1986). However, it cannot be taken for granted that the chronology of Gdansk-Pomerania consists entirely of Northern Polish oaks, even though the buildings used are situated in and around Gdansk. The oaks may have been floated down the Vistula from southeast Poland or modern-day West Ukraine, at least in part (ECKSTEIN and WROBEL, 2007). The growth ring pattern observed in the Gdansk–Pomerania chronology (defined as *Netherlands Type II*) correlates to the patterns found in the articles located in Antwerp (BAUCH *et al.*, 1978), Denmark (BONDE, 1990), Amsterdam, Brussels, Cologne and Lübeck, thus confirming trade relations between Poland and Western Europe (ECKSTEIN *et al.*, 1986). The findings of this research allow to understand the absence of Netherlands Type II tree rings patterns in artworks and buildings after 1650 after the Thirty Years War cut trade relations in the Baltic Sea and the Second

[44] WAZNY, T. (1996-05-08): NOAA/WDS Paleoclimatology - Wazny - East Pomerania - QURO - ITRDB POLA006. NOAA National Centers for Environmental Information. https://doi.org/10.25921/hmy4-n833. Accessed [14.06.2016].

Swedish/Polish War (1655-1660) caused the complete breakdown of trade (ECKSTEIN *et al.*, 1986; KLEIN, 1998b).

Over the last two decades, oak chronologies have been established for the Baltic states, with an increasingly ancient period in the context of archaeological excavations (PUKIENÉ, 2002; BRAZAUSKAS, 2003, 2005; VITAS and ZUNDE, 2007; VITAS, 2020). PUKIENÉ (2002) developed a 201-year-old mediaeval chronology with *Quercus robur* L. timbers from Vilnius Lower Castle excavations. VITAS (2020) established a mediaeval oak chronology with archaeological material from Klaipëda (Lithuania) from 1247 to 1552, indicating that the forests of the BALTIC1 chronology and certain Dutch chronologies originated in western Lithuania. VITAS and ZUNDE (2007) developed an oak chronology spanning 778 to 1325 years from Smurgainiai (modern-day Belarus). According to the scientists, examinations of oak tree rings in the Baltic states have yielded limited results thus far since historical oak trees are extremely rare. Over the last two millennium, the dimensions of the oak forest have been considerably reduced due to the deterioration of the climate and the rapid destruction of the oak forest for agriculture, shipbuilding, and high exports of timber.

3.7.2. Dendroprovenance: the soundboard´s wood

The main probable soundboard woods used in string and keyboard musical instruments from the XVII to the XIX centuries (*Abies alba* Mill., *Larix decidua* Mill. and *Picea abies* (L.) H.Karst.) have a somewhat different natural distribution region but a comparable area that relates to the Alps (Figure 26). BEUTING (2009) identified five major regions of spruce resonance linked to musical instruments: Northern Alps (region around Innsbruck and Mittenwald), Southern Alps including the Italian part, Southern Germany, Bavarian/Bohemian Forest, and Erzgebirge/Vogtland (Figure 27).

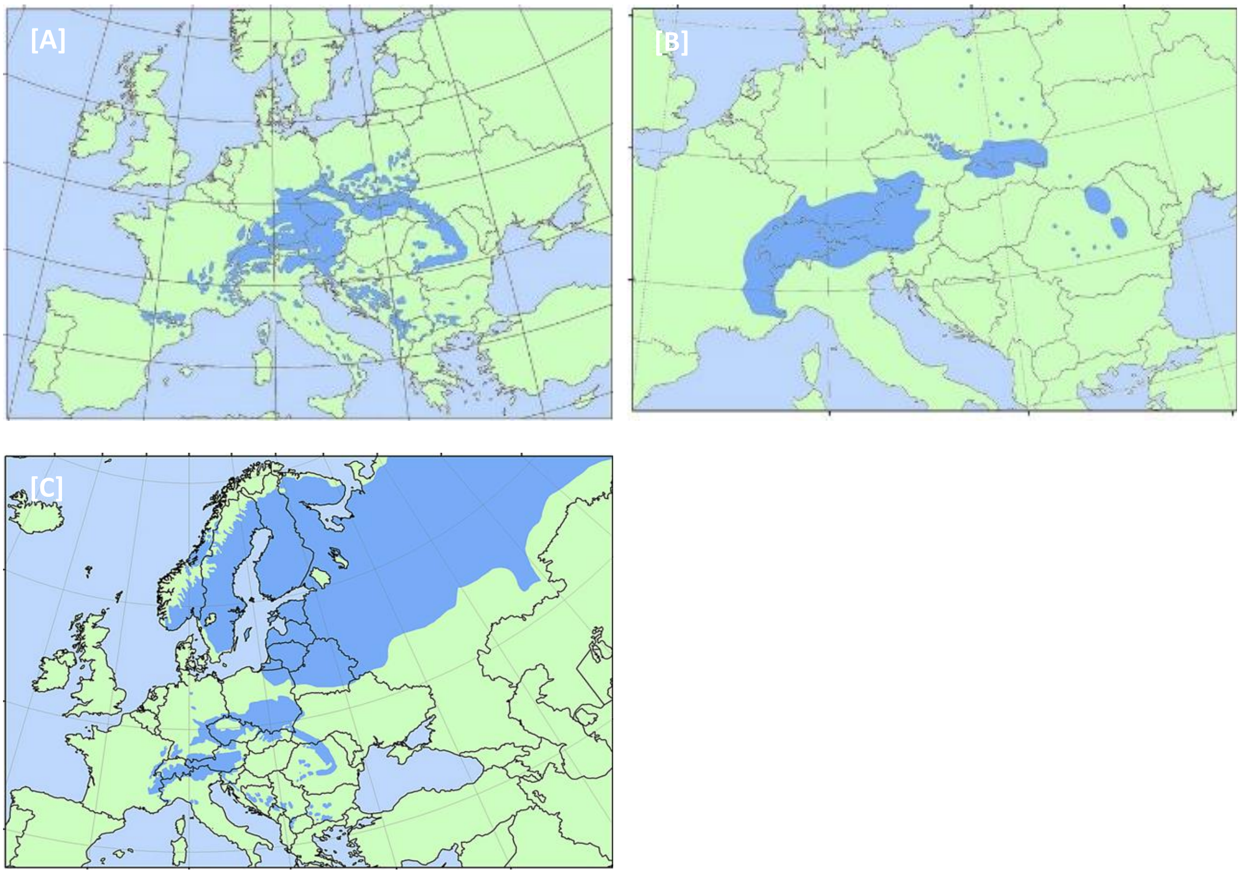


Figure 26. Distribution range of **[A]** *Abies alba* Mill.; **[B]** *Larix decidua* Mill.; and **[C]** *Picea abies* (L.) H. Karst. (SOURCE: www.euforgen.org, consulted on 10.01.2020).

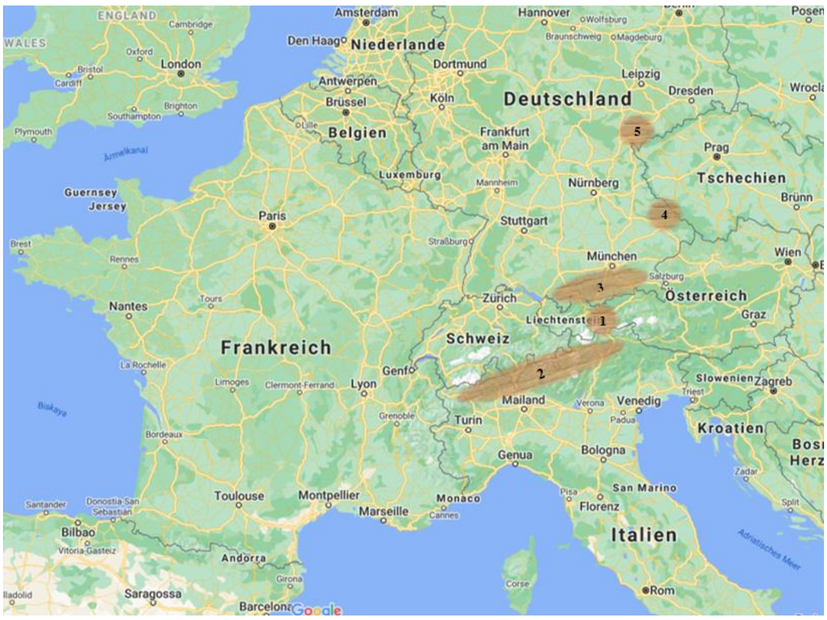


Figure 27. Sketch of the major regions of spruce resonance applied to musical instruments identified by BEUTING (2009): **(1)** Northern Alps (region around Innsbruck and Mittenwald); **(2)** Southern Alps including the Italian part; **(3)** Southern Germany; **(4)** Bavarian/Bohemian Forest; and **(5)** Erzgebirge/Vogtland.

The dendroprovenance of the soundboard's wood can be more meticulous, considering the heterogeneity of growth rates between nearby areas and at various altitudes (WILSON and HOPFMUELLER, 2001; EISSING and DITTMAR, 2011). BERNABEI and BONTADI (2011) and RATCLIFF (2014b) suggested that the mixture of reference chronologies spanning a broader area, which enables the accurate dating of the musical instrument to be replicated, did not reach adequate amounts to deduce a precise place for the growth of the trees. In some climatic circumstances, the location (namely, height and forest structure) and the age of the tree can determine distinct growth trends even in relatively small regions (WILSON and HOPFMUELLER, 2001; BERNABEI and BONTADI, 2011; BUCUR, 2016). Although the geographical coverage may be very well known, one of the difficulties related to dendroprovenance applied to ancient stringed instruments is precisely the high orographic and climatic variability within the region (BERNABEI and BONTADI, 2011). There are few dendroprovenance studies in the Alpine environment (WILSON and HOPFMUELLER, 2001; EISSING and DITTMAR, 2011; GUT, 2018). WILSON and HOPFMUELLER (2001) have developed three distinct Norway spruce master chronologies over an altitudinal gradient, from low to a high elevation, in the Bavarian Forest (Germany). They concluded that tree growth was mainly influenced by the availability of humidity at lower elevations than at high altitudes. The climate signal was relatively weak, indicating that Norway spruce development may be affected by topography and other non-climatic influences, such as air quality, as also suggested in other dendrochronological studies. Norway spruce growth patterns discrepancies between two altitude levels were established by EISSING and DITTMAR (2011): lower elevation (500 a.s.l.) with warmer and dryer conditions and high elevation (1700 a.s.l.) under cold and wet conditions. In several years, both chronologies showed predominant signals, but there were drastic signals in other years. For instance, good growth conditions for high altitudes in the known hot and dry years, but worse growth for lower altitudes. Due to such discrepancies between chronologies, the authors found it necessary to establish specific chronologies according to the area and altitude for dating historical material.

At the intra-tree level, there is also heterogeneity in growth trends as a function of altitude. KLEIN *et al.* (1986) found that there was a high correlation in the growth pattern relative to different radii of a spruce tree for sounding wood from the Alpine zone, while the growth rings along radii from spruce trees from lower areas could vary considerably within a single tree.

ORIGINAL RESEARCH

1. MATERIAL AND METHODS

1.1. Material

Figure 28 presents a scheme of the study objects chosen for dendrochronological research, which are detailed in the following sections based on museum catalogues, literature, and historical data stored in the piece.

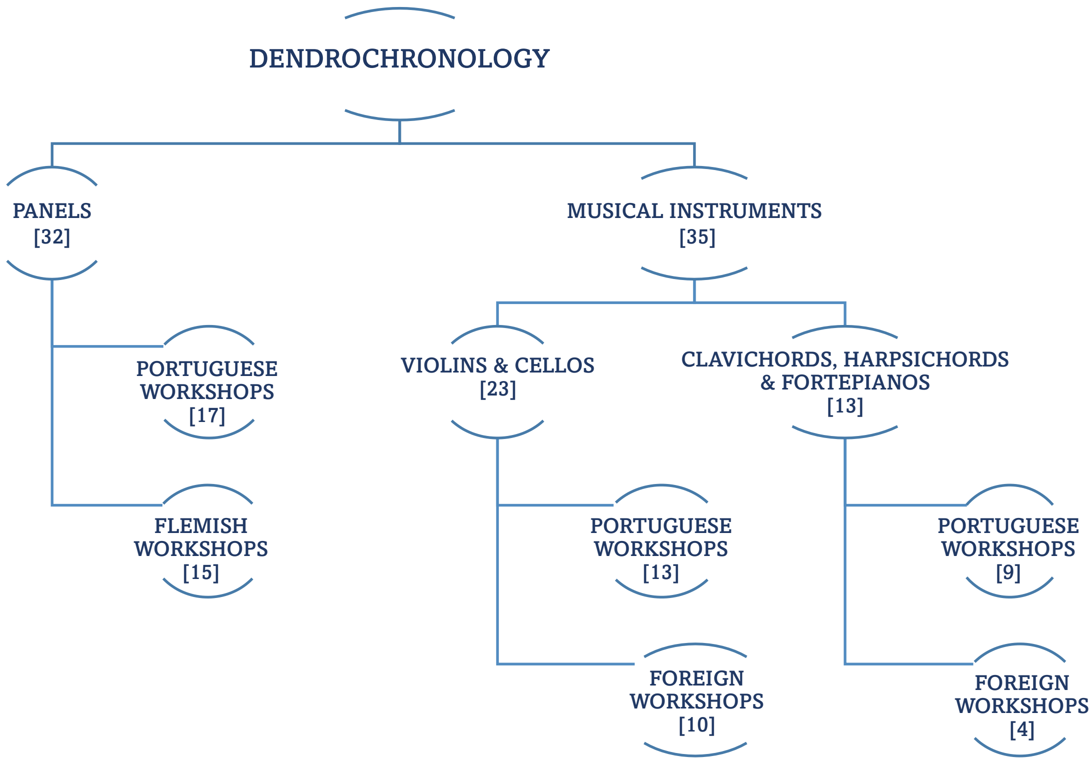


Figure 28. Artworks selected for the dendrochronological research.

1.1.1. Panels

The dendrochronological research was carried out on two sets of oak panels: **(1)** fifteen Flemish panels of thirteen artworks from the MASF's collection; and **(2)** two altarpieces of Portuguese workshops from the collection of MNAA – *Vida de S. Tiago* and *S. Francisco de Évora*, both classified of national interest (Law No. 107/2001 of 8th September and Decree No. 19/2006 of 18th July) (see ANNEXES 1 and 2). The images and information regarding the fifteen Flemish panels from the MASF's collection is detailed in the scientific article accepted (with revision) in *Journal of Archaeological Science: Reports* (see subchapter 2.2. *Dendrochronological research of Flemish panels (ARTICLE)*). It is therefore not repeated here.

The *Vida de S. Tiago* altarpiece originally consisted of twelve panels on oak wood, of which only eight panels remained (Figure 29). The great artwork was originally destined for the church *S. Tiago* at the convent *Espatário of Palmela*. Very possibly remained there probably until 1834, the date of the extinction of religious orders in Portugal, and was then moved to Lisbon (PEREIRA, 1990). The author based his view on the historical analysis done by Dagoberto Markl in 1982. The assignment varied over time, being referred to in MatrizNet as "unknown assignment", following GONÇALVES (1963) who proposed that the altarpiece was painted in collaboration with two distinct masters, a quite common method among Portuguese painters of the XVI century. PEREIRA (1990) agreed but added that the work would be done by the alleged Mestre Marcos because the name “Marcos” is readable in two panels. This fact, according to the author, can be considered a documentary identification of a painter, most likely trained in Flanders or of Flemish descent, whose first or surname was Marcos. The authorship of Mestre da Lourinhã and perhaps the famous Portuguese painter Gregório Lopes were mentioned by other authors (PEREIRA, 1990; FERNANDES, 2009). Art historians largely agree on its historical date for the years 1520-1530, and it is referred to as 1520-1525 in MatrizNet. According to PEREIRA (1990), this altarpiece is one of the most impressive examples of Renaissance art in Portugal, as well as an essential representation of Portuguese culture during the Age of Discovery.

The *S. Francisco de Évora* altarpiece is one of the collection of altarpieces of the Royal Monastery *S. Francisco de Évora*. The altarpiece originally consisted of 16 panels with a central sculptural axis (Figure 30) (SERRÃO, 2002; PEREIRA *et al.*, 2013). There are now fifteen panels, eleven of them belonging to the MNAA, on which dendrochronological studies have been performed. The remaining four panels are held by Casa-Museu dos Patudos, in Alpiarça (SERRÃO, 2002). SERRÃO (2002) attributed this altarpiece, which dates from 1509 to 1511, to Francisco Henriques, a Flemish painter who settled in Portugal. According to the author, the altarpiece is one of the major and most costly masterpieces funded by King Manuel I, with the participation of the renowned Flemish carver Olivier de Gand.

Each of the panels of the two altarpieces and their respective measurements are described in Table 12. The names of each of the works listed in this study are based on the MatrizNet criteria, slightly different from those stated in the literature (GONÇALVES, 1963; PEREIRA, 1990; SERRÃO, 2002).

Figure 29. Conjectural reconstitution of the *Vida de S. Tiago* altarpiece (SOURCE: PEREIRA *et al.*, 2013).

Figure 30. Conjectural reconstitution of the *S. Francisco de Évora* altarpiece (SOURCE: SERRÃO, 2002; PEREIRA *et al.*, 2013).

Table 12. Identification of the panels belonging to the *Vida de S. Tiago* and *S. Francisco de Évora* altarpieces curried at National Museum of Ancient Art, Lisbon [[1] not studied due to the poor state of conservation; [2] information available on MatrizNet].

NAME [INVENTORY NUMBER]	DIMENSIONS, cm (height × width)
***Vida de S. Tiago* altarpiece, unknown attribution (1520-1525)**	
Investidura de um Mestre da Ordem de Santiago [16 Pint]	84.0 x 128.0
Entrega da bandeira a um Mestre da Ordem de Santiago [17 Pint][1]	84.0 x 99.0[2]
Aparição da Virgem a um Mestre da Ordem de Santiago [18 Pint]	83.5 x 129.0
São Tiago combatendo os mouros [19 Pint]	85.0 x 130.0
Conversão de Hermógenes [20 Pint]	84.0 x 128.0
O Corpo de S. Tiago conduzido ao Paço da Rainha Loba [21 Pint]	84.0 x 128.0
Cristo envia S. Tiago e S. João em missão apostólica [22 Pint]	83.5 x 127.0
Pregação de S. Tiago [24 Pint][1]	83.0 x 126.5[2]
S. Francisco de Évora altarpiece, atribute to Francisco Henriques (1508-1511)	
Degolação dos Cinco Mártires de Marrocos [89 Pint]	144.5 x 87.4
Missa de São Gregório [91 Pint]	121.5 x 87.1
Apanha do Maná no Deserto [92 Pint]	122.0 x 88.2
Encontro de Abraão e Melquisedeque [93 Pint]	122.5 x 88.9
Última Ceia [94 Pint]	121.5 x 89.2
Descida da Cruz [95 pint]	167.0 x 87.7
Cristo a Caminho do Calvário [96 Pint]	167.0 x 87.6
Cristo no Horto [97 Pint]	167.0 x 87.7
Deposição de Cristo no Túmulo [98 Pint]	167.0 x 86.4
São Boaventura e São Luís de Tolosa [99 Pint]	142.5 x 87.2
São Bernardino de Siena e Santo António [293 Pint]	142.5 x 87.8

1.1.2. Musical instruments

1.1.2.1. Violins and cellos

The information regarding the violins and cellos is compiled in the scientific article "*Violins and cellos from Portuguese collections. A tree ring study as a historical source of the Portuguese heritage*", published in *Journal of Cultural Heritage* (see subchapter 2.3.2. Violins and cellos (ARTICLE)) and is not replicated here. The ANNEX 3 shows the photographs of the instruments.

1.1.2.2. Harpsichords and fortepianos

Thirteen string keyboard instruments from the XVII and XVIII centuries, including four fortepianos, five harpsichords, three clavichords and one virginal, belonging to MNM and CRMM collections, were dated through a dendrochronological analysis (see ANNEX 4). The inventory numbers, attribution, and historical and stylistic dating, as well as description of wood species used in their construction are summarised in Table 13.

Nine instruments had the strings in place and were in condition to be played. The Portuguese fortepiano assigned to Mathias Bostem (CRMM) could not be played since it was on the last phase of restoration. In most of the instruments, the strings were in a parallel position to the soundboard's boards, except for the Portuguese harpsichord (MNM0681) and the Ruckers virginal (MNM0395) (Figure 31).

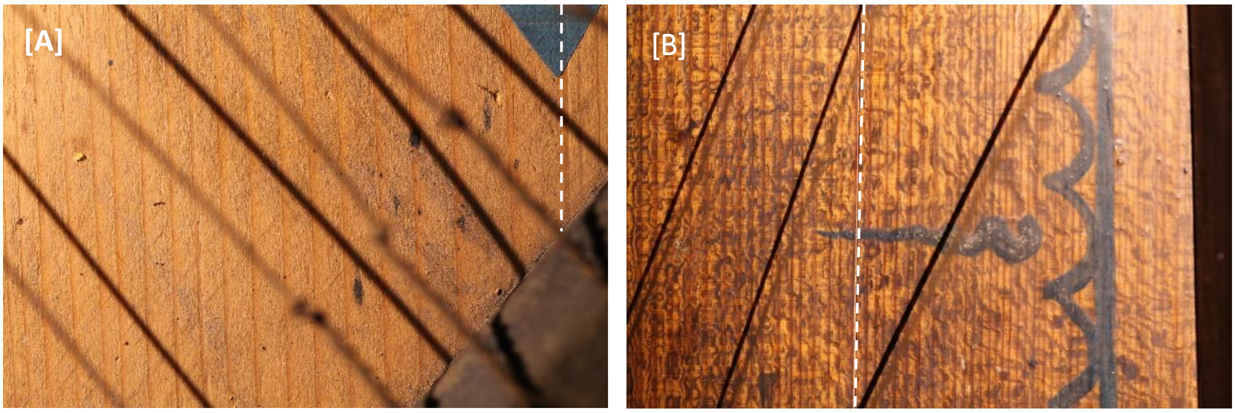


Figure 31. No parallelism of the strings in relation to the boards of the soundboard in: **[A]** Portuguese harpsichord (inventory number MNM0681); and **[B]** Dutch virginal attributed to Ruckers family (inventory number MNM0395) [The dashed white line represents the separation of the two boards].

The photographs of the 13 keyboard instruments may be seen in ANNEX 4. In nine of them, the date inscription is seen as follows:

1. Fortepiano (MNM0425, Henry van Casteel, Portugal, 1763):

The signature "*HENRIQUE VAN CASTEEL 1763*" is stamped on the veneer of the upper surface of the front rail of the hammer rack; two inscriptions are written in ink "*henrijque van Casteel*" (lengthways) and "*1763*" (across) on the lever of key 51.

2. Fortepiano (CRMM, Mathias Bostem, Portugal, 1777)

The signature "*MATHIAS BOSTEM FECIT LISBOA 1777*" is stamped on the veneer of the upper surface of the front block of the hammer rack; there are two flowers, one above the other, between "*BOSTEM*" and "*FECIT*", as well as between "*LISBOA*" and the date. "*Anno 1777*" is written in ink on the key lever 53.

3. Fortepiano (MNM0648, Mathias Bostem, Portugal, 1786)

The instrument was originally a harpsichord and was later converted to a fortepiano. The signature "*MATHIAS BOSTEM FECIT LISBOA 1786*" is stamped on the wrestplank with two fleurs-de-lis, one above the other, at the beginning, at the end and between the individual words.

4. Fortepiano (MNM0833, Mathias Bostem, Portugal, 1789)

The instrument was a harpsichord and was later converted to a fortepiano. The signature "*MATHIAS BOSTEM FECIT LISBOA 1789*" is stamped on the wrestplank with two fleurs-de-lis, one above the other, at the beginning, at the end and between the individual words.

5. Harpsichord (MNM0373, João Baptista Antunes, Portugal, 1789)

The signature "*1789 Antunes*" is marked in ink on key levers 1 and 65.

6. Harpsichord (MNM0372, Joaquim José Antunes, Portugal, 1758)

The name of the maker is read in intarsia: *JOACH: JOZÉ, ANT:*[es] on the front surface of the front wall, above the keyboard; the first key lever (C), on which according to the tradition, the date "*1758*" was written, has been stolen.

7. Harpsichord (MNM1096, Joseph-Pascal Taskin, France, 1782)

According to Decree No. 19/2006 of 18 July, the musical instrument is listed as a national treasure. According to BRAUCHLI (2000), the harpsichord reveals references to two authors, based on the following visible inscriptions: **(1)** "*ANDRE RUCKUERS ANNEE 1636*", probably painted by Taskin in golden letters, on the soundboard; **(2)** "*FAIT PAR PASCAL TASKIN À PARIS, 1782*", on the wrestplank in front of the tuning pins; **(3)** "*1636*" in two different locations on the soundboard, with different font styles; and **(4)** a rose with the letters "AR" identical to those used back of the lower manual key Andreas Ruckers from 1636 to 1694. The author also pointed the hidden inscriptions: **(1)** "*PASCAL TASKIN, Facteur/ de Clavecins & Garde des Instruments de Musique du Roi, Elève & Succes-\seur de M. BLANCHET, rue de la / Verrerie, vis-à-vis S. Merry. / A PARIS*" on the trade-card glued inside the instrument; **(2)** "*(A) R 1636*" in red chalk of the lower manual key-frame; **(3)** "*AR 1636*" on underside of the front rail between the two keyboards; and **(4)** "*943*", probably an inventory number in red paint on the spine-side of the main lid. There are different opinions as to the instrument's authenticity. According to BRAUCHLI (2000), it is a harpsichord designed entirely by Pascal Taskin, whose soundboard may be harnessed from an original Ruckers virginal, as well as the golden rosette with the initials "AR". On the other hand, O'BRIEN (1990) included this harpsichord in the catalogue of "non-authentic" Ruckers instruments and specifically noted that it is an instrument with a soundboard made up of parts taken from a virgin Flemish, decorated in the style of the Ruckers School. The soundboard, however, offers a floral and vegetal decoration of far poorer quality than that diffused by the Ruckers family.

8. Harpsichord (MNM0374, unknown attribution, Italia or Portugal, 1724)

The date “*1724*” is painted in black on the front surface of the jack rail, as well as on key lever 1 (C).

9. Virginal (MNM0395, Hans Ruckers, Southern Netherlands, XVI/XVII century)

The inscription “*HANS RUCKERS MÊ FECIT ANTWERPIAE ANNO 1620*” is painted in gold on the bridge of the soundboard.

Table 13. Identification of the string keyboard instruments (fortepiano, harpsichord, clavichord, and virginal), attribution, historical and stylistic dating and the wood identification applied in their construction. [1] Orientation of the strings in relation to the boards of the soundboard.

MUSICAL INSTRUMENT [INVENTORY NUMBER]	ATRIBUTTION	LIFETIME/ ACTIVITY PERIOD	HISTORICAL/ STYLISTIC DATE	STRINGS ORIENTA-TION[1]	WOOD SPECIES
PORTUGUESE INSTRUMENTS					
Clavichord [MNM0406]	Unknown	n.a.	XVIII century (2nd quarter)	Parallel	Coniferous, boxwood, rosewood, and walnut (DODERER and VAN DER MEER, 2005)
Clavichord [MNM0407]			1750-1790	Without strings	Beech, coniferous, boxwood, chestnut, and rosewood (DODERER and VAN DER MEER, 2005)
Fortepiano [MNM0425]	Henry van Casteel	1722-1790	1763	Parallel	Boxwood, chestnut, coniferous, fruitwood, mahogony, myrtle, rosewood, and walnut (DODERER and VAN DER MEER, 2005)
Fortepiano [CRMM]	Mathias Bostem	1731 - 1806	1777	Without strings	Boxwood, chestnut, coniferous, ebony, fruitwood, mahogany, tulip wood, and walnut (DODERER and VAN DER MEER, 2005)
Fortepiano [MNM0648]			1786	Parallel	Boxwood, chestnut, coniferous, ebony, fruitwood, mahogany, myrtle, poplar, tulip wood, and walnut (DODERER and VAN DER MEER, 2005)
Fortepiano [MNM0833]			1789	Without strings	Beech (not original), boxwood, chestnut, coniferous, myrtle, mahogany, and walnut (DODERER and VAN DER MEER, 2005)
Harpsichord [MNM0373]	João Baptista Antunes	1737-1822	1789	Parallel	Boxwood, cherry tree, coniferous, mahogany tree, myrtle, orange tree, rose wood, and walnut (DODERER and VAN DER MEER, 2005)
Harpsichord [MNM0372]	Joaquim José Antunes	XXX	1758	Parallel	Boxwood, coniferous, ebony, mahogany, tulip wood, and walnut (DODERER and VAN DER MEER, 2005)
Harpsichord [MNM0681]	Unknown	n.a.	After 1725	Oblique	Beech, *Pinus sylvestris* L., and rosewood (MatrizNet)
FOREIGNERS INSTRUMENTS					
Clavichord [MNM0419]	Unknown, Germany	n.a.	XVIII century	Parallel	Boxwood, ebony, linden tree, *Pinus sylvestris* L., and walnut (MatrizNet)
Harpsichord [MNM1096]	Pascal Taskin, France	1723-1793	1782 (&1636)	Parallel	Acer sp., *Cupressus* sp., ebony, *Picea* sp., *Populus* sp. and *Quercus* sp. (ESTROMPA, 2012)
Harpsichord [MNM0374]	Unknown, Italia or Portugal	n.a.	1724	Without strings	Beech, ebony, fruitwood, spruce, and walnut (DODERER and VAN DER MEER, 2005)
Virginal [MNM0395]	Hans Ruckers family, Southern Netherlands	n.a.	1620	Oblique	Coniferous, poplar and oak sp. (MatrizNet)

1.2. Methods

1.2.1. Preparation of material, measurement, and recording

1.2.1.1. Panels

The dendrochronological analysis in the panel involved its displacement from the wall, removal of the frame and horizontal positioning. This method has mostly been carried out by specialised museum collaborators and supervised by a conservator-restorer (Figures 32 A, B and C).

Figure 32. First stages of the dendrochronological study of *Nossa Senhora do Amparo* panel (MASF39), MASF, assigned to Jan Gossart and followers: **[A]** removal of the panel from the wall; **[B]** removal of the frame; **[C]** panel without frame to view the cross section of the boards; **[D]** cleaning the wood surface; and **[E]** preparation of the wood surface with a blade.

Dendrochronological research was conducted only through direct observation, since it is impossible to take samples of the artwork. By means of a previous preparation with a blade, the transverse section of the boards permitted the visualisation of the growth rings (Figures 32D and E). Regularization and surface regeneration provided a clear visualisation of the growth rings (Figure 33A). The state of conservation of the boards, on the other hand, did not always allow for a dendrochronological study. The failure to carry out a continuous measurement of the growth rings may be justified for numerous reasons: **(1)** the installation of newer wooden pieces (Figure 33B); **(2)** the consolidation plasters used in the previous conservation and restoration works (Figure 33C); **(3)** the deterioration of wood (Figure 33D); and **(4)** the xylophagous galleries (Figure 33E).

Figure 33. Transverse sections of oak boards from *Mater Misericordiae*, NMCPSMS, assigned to Portuguese painter Gregório Lopes: **[A]** with and without preparation; **[B]** newer wood; **[C]** consolidation plaster; **[D]** wood degradation; and **[E]** xylophagous galleries (SOURCE: CEF-ISA unpublished).

Measurements of the width and thickness of the boards were taken at this point since the panel was without the frame. The top or lower section of the panel was chosen for investigation based on a combination of the wood conservation state and the width of the board. When the two cross-sections were not measured, the preference was for the broadest side of the board to be measured, with a greater number of rings to be measured. In terms of thickness, thinner panels might cause measurement mistakes in some situations since it is difficult, if not impossible, to visualize the sequence of the same ring between the two sides of the same medullar rays.

There are several methods for the tree rings measurements: **(1)** directly on the object, using a magnifying glass; **(2)** a microscope attached to a measuring table; or **(3)** photographs. In the present study, the dating technique was based on macro-photographs calibrated on a semi-millimetric scale of the cross-section of each board (FRAITURE, 2009) with a digital camera (CANNON EOS 1100D) and a macro-lens (CANON OBJ. 60 mm f/2.8 EF-S MACRO). The camera was mounted on a 60 cm long slider, maintaining the same distance between the lens and the cross-section of the board, as well as smoother overlapping of the images (Figure 34).

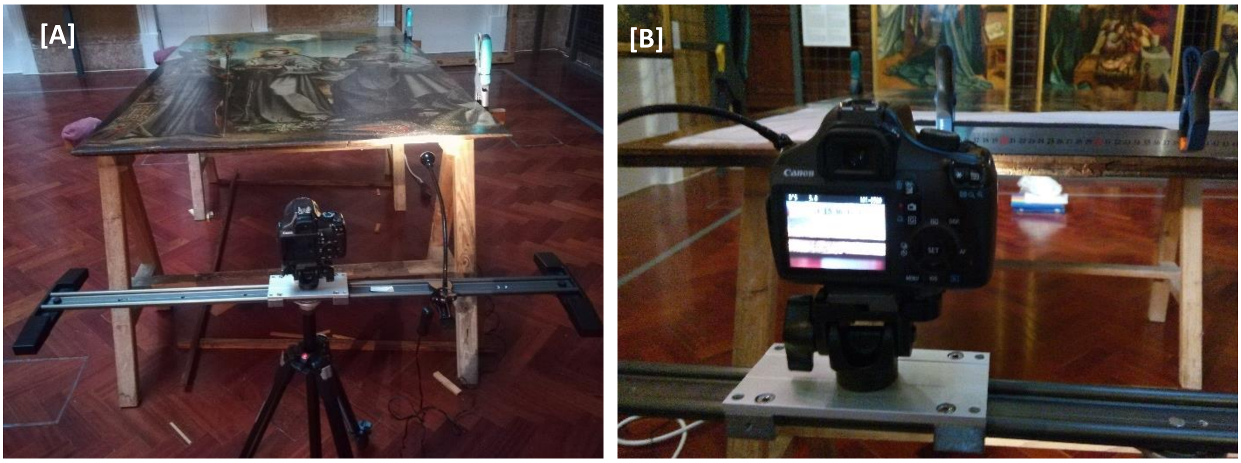


Figure 34. [A] Image acquisition equipment; and **[B]** calibrated macro-photographs of the lower cross-section of the boards with a digital camera on a slider.

The measurement of the growth rings was carried out with Analisys software (version 3.2, AnalySIS Soft Imaging System GmbH, Munster, Germany) by the sequential and overlapping display of the images (Figure 35A). The criterion for measuring the growth rings was according to the direction of the medullar rays (Figure 35B). The criteria based on the horizontal line along the image can only be extended until the board has a full radial cut, with the medullar rays parallel to the image.

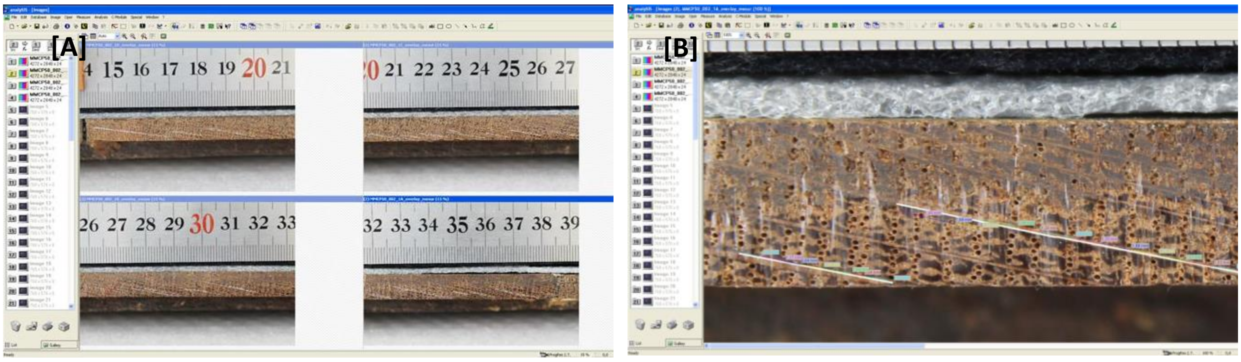


Figure 35. [A] Tree-ring measurements in Analisys software in four consecutive and overlapping images; and **[B]** measurement of the growth rings along the medullar rays on an oak board.

1.2.1.2. Musical instruments

1.2.1.2.1. Violins and cellos

In cases where the musical instruments were on exhibition in the museum, the study required their removal from the window. This procedure has exclusively been carried out by museum specialists, always in the presence of a technical expert (Figure 36A).

The dendrochronological study was conducted in the front section of the resonance body of a violin or cello (*belly*). The strings had to be removed because the shadow they projected on the instrument surface affected the measuring of the tree rings (Figure 36B).

Previously, it was essential to identify the number of pieces that composed the instrument. The radial cross-section of the wood piece allows the growth rings to be visualised and the limits of each part to be established (Figure 36C). The belly may be composed of one or more pieces, consisting of two parts in most violins, with a joint in the middle. Due to the increased size of the instrument and the lack of appropriate board width, cellos are more commonly composed of four pieces (two parts on the bass side and two parts on the treble side). In practical terms, the *bass side* identifies the left side, while the *treble side* identifies the right side.

There are several techniques applied to violins and cellos to obtain dendrochronological data, such as photography, direct measurement with a graduated magnifying glass, x-ray, and scanner. In this research, the approach used was the same as that specified for the panels, considering the benefits indicated above. The main change was the position of the ruler for image calibration, as the musical instrument was shot vertically. As a result, labels (previously examined and approved by a luthier) were applied for calibration and identification of the boundaries of the components that composed the belly (Figure 36D).

The growth rings were measured at the widest area of the instrument to ensure the highest number of growth rings. However, two additional levels were considered to compare/correct the lower-level measurements.

Figure 36. Dendrochronological study stages of a Portuguese cello, MNM, assigned to Joaquim José Galrão: **[A]** window removal; **[B]** cello without strings and labelling in three levels for the growth rings measurements; **[C]** radial cross-section macro-photographs; and **[D]** separation between bass side and treble side.

1.2.1.2.2. Harpsichords and fortepianos

The dendrochronological dating of the string keyboard instruments was done by means of an inspection of the corresponding soundboard and, in three cases, the wrestplank as well. In all the instruments examined, the soundboard was made of softwood, as well as the wrestplank in the Antunes harpsichord (MNM0372), Antunes harpsichord (MNM0373) and Taskin harpsichord (MNM1096).

The photographic equipment was configured considering the scale and form of each instrument by attaching a 60 cm slider to the edge of two tripods with a maximum length of 191 cm (MANFROTTO GIRAFA 420B). In this manner, the camera could be mounted such that the lens was parallel to the soundboard and wrestplank and could be moved across the width of the instrument (Figures 37A and B). Since the distance between the operator and the camera in the innermost sections of the soundboard did not allow access to the camera for focusing and firing, it was appropriate to connect it to a laptop with a shutter cable (HAHNEL HRC-280). The image acquisition on this sort of instrument needed a second operator, so the strings could not be removed. The shadows produced on the soundboard were mistaken for the growth rings due to the parallelism between them (Figure 37C). To distinguish between the strings and the earlywood/latewood in each ring, it was important to change the light in each photo. Decision on the best adjustment based on the image obtained in the laptop (Figure 37D). This method was also used to reduce the reflection caused by application of varnish, namely in the Taskin harpsichord (MNM1096), Ruckers virginal (MNM0395) and Henry van Casteel fortepiano (MNM0425). This approach has demonstrated that dendrochronology may be investigated without the need of specialized equipment, such as the prototype of a translation table proposed by HOUBRECHTS (2004, 2006). Regardless of the approach used, the flaws discovered by BERNABEI and UFAR (2018) in picture calibration for subsequent tree ring measurements, especially the inaccuracies associated with parallax and lens distortion, should not be overlooked.

The number of boards was defined and delimited in each instrument at various levels of its length. The measurements of the growth rings were established at least at two levels on each board, perpendicular to the grain, and a representative mean series was obtained (Table 7; Figure 38A). The goal was to optimise the amount of available growth rings while preventing errors caused by distortions. On certain instruments, the soundboard and wrestplank, and the tuning pins restricted the continuous distinction of the growth rings. Measurement at different levels of the same board settled this problem (Figure 38B).

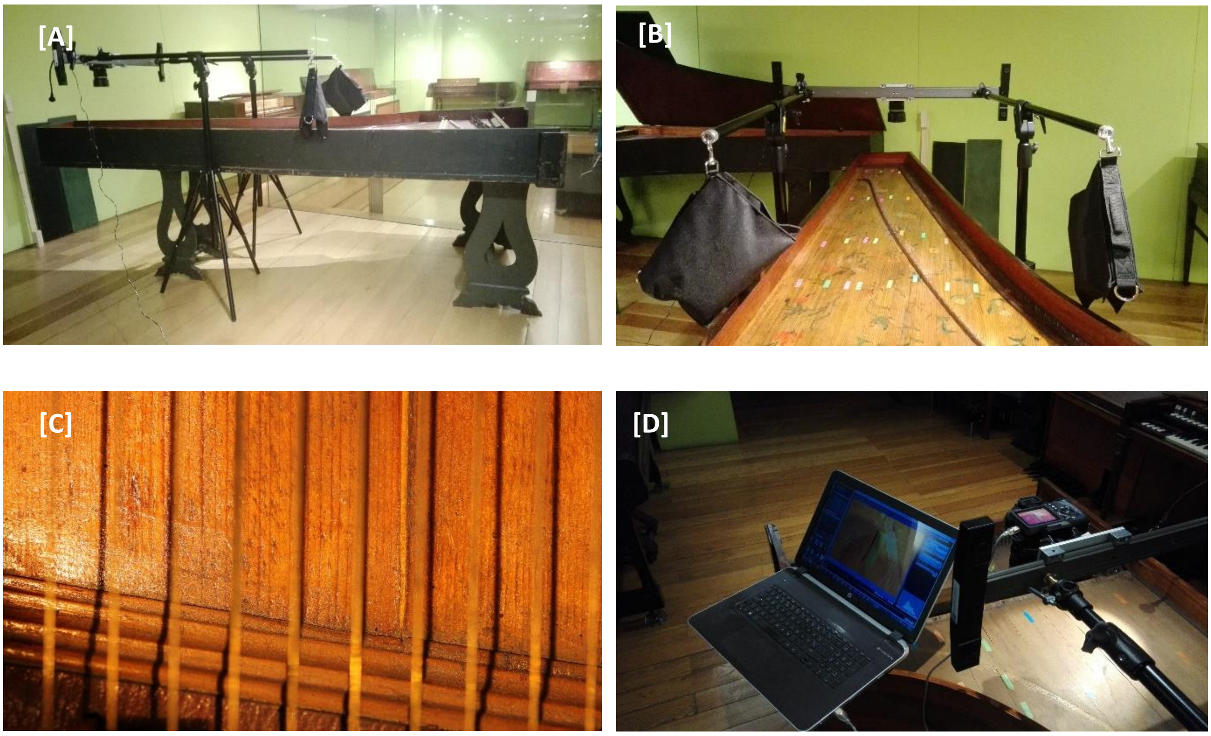


Figure 37. Image acquisition methodology for the dendrochronological study of: **[A-B]** the Portuguese harpsichord assigned to João Baptista Antunes (MNM0373); **[C]** parallelism between growth rings and strings in Portuguese fortepiano assigned to Mathias Bostem (CRMM); and **[D]** display of the tree rings on laptop.

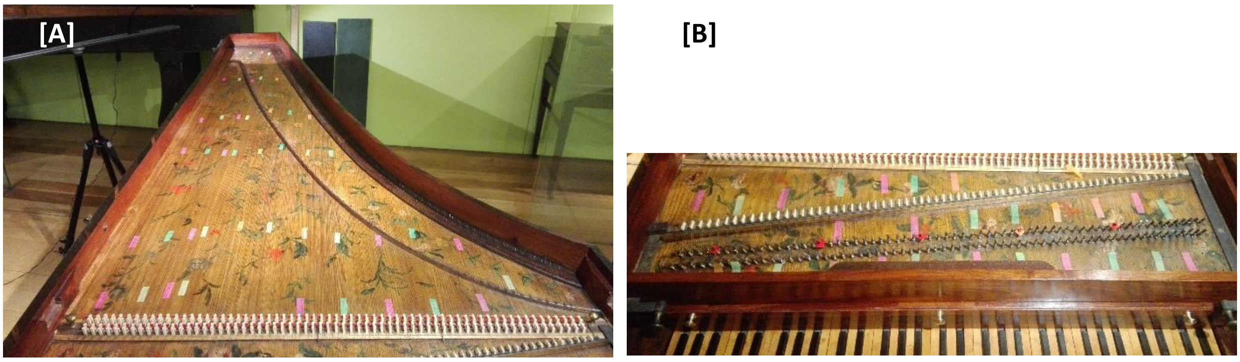


Figure 38. Boards' identification in several levels in the Portuguese harpsichord (MNM0373), MNM, assigned to João Baptista Antunes: **[A]** 15 panel boards in the soundboard; and **[B]** 12 panel boards in the wrestplank with tuning pins.

1.2.2. Wood identification in panel

The identification procedures used for this type of artwork are constrained by its uniqueness, purpose, and historical value. For this reason, only the *Conversão de Hermógenes* panel (20 Pint) from the *Vida de S. Tiago* altarpiece was anatomically studied by removing a very small sample from the back side. It was decided to proceed through the observation by scanning electron microscope Hitachi TM 3030 Plus a 5 kV (SEM) (Figure 39) since the sample was too small to be cut in thin sections. The terminology follows the IAWA list of microscopic features for hardwood identification (IAWA COMMITTEE, 1989).

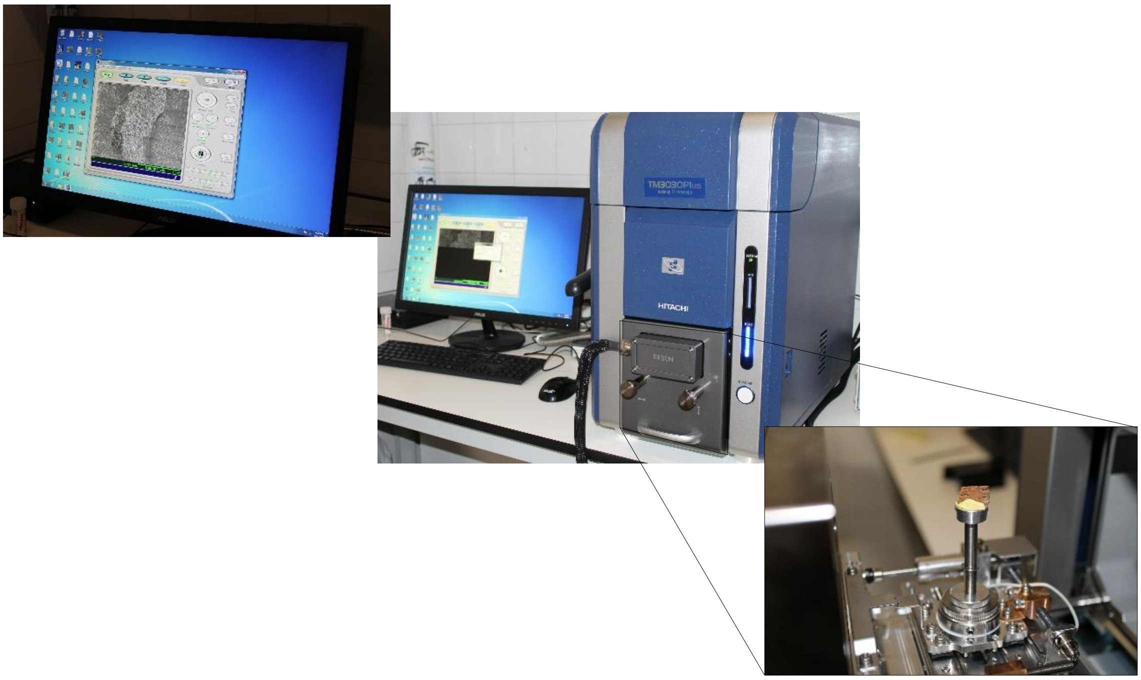


Figure 39. Scanning electron microscope (SEM)

1.2.3. Dendrochronological dating

The selected software package for the dendrochronological dating was TRiCYCLE (BREWER *et al.*, 2011), TSAP Win Scientific 4.64 (RINN, 2008) and COFECHA (HOLMES, 1983).

The visual combination of two tree-ring patterns is regarded as the first step in dendrochronological analysis. Successive tree ring width in years tends to be a random unpredictable curve, but patterns towards wider or narrower rings suggest, respectively, an increase or worsening in growing conditions. These patterns can be long or short-term and of differing severity. The visual comparison of tree-ring width graphs includes overlapping of the two curves under analysis and changing their relative locations until a significant consensus is found between them. In practise, the researcher looks at significant features such as wide or narrow rings, narrow stripes, trends or obvious patterns on one curve and tries to replicate them on the second curve. However, visual correspondence can be subjective (BAILLIE, 1982).

The second step is to control the cross dating using statistical parameters such as *Gleichläufigkeit*, t-test, and several statistical standard parameters that describe a series of tree ring measurements, as described below.

- **AVERAGE AND STANDARD DEVIATION**

The average growth rate [I] and the standard deviation [II], computed from the tree ring measurements series, are variables that enable us to quantify the grain (SCHWEINGRUBER, 1988). Combining all growth-ring characteristics permits the quantification of the overall uniformity of the lumber.

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad [I]$$

$$S_y = \pm\sqrt{\frac{1}{n-1} \times \sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad [II]$$

where,
y_i = ring width in the year *i*

- **MEAN SENSITIVITY**

The sensitivity measures the relative difference between two successive values of a tree ring measurements series. The average of the absolute values of the individual sensitivities in a series is called the mean sensitivity (MS), and it represents the amplitude of the series from year-to-year (SCHWEINGRUBER, 1988). The single values of the sensitivity range between 0 (no difference between consecutive tings) to 2 (a zero occurs net to a non-zero). A tree ring series with high mean sensitivity (*sensitive series*) is preferable to one with poor mean sensitivity (*complacent series*) it is a statistical parameter that measures the signal and the variation of the series.

$$MS = \frac{1}{n-1}\sum_{i=1}^{n-1}\left|\frac{2(y_{i+1} - y_i)}{y_{i+1} + y_i}\right|$$

where,
n=number of years
y_i = ring width in the year *i*
y_{i+1} = ring width in the following year

- ***GLEICHLÄUFIGKEIT*** **(**or **PERCENTAGE OF PARALLEL VARIATION)**

The ***Gleichläufigkeit*** (Glk) is a measure of the similarity between two curves based on the first difference between successive tree-rings expressed as percentage (ECKSTEIN and BAUCH, 1969). This test can be used to compare undetrended series, since it only considers the differences between directly adjacent ring widths. The intervals between consecutive points in time are examined for their upward or downward trends. When common intervals behave in the same way, a Glk value of 1 is assigned; when they do not agree, a Glk value of 0 is assigned. If the curve has two consecutive points without a change, a value of 0.5 is assigned. This analysis of annual trends permits the researcher to compare the trend of wood samples and the ring widths. When the intervals of the annual curves of the rings run parallel for many years, it can be assumed that the factors influencing growth were similar in both cases. The calculation of *Gleichläufigkeit* score is based on two equations according to ECKSTEIN and BAUCH (1969).

$$Glk = \frac{1}{n-1}\sum_{i=1}^{n-1}\left|G_{ix} + G_{iy}\right|$$

$$Glk = +0.5 \; if \; \Delta_i > 0$$

$$Glk = 0 \; if \; \Delta_i = 0 \qquad \Delta_i = (y_{i+1} - y_i)$$

$$Glk = -0.5 \; if \; \Delta_i < 0$$

where,
n=number of years
y_i=ring width in the year *i*
y_{i+1}=ring width in the following year
G_{ix}=value added to the G score whether ring width is increasing, staying the same, or decreasing in each interval for series *x*
G_{iy}=value added to the G score for series *y*; *n* is the number of years being compared

The significance of an observed value of $Glk_{(x,y)}$ is calculated by transforming it into a *z*-score.

$$z = \frac{Glk - 0.5}{S}$$

The standard normal curve is used to determine the probability (P) that the observed or an even higher value of *z*-score occurs when no match exists between the series (the probability of exceedance (JANSMA, 1995).

Before calculating the correlation coefficient, it is advisable to remove the long-term fluctuations (e.g., age trend and annual changes) contained in the raw data curves (BAILLIE, 1982; SCHWEINGRUBER, 1988). There are several transformation procedures provided by the different commercial and open-source software. However, the selection of any transformation procedure of a chronological series always implies the loss of information. The two most common statistical analysis used in dendroarchaeology are the data transformation function and Student's t-test adapted by BAILLIE and PILCHERH (1973) (HANECA, 2005; BERNABEI *et al.*, 2019) and by HOLLSTEIN (1980) (HANECA *et al.*, 2005):

- **BAILLIE AND PILCHER ALGORITHM**

For the Baillie and Pilcher (BP) procedure, the statistical parameters are calculated in the following sequential order.

1. Standardization on which each ring width is converted to a percentage of the mean of the five ring widths of which it is the centre value (known as *5-yr moving average*). In this form the data varies about a mean of 100 without a normal distribution. It is obtained through the log to base *e* of the percentage values (BAILLIE and PILCHERH, 1973).

$$\boldsymbol{y_{i,BP}} = \ln\left(\frac{\boldsymbol{5y_i}}{\boldsymbol{y_{i-2}} + \boldsymbol{y_{i-1}} + \boldsymbol{y_i} + \boldsymbol{y_{i+1}} + \boldsymbol{y_{i+2}}}\right)$$

2. The correlation coefficient (r) is used as measure of the strength of the agreement between two series.

$$r = \frac{\sum_{i=1}^{n}(x_{i,BP}y_{i,BP}) - n\bar{x}_{BP}\,\bar{y}_{BP}}{\sqrt{\left(\sum_{i=1}^{n} x_{i,BP}{}^2 - nx_{BP}{}^{-2}\right)\left(\sum_{i=1}^{n} y_{i,BP}{}^2 - ny_{BP}{}^{-2}\right)}}$$

3. The corresponding *t*-value (t_{BP}) gives a measure of the probability that the observed correlation coefficient is significatly different from zer. It is calculated according to the following formula.

$$t_{BP} = \frac{r\sqrt{n-2}}{(1-r^2)}$$

where,
y_i and yx_i = ring width of the series *y* and x in the year *i*
y_{iBP} and x_{iBP}= tree-ring indices of the series y and x at the year i, after Baillie and Pilcher transformation (BAILLIE and PILCHERH, 1973)
$\bar{y}_{BP}$ and $\bar{x}_{BP}$= mean of tree-ring indices of the series y and x
n = number of overlapping years between series

- **HOLLSTEIN ALGORITHM**

For the Hollstein (H) procedure, the statistical parameters are calculated in the following sequential order.

1. Standardization by a logarithmic transformation after division of each ring-width value by its following value as presented in the below formula, called as Wuchswert-formula (HOLLSTEIN, 1980).

$$y_{i,H} = 100 \times \log_{10} \frac{y_i}{y_{i+1}}$$

2. The correlation coefficient (r) is used as measure of the strength of the agreement between two series.

$$r = \pm \frac{\sum_{i=1}^{n}(x_{i,H} - \bar{x}_H)(y_{i,H} - \bar{y}_H)}{\sqrt{\sum_{i=1}^{n}(x_{i,H} - \bar{x}_H)^2 \sum_{i=1}^{n}(y_{i,H} - \bar{y}_H)^2}}$$

3. The corresponding *t*-value (t_H) gives a measure of the probability that the observed correlation coefficient is significatly different from zer. It is calculated according to the following formula.

$$t_H = \frac{r\sqrt{n-2}}{(1-r^2)}$$

where,
y_i and yx_i = ring width of the series *y* and x in the year *i*
$y_{i,H}$ and $x_{i,H}$= tree-ring indices of the series y and x at the year *i*, after Hollstein transformation
$\bar{y}_H$ and $\bar{x}_H$= mean of tree-ring indices of the series y and x
n = number of overlapping years between series

1.2.3.1. Panels

Previously, comparison of tree ring curves from the same artwork was performed through visualization and then by statistical analysis in TSAP Win software. If two or more tree ring curves are considered to have originated from the same tree, the average tree ring measurements for later dates have been determined. However, from a methodological point of view, there is no settled principle that boards come from the same tree. It is based on different criteria that the dendrochronologist draws a conclusive decision. The following set of criteria was applied to oak boards: **(1)** t-value Baillie-Pilcher, t_{BP} (BAILLIE and PILCHERH, 1973), greater than 9.0; **(2)** graphical similarity between the two growth curves (*synchronization*); **(3)** similar tree-ring widths of compared sequences; **(4)** agreement of pointer years; and **(5)** nearly the same year of the beginning or end of the sequences (BEUTING, 2009; FRAITURE, 2011).

In addition to an effective replication of the date, BAILLIE (1982) defined an appropriate dating as a t_{BP} equal to or greater than 3.5, with a significance level of 0.001 and an overlap equal to or greater than 100 rings. However, there is no widely agreed criterion, which varies depending on the researchers/laboratories. The current analysis was based on JANSMAN (1995), who identified a good threshold value as a t_{BP} value equal to or greater than 5.0, a significance level equal to or lower than 0.001 (or equal to or greater than 0.999), and an absolute replication of distinct chronological series.

The single or average series was statistically correlated with published and unpublished references, as well as ring patterns found in other panels, historical buildings, and archaeological samples for dating purposes. Table 14 summarises a list of oak reference chronologies that could date the artworks under research, provided their sources and period, in alphabetical order by local. A set of tree-ring series of Portuguese and Flemish paintings from public and private collections in Portugal, available by the Instituto José de Figueiredo (Direcção Geral do Património Cultural) under the research project *Desenvolvimento de cronologias-padrão de anéis de crescimento em Portugal – um instrumento para a datação de achados arqueológicos e de obras de arte* (PTDC/HIS-ARQ/117099/2010)[45], and Centro de Estudos Florestais, Instituto Superior de Agronomia (Universidade de Lisboa), was also included in the research (Table 15).

Table 14. Oak chronologies relevant for dendrochronological research in Portuguese and Flemish panels [(a) unpublished chronologies, kindly provided by Peter Klein, which were developed by Josef Bauch, Dieter Eckstein and Peter Klein of the Institute of Wood Science, University of Hamburg].

LOCATION	IDENTIFICATION CODE	FIRST YEAR	LAST YEAR	OBSERVATIONS	SOURCE
Imported wood					
Baltic	BALTIC1	1156	1597	Art	HILLAM and TYERS (1995)
	BALTIC2	1257	1615		
	BOWHILL-B	1161	1483	Buildings structures	GROVES (2002a)
	GRIMSBY1	1100	1405	Archaeological findings	GROVES (1992)
	NL BALTIC A	1030	1602	Wood artefacts	JANSMA (unpublished)
	NL BALTIC B	1167	1544		
	NL BALTIC Import	1167	1637	Art and furniture	JANSMA *et al.* (2004)
	WMNSTR14	1137	1375	Furniture	MILES and BRIDGE (2008)
	WMNSTR20	1151	1369		
	WHTOWR4	1245	1440		MILES (2007)
	0520001M	1173	1619	Niederl. Sued Gemaelde	(a)
	0520002M	1199	1635	Niederl. Nord Gemaelde	(a)
	0520003M	1115	1643	Niederl. Gesamt Gemaelde	ECKSTEIN *et al.* (1975)
	0520004M	1363	1643	Wouwermann G. Typ NL	(a)
	0520005M	1400	1655	Wouwermann G. Typ W	(a)
	0520006M	1146	1491	Leiden Gemaelde	(a)
	0520007M	1000	1490	Koeln G. Typ W	(a)
	0520008M	1036	1972	Niederlande Bauholz	(a)

[45] Proposing Institution: Instituto Superior de Agronomia (ISA), Universidade de Lisboa; Participating Institution: Direcção Geral do Património Cultural (DGPC); Main research units: Centro de Estudos Florestais (CEF-ISA) and Instituto José de Figueiredo (IJF-DGPC)

LOCATION	IDENTIFICATION CODE	FIRST YEAR	LAST YEAR	OBSERVATIONS	SOURCE
England	BRUCE 3	1434	1542	Buildings structures	BRIDGES (1998)
	BRUCE 4	1421	1544		
	SINAI	1227	1750	Buildings structures	TYERS (1997)
England (Mid-West)	BOWHILL-A	1292	1468	Buildings structures	GROVES (2002a)
England (Southern)	CROAKBRIDGE	1083	1589	Buildings structures	BRIDGES (1988)
Germany	0525001M	822	1964	-	HOLLSTEIN (1965)
	WDEUTSCH_EICHE	690	1975	Archaeology and art history	HOLLSTEIN (1980)
	EMS_WESER IV	1314	1618		
Germany (Trier)	TRD1	1124	1450		
	TRSS	1274	1450		
Belgium Eastern & Germany (Ardennes-Eiffel)	ARDENNEN_EIFEL II	94	1756		
Germany (Rhein-Main)	RHEIN-MAIN II	440	1787		
Germany & Luxembourg & France Eastern	SAAR-MOSEL IV	730	1975		
Known source					
Germany (South)	EICHEN_GERM	370	1950	Structural timbers	BECKER (1981)
Lithuania	VILQURO1	1208	1408	Buildings structures	PUKIENÉ (2002)
	MEMEL	1288	1580	Archaeological architecture	BRAZAUSKAS (2005)
Netherland	NETH001	1311	1550	Structural timbers	ITRDB[46]
Netherland	NETH016	1191	1457	Structural timbers	ITRDB[47]
Poland	POL006	996	1985	Buildings structures (East Pomerania)	ITRDB[48]
	0670108M	725	1985	Buildings structures (Gdanks, Pomerania)	WAZNY (1990)

Table 15. Source of the tree-ring series for dendrochronological research in Portuguese and Flemish panels from public and private collections in Portugal.

INSTITUTION / AUTHOR	PAINTING WORKSHOP	TIME SPAN	NR. SERIES
Instituto José de Figueiredo (Direcção Geral do Património Cultural)	Portuguese	1157-1593	89
	Flemish	1041-1536	47
Forest Research Centre, School of Agriculture, University of Lisbon	Portuguese	1144-1599	98
	Flemish	1186-1553	52

FLETCHER *et al.* (1974) produced one of the longest oak master chronologies (known as MC18), which originally dated from 1230 to 1546 and was revised by BAILLIE *et al.* (1985) *posteriori* for the period 1234 to 1550. FLETCHER (1977) established five new chronologies (REF1-REF5) through the inclusion of new series obtained in panels to the MC18 chronology. As a result, even though these chronologies

[46] JANSMA, E. (2002-04-26): NOAA/WDS Paleoclimatology - Jansma - S-Hertogenbosch - QUSP - ITRDB NETH001. NOAA National Centers for Environmental Information. https://doi.org/10.25921/hwp8-sz05. Accessed [15.07.2016].
[47] JANSMA, E., VAN RIJN, P. (2002-04-26): NOAA/WDS Paleoclimatology - Jansma - Maastricht St. Jan's Church Roof Timbers - QUSP - ITRDB NETH016. NOAA National Centers for Environmental Information. https://doi.org/10.25921/1td2-y529. Accessed [15.07.2016].
[48] WAZNY, T. (1996-05-08): NOAA/WDS Paleoclimatology - Wazny - East Pomerania - QURO - ITRDB POLA006. NOAA National Centers for Environmental Information. https://doi.org/10.25921/hmy4-n833. Accessed [2.02.2016]

are usable, they were not included in the current study's replication research. Flecther's data was reanalysed by HILLAM and TYERS (1995), who generated two master chronologies from the larger data set: “BALTIC1” is made up of 67 tree-ring sequences that span 1156 to 1597, while “BALTIC2” is made up of 40 tree-ring sequences that span 1257 to 1615. The differences between the two chronologies may be due to shifts in the originating regions for oak wood, which had to be transported from the area surrounding the eastern Baltic Sea region. This shift in the source area may be attributed to fluctuations in exports from various ports due to changing tree harvesting supply (HILLAM and TYERS, 1995). These master chronologies have proven to be incredibly useful for dating purposes (HANECA *et al.*, 2005). There is a global arrangement between the two master curves, but a disagreement regarding the "pointer years" – narrow rings in 1357 and 1358 und narrow-wide-narrow in 1395-1397 are characteristic of BALTIC1; narrow ring in 1361 is common amongst the BALTIC2 chronological series. BALTIC2 is a dendrochronological series set that is more diverse than BALTIC1 (HILLAM and TYERS, 1995). Since REF1-REF5 are not independent of BALTIC1 and BALTIC2, they should be viewed with caution when evaluating data replication dating.

The ITRDB database, which is maintained by *NCEI's Paleoclimatology Team* and the *World Data System for Paleoclimatology*, is the world's largest public repository of tree ring data. It provides a huge collection of historical series and site chronologies of various species, sites, and time periods. However, since there are few oak reference chronologies covering the XV and XVI centuries, this set is not so useful for dating paintings.

Since the number of sapwood rings in oak species varies depending on a variety of factors, the selection criterion is based on the information obtained through dating, specifically the provenance region (see subchapter 3.6.1.2. *Sapwood number*). If the source area of the trees used in the panels supports refers to the BALTIC region (as is most likely for the Flemish and Portuguese panels from XV-XVI centuries), the criterion for the number of sapwood rings identified by WAZNY (1990) shall be applied: the minimum is 9, the median is 15, and the mean is 23. According to KLEIN (1998a), if the boards come from trees over 200 years of age, it is more fitting to add the median value of the sapwood rings instead of the minimum. BAUCH (2002) proposed a minimum of 15 sapwood rings for oaks older than 300 years.

There is also a need to consider the time between tree cutting and wood panel preparing, including felling, transport, cutting, seasoning, and finishing (FRAITURE, 2002; BERNABEI *et al.*, 2007). In the present research, a minimum of two years has been considered since it deals with Flemish panels from the XVI century on wood from the Baltic region. A similar approach has been taken to the

Portuguese panels. In the case of oak trees transported into Portugal, the inclusion of travel time may be questionable. A maritime trip between Lisbon and Estonia, according to MARQUES (1959), could take about 42 days, not including the time required for stopover ships. Therefore, provided the travel time of nearly two months, the original estimation of the two-year period would not be overestimated.

1.2.3.2. Musical instruments

The following criteria were used to decide whether two coniferous wood instrument parts come from the same tree: **(1)** t-value after Hollstein, t_H (HOLLSTEIN, 1980) greater than 8.0; **(2)** Glk equal or greater than 70%; **(3)** statistical significance of 0.999; **(4)** a minimum of 70 years of tree rings overlap; **(5)** graphical similarity between the two growth curves (*synchronization*); **(6)** similar tree-ring widths of compared sequences; **(7)** agreement of pointer years; and **(8)** nearly the same year of the beginning or end of the sequences (BEUTING, 2009).

The following criterion has been used to achieve a statistically accurate dating: **(1)** t-value after Hollstein (t_H) equal or greater than 4.0; and **(2)** *Gleichläufigkeit* equal or greater than 60% (ČUFAR *et al.*, 2015; ČUFAR *et al.*, 2017). The *terminus post quem* is given by the most recent ring on one of the boards that make up the musical instrument. According to KLEIN *et al.* (1986) and subsequent dendrochronological investigations of musical instruments undertaken thereafter, there is no common opinion on the use of sapwood in their construction. Therefore, it is assumed that sapwood has not been removed.

For dating, the single or average sequences obtained from the musical instrument were statistically correlated with published and unpublished reference chronologies, as well as to single and average sequences obtained from many other instruments and historical buildings. For the present research, the key sources of reference chronologies that ensured the necessary date replication for a dendrochronological analysis appointed by BAILLIE (1982) were: **(1)** ITRDB (Table 16); **(2)** Laboratory for Dendrochronological Investigations on Musical Instruments and Art Objects of Micha Beuting (Germany); and **(3)** Laboratory of Dendrochronology, University of Liège (HOUBRECHTS 2004, 2006).

During the present research, a new database (CEF-ISA database) was created and used in various stages of development. Step 1 of the CEF-ISA database's continuous enhancement involved 130 musical instruments and led to the dating of the violins and cellos mentioned in the article "*Violins and cellos from Portuguese collections. A tree ring study as ahistorical source of the Portuguese* *heritage*". Phase 2 contained the latest sequences of these instruments and was used for the dating of harpsichords and fortepianos, leading to phase 3, which contains a total of 159 instruments (see subchapter 2.3.1. *Development of a new database to coniferous wood artworks*).

Reference chronologies of various wood species were considered for dating based on literature: Norway spruce (*Picea abies* Karst), larch (*Larix decidua* Mill.), silver fir (*Abies alba* Mill.) and Arolla pine (*Pinus cembra* L.).

Table 16. Reference chronologies obtained from International Tree-Ring Data Bank (ITRDB) used to date musical instruments [LAT – Latitude, LON – Longitude].

SITE				IDENTIFICA-TION CODE	FIRST YEAR	LAST YEAR	SPECIES
COUNTRY	NAME	COORDINATES (LAT, LON)	ELEVA TION (m)				
Austria	Obergurgl	46.51, 11.01	2 000	AUST003[49]	1789	1974	*Picea abies* Karst.
France	Les Merveilles	44.02, 7.27	2 165	FRAN009[50]	1187	1974	*Larix decidua* Mill.
			2 150	FRAN010[51]	988	1974	*Larix decidua* Mill.
	L'Orgere	45.13, 6.41	2 100	FRAN011[52]	1539	1972	*Larix decidua* Mill.
			1 900	FRAN012[53]	1353	1958	*Larix decidua* Mill.
	Vizzavona Mount Renoso	42.05, 9.12	1 500	FRAN038[54]	1678	1980	*Abies alba* Mill.
Germany	Bayerischer Wald	48.45, 13.00	940	GERM004[55]	1541	1951	*Abies alba* Mill.
	Bayerischer Wald		940	GERM005[56]	1541	1951	*Abies alba* Mill.
	Kreuth	47.38, 11.45	1 150	GERM012[57]	1586	1961	*Abies alba* Mill.
	Falkenstein	49.06, 13.20	1 325	GERM040[58]	1540	1995	*Picea abies* Karst.
Italy	Fodara Vedla Alm	46.38, 12.06	1 970	ITAL024[59]	1520	1990	*Larix decidua* Mill.
	Fodara Vedla Alm			ITAL025[60]	1598	1990	*Picea abies* Karst.
	Val Presanella	46.15, 10.39	1 910	ITAL042[61]	1550	2005	*Larix decidua* Mill.

[49] GIERTZ, V. (2005-08-25): NOAA/WDS Paleoclimatology - Giertz - Obergurgl - PCAB - ITRDB AUST003. NOAA National Centers for Environmental Information. https://doi.org/10.25921/311f-2q80. Accessed [21.11.2015].
[50] SERRE-BACHET, F. (2002-04-26): NOAA/WDS Paleoclimatology - Serre-Bachet - Les Merveilles Live Trees - LADE - ITRDB FRAN009. NOAA National Centers for Environmental Information. https://doi.org/10.25921/hx67-qg07. Accessed [21.11.2015].
[51] SERRE-BACHET, F. (2000-06-01): NOAA/WDS Paleoclimatology - Serre-Bachet - Les Merveilles Mixed Source (Live+Dead) - LADE - ITRDB FRAN010. [indicate subset used]. NOAA National Centers for Environmental Information. https://doi.org/10.25921/x7t5-hp12. Accessed [21.11.2015].
[52] TESSIER, L. (1996-05-08): NOAA/WDS Paleoclimatology - Tessier - L'Orgere B - LADE - ITRDB FRAN011. NOAA National Centers for Environmental Information. https://doi.org/10.25921/6v3d-cm81. Accessed [21.11.2015].
[53] TESSIER, L. (1996-05-08): NOAA/WDS Paleoclimatology - Tessier - L'Orgere A - LADE - ITRDB FRAN012. NOAA National Centers for Environmental Information. https://doi.org/10.25921/6syt-n993. Accessed [21.11.2015].
[54] SCHWEINGRUBER, F.H. (2002-07-31): NOAA/WDS Paleoclimatology - Schweingruber - Vizzavona Mount Renoso - ABAL - ITRDB FRAN038. NOAA National Centers for Environmental Information. https://doi.org/10.25921/hwpj-5t29. Accessed [21.11.2015].
[55] BECKER, B. (1990-08-01): NOAA/WDS Paleoclimatology - Becker - Bayerischer Wald B - ABAL - ITRDB GERM4. NOAA National Centers for Environmental Information. https://doi.org/10.25921/jeke-9n16. Accessed [21.11.2015].
[56] BECKER, B. (1990-08-01): NOAA/WDS Paleoclimatology - Becker - Bayerischer Wald - ABAL - ITRDB GERM5. NOAA National Centers for Environmental Information. https://doi.org/10.25921/qrfd-fy82. Accessed [21.11.2015].
[57] BECKER, B. (1990-08-01): NOAA/WDS Paleoclimatology - Becker - Kreuth - ABAL - ITRDB GERM12. NOAA National Centers for Environmental Information. https://doi.org/10.25921/f1vm-k153. Accessed [21.11.2015].
[58] WILSON, R.J.S. (2002-05-22): NOAA/WDS Paleoclimatology - Wilson - Falkenstein - PCAB - ITRDB GERM040. NOAA National Centers for Environmental Information. https://doi.org/10.25921/3hhr-cc17. Accessed [21.11.2015].
[59] HUESKEN, W. (2006-11-22): NOAA/WDS Paleoclimatology - Huesken - Fodara Vedla Alm - LADE - ITRDB ITAL024. NOAA National Centers for Environmental Information. https://doi.org/10.25921/ep0j-4b42. Accessed [21.11.2015].
[60] HUESKEN, W. (2006-11-22): NOAA/WDS Paleoclimatology - Huesken - Fodara Vedla Alm - PCAB - ITRDB ITAL025. NOAA National Centers for Environmental Information. https://doi.org/10.25921/ybq4-xf76. Accessed [21.11.2015].
[61] COPPOLA, A., BARONI, C. (2016-01-13): NOAA/WDS Paleoclimatology - Coppola - Val Presanella - LADE - ITRDB ITAL042. NOAA National Centers for Environmental Information. https://doi.org/10.25921/mhzm-kt33. Accessed [5.2.2018].

SITE				IDENTIFICA-TION CODE	FIRST YEAR	LAST YEAR	SPECIES
COUNTRY	**NAME**	**COORDINATES (LAT, LON)**	**ELEVA TION (m)**				
Switzerland	Simmental	46.24, 7.26	1 900	SWIT169[62]	1532	1986	*Picea abies* Karst.
	Obersaxen	46.44, 9.05	1 520	SWIT173[63]	1537	1995	*Picea abies* Karst.
	Lauenen	46.25, 7.19	1 250	SWIT177[64]	982	1976	*Picea abies* Karst.
	Lötschental 3	46.28, 7.51	2 200	SWIT293[65]	1508	2004	*Larix decidua* Mill.
	Tamangur	46.41, 10.22	2 200	SWIT347[66]	1478	2002	*Pinus cembra* L.
HISTORICAL TIMBERS AND MUSICAL INSTRUMENTS							
Germany/ Austria	Obergurgl	n.a.	n.a.	GERM021[67]	1333	1976	*Pinus cembra* L.
Germany	Mittenwald Neuner School Violin 1			GERM062[68]	1490	1803	*Picea abies* Karst.
	Mittenwald Neuner School Violin 2			GERM063[69]	1605	1805	*Picea abies* Karst.
	Mitterfels Schloss			GERM087[70]	1633	1782	*Abies alba* Mill.
	Regensburg			GERM090[71]	164	1838	*Abies alba* Mill.

1.2.4. Chronology development

To provide an objective quantitative base to evaluate the dendrochronological potential of the tree-ring chronology, TRiCYCLE (BREWER *et al.*, 2011), COFECHA (HOLMES, 1983) and ARSTAN (version 49v1bWin) (COOK *et al.*, 2017) software are applied. The tree ring measurement series obtained in each altarpiece were detrended and standardized into growth-index series with ARSTAN, using a smoothing spline with a degree of smoothing of 50% frequency cut-off. The aim was to suppress the low frequency variance and to enhance the dating potential of the growth-index series.

To compile a new average tree-ring chronology, the degree of similarity between the underlying growth indices is estimated according to the value of the correlation coefficient (r_i) obtained between

[62] SCHWEINGRUBER, F.H. (2002-05-28): NOAA/WDS Paleoclimatology - Schweingruber - Simmental, Iffigenalp - PCAB - ITRDB SWIT169. NOAA National Centers for Environmental Information. https://doi.org/10.25921/2709-r005. Accessed [21.11.2015].
[63] SCHWEINGRUBER, F.H. (2002-05-29): NOAA/WDS Paleoclimatology - Schweingruber - Obersaxen, Meierhof, GR - PCAB - ITRDB SWIT173. NOAA National Centers for Environmental Information. https://doi.org/10.25921/7w8m-3x42. Accessed [21.11.2015].
[64] SCHWEINGRUBER, F.H. (2002-05-29): NOAA/WDS Paleoclimatology - Schweingruber - Lauenen + div. Stao CH - PCAB - ITRDB SWIT177. NOAA National Centers for Environmental Information. https://doi.org/10.25921/6rdm-eq19. Accessed [21.11.2015].
[65] BÜNTGEN, U., ESPER, J., FRANK, D.C., NIEVERGELT, D., VERSTEGE, A. (2010-06-10): NOAA/WDS Paleoclimatology - Büntgen - Lötschental 3 - LADE - ITRDB SWIT293. NOAA National Centers for Environmental Information. https://doi.org/10.25921/qap9-wb72. Accessed [21.11.2015].
[66] ESPER, J., FRANK, D.C., BEBI, P., NIEDERER, R. (2010-06-10): NOAA/WDS Paleoclimatology - Esper - Tamagur - PICE - ITRDB SWIT347. [indicate subset used]. NOAA National Centers for Environmental Information. https://doi.org/10.25921/p0rr-1a34. Accessed [21.11.2015].
[67] BILLAMBOZ, A. (2002-04-26): NOAA/WDS Paleoclimatology - Billamboz - Bodensee 1 Archaeological - QUSP - ITRDB GERM021. NOAA National Centers for Environmental Information. https://doi.org/10.25921/0pre-tm54. Accessed [21.11.2015].
[68] Ratcliff, P. (2010-10-15): NOAA/WDS Paleoclimatology - Ratcliff - Mittenwald Neuner School Violin 1 - PCAB - ITRDB GERM062. NOAA National Centers for Environmental Information. https://doi.org/10.25921/kxmd-xs73. Accessed [21.11.2015].
[69] Ratcliff, P. (2010-02-10): NOAA/WDS Paleoclimatology - Ratcliff - Mittenwald Neuner School Violin 2 - PCAB - ITRDB GERM063. NOAA National Centers for Environmental Information. https://doi.org/10.25921/k935-9k33. Accessed [21.11.2015].
[70] WILSON, R.J.S. (2010-06-23): NOAA/WDS Paleoclimatology - Wilson - Mitterfels Schloss 2 Historical Timbers - ABAL - ITRDB GERM087. NOAA National Centers for Environmental Information. https://doi.org/10.25921/16wn-kw78. Accessed [21.11.2015].
[71] WILSON, R.J.S. (2010-06-23): NOAA/WDS Paleoclimatology - Wilson - Am Olberg Str. 3+5 1 Regensburg Historical Timbers - ABAL - ITRDB GERM090. NOAA National Centers for Environmental Information. https://doi.org/10.25921/18cb-9290. Accessed [21.11.2015].

each growth index (g_i) and the average chronology of all other growth indices in the data group except g_i. If the mean correlation value ($\bar{r}$, i.e., the average of all r_i) is lower than 0.50, specific growth indices can be rejected to allow the increase of $\bar{r}$. The following procedure is used for sequence rejection:

[1] Calculate the correlation coefficient (r) between g_i and the average chronology resulting from all growth indices excluding g_i in 50-years comparison intervals shifting in 25 years intervals (r_i^k, with k ranging from 1 to the number of 50-years intervals contained in g_i).

[2] Reject the growth indices of more than two intervals with $r_i^k \leq 0.32$, since $r_i^k \leq 0.32$ are not statistically significant at confidence level equal to 0.05 (JANSMA, 1995).

The strength of the common signal of the resulting chronology was estimated using the Expressed Population Signal (EPS) described by WIGLEY *et al.* (1984) and later readapted by BRIFFA and JONES (1990). Its estimate requires a series of statistical parameters, as described below (BRIFFA and JONES, 1990). WIGLEY *et al.* (1984) suggest an EPS threshold equal to or higher than 0.85.

- **CORRELATION MATRIX GRAND MEAN**

It corresponds to the mean of all correlations among different cores - both within and between trees (r_{ilj}).

$$\bar{r}_{tot} = \frac{1}{N_{tot}} \sum_{i=1}^{t} \sum_{\substack{l=1 \\ i \neq l}}^{t} \sum_{j=1}^{c_i} r_{ilj} \qquad N_{tot} = \frac{1}{2}\left(\sum_{i=1}^{t} c_i\right)\left[\left(\sum_{i=1}^{t} c_i\right) - 1\right]$$

where,
c_i=number of cores from tree i
i=1 to t trees
j=1 to c cores

- **WITHIN-TREE SIGNAL**

It corresponds to the mean of all correlations among different cores - both within and between trees.

$$\bar{r}_{wt} = \frac{1}{N_{wt}} \sum_{i=1}^{t}\left(\sum_{j=2}^{c_i} r_{ij}\right) \qquad N_{wt} = \sum_{i=1}^{t} \frac{1}{2} c_i (c_i - 1)$$

- **BETWEEN-TREE SIGNAL**

It corresponds to the mean of all correlations among different cores - both within and between trees.

$$\bar{r}_{bt} = \frac{1}{N_{bt}} (\bar{r}_{tot} N_{tot} - \bar{r}_{wt} N_{wt}) \qquad N_{bt} = N_{tot} - N_{wt}$$

- **EFFECTIVE NUMBER OF CORES**

An effective number of cores (c_{eff}) should be used when there is as unequal number of cores per tree.

$$\frac{1}{c_{eff}} = \frac{1}{t}\sum_{i=1}^{t}\frac{1}{c_i}$$

- **EFFECTIVE CHRONOLOGY SIGNAL**

It corresponds to the chronology-signal estimate that incorporates both within- and between-tree signals.

$$\bar{r}_{eff} = \frac{\bar{r}_{bt}}{\bar{r}_{wt} + \frac{1-\bar{r}_{wt}}{c_{eff}}}$$

- **EXPRESSED POPULATION SIGNAL**

It quantifies the degree to which a particular sample chronology reflects the hypothetical perfect chronology. Since this parameter is not often a constant over the different parts of the chronology, BRIFFA and JONES (1990) consider it important to appreciate the degree to which EPS varies over time as a function of r and series replication variations. This value is calculated by ARSTAN in the present research. The EPS values were calculated in 50 years segments, using lags of 25 years. The advantage of this interval-analysis is that the results clearly demonstrate which parts of the chronology have an enough sample size and which parts require additional series.

$$EPS = \frac{t \cdot \bar{r}_{eff}}{1+(t-1)\cdot \bar{r}_{eff}}$$

- **CHRONOLOGY STANDARD ERROR**

According to JANSMA (1995), standard error (SE) values of 0.15 or less are more appropriate in most cases. The chronology error increases as the sample size decreases.

$$SE = \sqrt{\frac{1-\bar{r}_{eff}}{t}}$$

1.2.5. Regularity of growth rings

The growth ring width, radial regularity, earlywood/latewood ratio and the frequency of indented rings (or *hazel growth*) stand out among the structural macroscopic characteristics in the wood assessment and selection for the construction of the musical instrument (DINULICĂ *et al.*, 2015).

The analysis of the regularity of the growth rings was extended to the three types of string keyboard instruments. To prevent a solely visual and qualitative assessment of the soundboards of each musical instrument (Figure 40), the regularity of the growth rings was quantified by: **(1)** four indices

(HOLZ, 1972; KRZYSIK, 1968; ROCABOY and BUCUR, 1990); and **(2)** percent of latewood measured based on partial measurements of each ring in the Image Analysis programme (Table 17).

The indented rings were visually identified in radial section as a sequence of V-shaped lines with a point towards the pith, as described by BONAMINI *et al.* (1991) and SCHWEINGRUBER (2007).

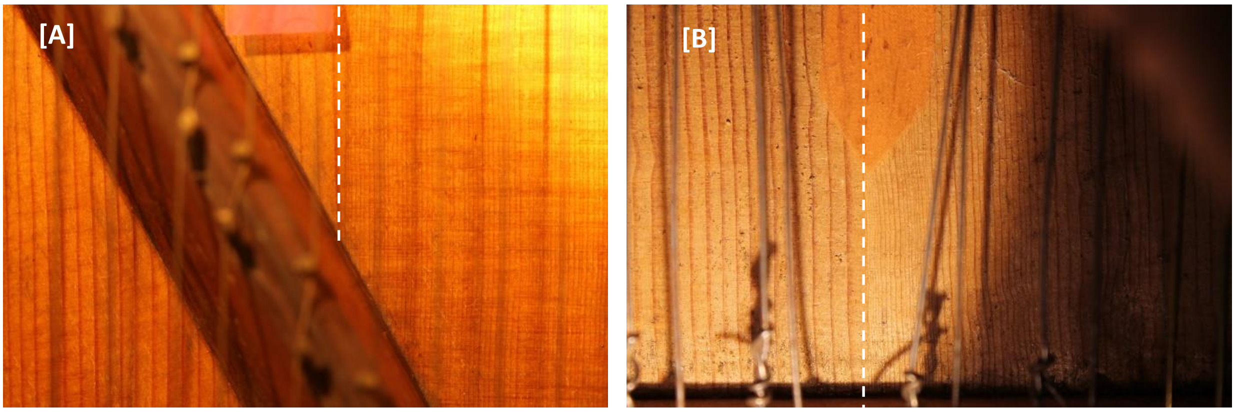


Figure 40. Examples of transition between boards with different growth rings' regularity and thickness in: **[A]** the Portuguese fortepiano attributed to Henry van Casteel (MNM0425); and **[B]** the Portuguese fortepiano attributed to Mathias Bostem (MNM0648) [The dashed white line represents the separation of the two boards].

Table 17. Main parameters to evaluate the regularity of growth rings' pattern *[*ε_J - coefficient of variation by growth ring width; ε_k=coefficient of variation by the number of rings per cm of radius; N=number of measurements; TRW_i=growth ring width in year I (mm); EW_i=earlywood in year i (mm); LW_i=latewood in year i (mm); $\Delta TRW_i = TWR_{(i+1)} - TRW_i$ (mm), i=1, 2, … , N-1; b_p=total sample length measured (cm); k_i=number of annual rings on each 1 cm radius; $\Delta k_j = k_{(i+1)} - k_i$, i=1, 2, … , b_p-1; ad.=adimension].

PARAMETER	FORMULA	EVALUATION CRITERIA
Coefficient of variation (ad.) HOLZ (1972)	$\varepsilon_J = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}\left(\frac{200\,\Delta\,TRW_i}{TRW_i + TRW_{i+1}}\right)^2}$	$\varepsilon_J < 30$
Coefficient of variation (ad.) HOLZ (1972)	$\varepsilon_k = \sqrt{\frac{1}{b_p-1}\sum_{i,j=1}^{N-1}\left(\frac{200\,\Delta\,k_J}{k_i + k_{i+1}}\right)^2}$	$\varepsilon_k < 30$
Difference between consecutive growth rings (mm) KRZYSIK (1968)	$\delta = \lvert TRW_{i+1} - TRW_i \rvert$	$\delta \leq 0.5$ mm
Regularity index (ad.) ROCABOY and BUCUR (1990)	$r_i = \frac{max(TRW_i) - min(TRW_i)}{max(TRW_i)}$	r < 0.70
Latewood (%)	$LW_i = \frac{TRW_i - EW_i}{TRW_i} \times 100$	20%<LW<25% (KRSYIK,1968); LW<25% (GHELMEZIU and BELDIE, 1972; ROCABOY and BUCUR, 1990)

2. RESULTS AND DISCUSSION

2.1. Dendrochronological research of Portuguese panels

Beyond dating, the dendrochronological research can provide information on the manufacture of a panel's wood supports. Some important issues of wood painting conservation and restoration (such as wood type and quality, pre-treatment, and seasoning) may be addressed during the dendrochronological investigation, but they may never lead to specifics on painting execution.

2.1.1. Vida de S. Tiago altarpiece

2.1.1.1. Wood identification

The panel could already be identified as oak (*Quercus* L.) macroscopically with high certainty given the distinct growth layers, a clear ring-porous structure, and large medullary rays in the transverse section (Figure 41). Despite the sample's limited cross-section, the microscopic anatomical features, as shown in Figures 41 and 42, supported the macroscopical wood identification. Earlywood vessels were often solitary or in groups of two even three vessels, spaced in up to three rows, and with a round to oval shape (Figure 41). The vessel elements showed simple perforation plates (Figures 42B and E) and the vessel–ray pits present distinct borders (Figure 42C). The presence of tyloses in some earlywood vessels was confirmed (Figure 42A). The axial parenchyma was difficult to distinguish in transverse section. Although uniseriate rays on the transverse surface can be detected with a hand lens in some cases (RUFFINATTO *et al.*, 2015), they were clearly identified by SEM, as shown in Figures 42C and D. Multiseriate rays could be seen macroscopically (Figure 41) and microscopically (Figure 42D). Rays were generally homocellular, consisting only of procumbent cells, which means ray parenchyma cells with the longest dimension radial visible in a radial section (Figures 42F and G). Presence of vasicentric tracheids in association of vessel elements (Figure 42E). Since the anatomical features observed in the small wood sample can be present in various tree species of *Quercus* L that are phylogenetically very similar, an accurate species diagnosis on the basis of anatomic characteristics was not possible. As a result, the anatomical identification is given as a genus. However, *Q. robur* or Q. *faginea* are two species that must be considered, not discarded, because their similar structure and their abundance in Portugal at XV- XVI centuries (SOUSA *et al.* 2014).

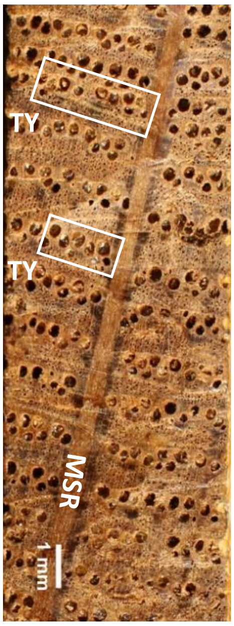
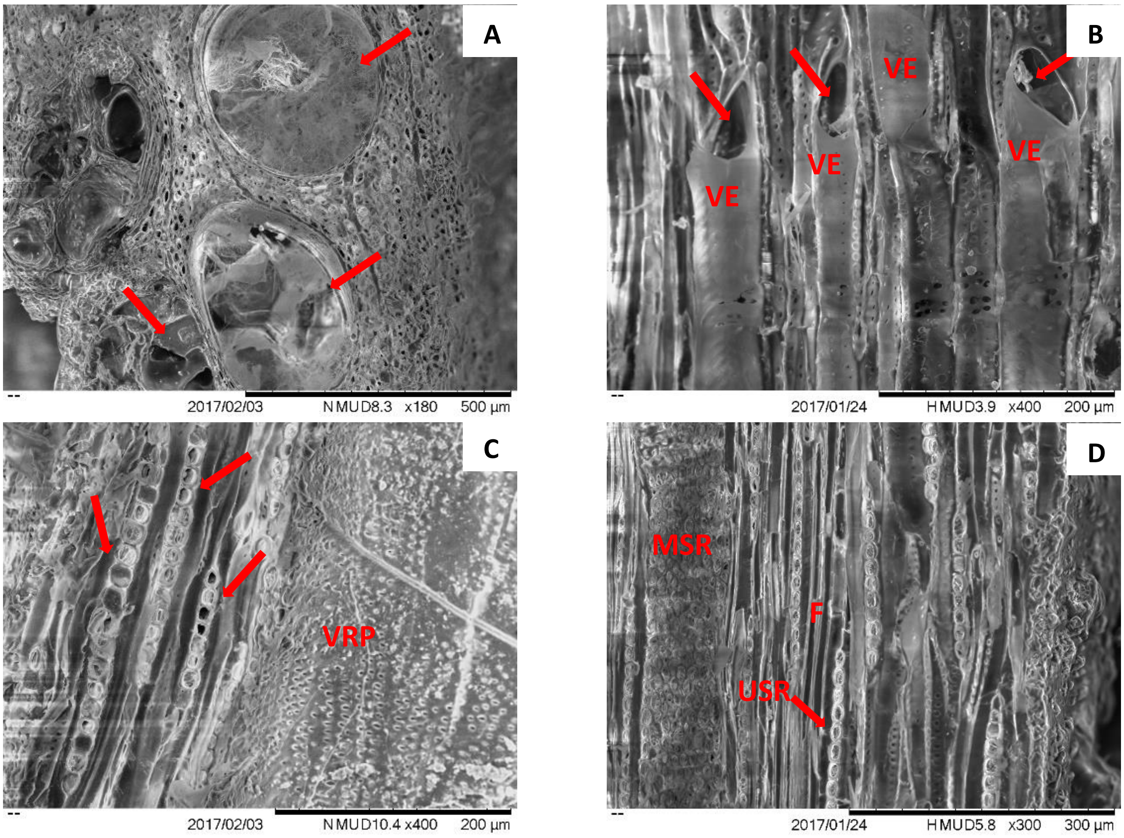


Figure 41. Transverse section of *Quercus* sp. board of *Conversão de Hermógenes* painting (20 Pint) showing a typical ring porous, earlywood vessels with tyloses (TY) and multiseriate rays (MSR).



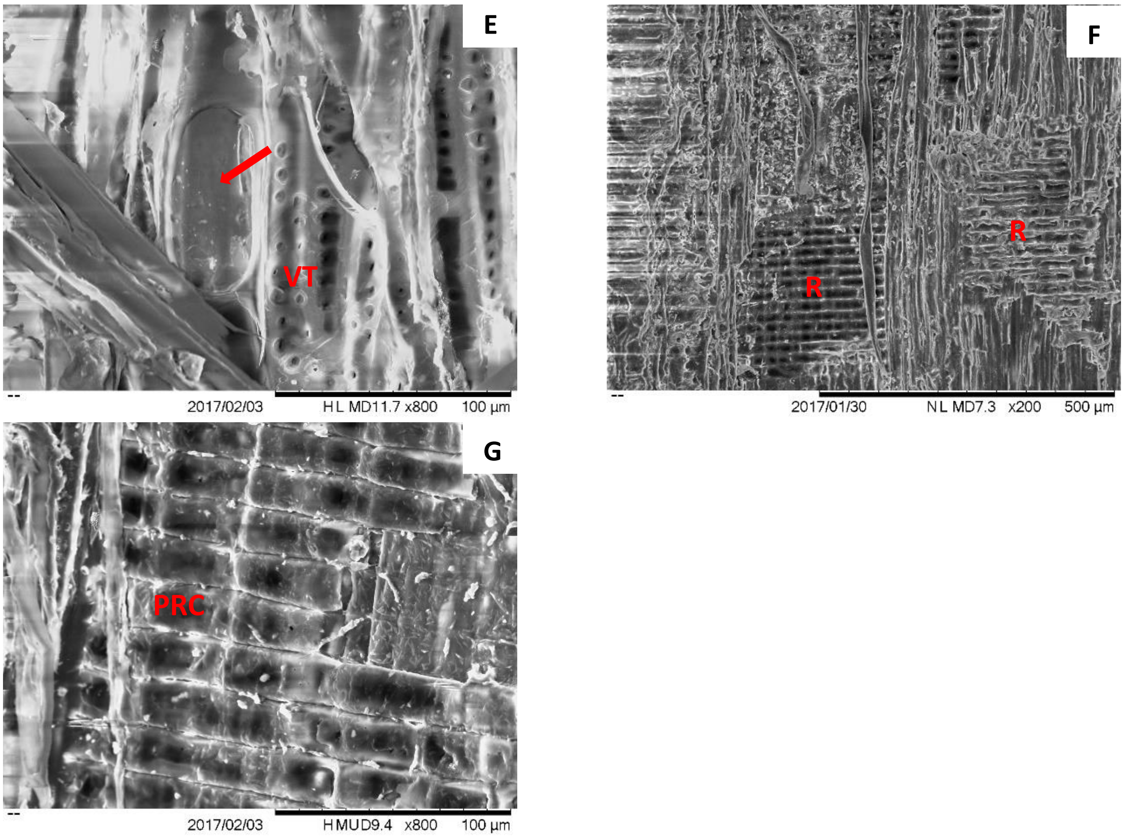


Figure 42. Anatomical details of *Quercus* sp. wood observed under SEM in different magnifications: **[A]** earlywood vessels (red arrows, ring porous) in transverse section; **[B]** vessel elements (VE) with simple perforation plates (red arrows) in radial section; **[C]** uniseriate rays (red arrows) and vessel–ray pits with distinct borders (VRP) in tangential section; **[D]** uniseriate (USR) and multiseriate (MSR) rays and fibres in tangential section; **[E]** simple perforation plate (red arrow) of vessel element and vasicentric tracheid (VT) in tangential section; and **[F and G]** homogenous ray (R) with procumbent ray cells (PRC) in radial section.

2.1.1.2. Assembly of the wood support

All the boards of each panel are arranged parallel to each other, with the grain parallel to the length of each panel and in the same direction. Two of the six panels examined was made up of three boards, 22 cm to 34 cm wide and 84 cm to 85 cm high (Table 18). The remaining four panels are assembled with four boards with a wider width (between 8 cm and 31 cm) and a length of 84 cm (Table 18). There are significant differences in width between the top and bottom panels in some panels, presumably to maximise the available wood options. The initial thickness of the panels ranges between 15 and 25 mm, in accordance with the values presented by WADUM (1998) for these Flemish panels. The edges were bevelled to fit the groove of the frame (Figure 43). The dendrochronological study in the cross-section was then carried out on boards with a thickness varying from 8 mm to 10 mm.

In all the panels analysed, the inner boards were wider than those on the outside (Table 18). This indicates that panel makers are likely to try to avoid locating joints in the most crucial area of artistic composition, thus reducing the possibility of cracks in the central section (WADUM 1998, DUNKERTON *et al.* 1999).

Table 18. Characterization of the boards that compose the supports of the six panels studied from the *Vida de S. Tiago* altarpiece, curated by the National Museum of Ancient Art, Lisbon [Type of cut - A: full radial (or full quarter); B: radial (or quarter); C: semi-radial (or false quarter); D: tangential (FRAITURE, 2011)].

NAME [INVENTORY NUMBER]	#	THICKNESS (mm)	TYPE OF CUT	WIDTH (cm)	
				TOP LEVEL	LOWER LEVEL
Investidura de um Mestre da Ordem de Santiago [16 Pint]	4	15 - 25	B/A/B/A	13.4/25.5/23.2/ 20.6	13.6/24.0/23.0/20.6
Entrega da bandeira a um Mestre da Ordem de Santiago [17 Pint]	Not studied due to the poor state of conservation				
Aparição da Virgem a um Mestre da Ordem de Santiago [18 Pint]	4	15 - 25	A/B/A/A	15.5/28.2/26.3/ 12.1	15.1/25.7/26.5/15.3
São Tiago combatendo os mouros [19 Pint]	3	15 - 25	C/A/B	26.3/29.5/27.5	27.3/29.8/26.0
Conversão de Hermógenes [20 Pint]	3	15 - 25	B/B/B	26.5/34.0/23.0	26.5/34.5/22.0
O Corpo de S. Tiago conduzido ao Paço da Rainha Loba [21 Pint]	4	15 - 25	B/A-B/A/B	17.0/31.0/20.0/ 13.7	19.5/28.5/20.0/13.5
Cristo envia S. Tiago e S. João em missão apostólica [22 Pint]	4	15 - 25	B/A/A/A	8.0/26.1/27.1/ 21.7	7.4/27.4/27.5/20.5
Pregação de S. Tiago [24 Pint]	Not studied due to the state of conservation				

Figure 43. Examples of bevelled edges of oak boards in: **[A]** *Cristo envia S. Tiago e S. João em missão apostólica* (22 Pint); and **[B]** *Conversão de Hermógenes* (20 Pint).

Three types of board cuts have been found in the altarpiece: full quarter, quarter, and false quarter (Table 18; Figure 44). Out of the 22 panels examined, distinct full quarter and quarter cuttings were observed in 20 panels (Table 18) demonstrating the robustness of the panels that make up this altarpiece. In the altarpiece, no board tangential cuts were identified. In fact, their use in painting support should be avoided due to increased swelling and shrinkage due to the considerable hygroscopicity of wood in this type of board (STAMM, 1935; EMILE-MALE, 1977; GETTENS and STOUT, 1942). Furthermore, a board with a tangential cut also tends to cup, since the centre side is more radially cut than the outside, and studies on the expansion and contraction behaviour of old paintings under different relative humidity have shown variations in the width of the board along the grain (GETTENS and STOUT, 1942).

The medullar rays have different orientations across the width of board II from *O Corpo de S. Tiago conduzido ao Paço da Rainha Loba* painting (21 Pint) (Figure 45A). This was also discovered in studies on Flemish panels conducted by FRAITURE (2011) and expected given the board's considerable width (30 cm, approximately). Some boards had slightly curved medullar rays (Figure 45B), while others had rectilinear medullar rays (Figure 45A).

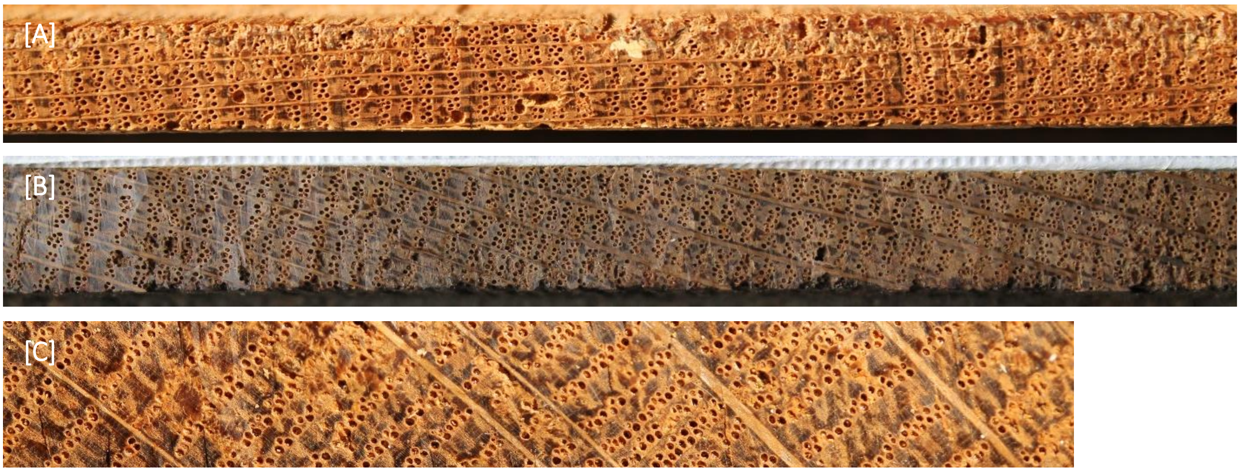


Figure 44. Type of boards' cut: **[A]** *full quarter* in *Cristo envia S. Tiago e S. João em missão apostólica* (22 Pint); **[B]** *quarter* in *Investidura de um Mestre da Ordem de Santiago* (16 Pint); and **[C]** *false quarter* in *São Tiago combatendo os mouros* (19 Pint).

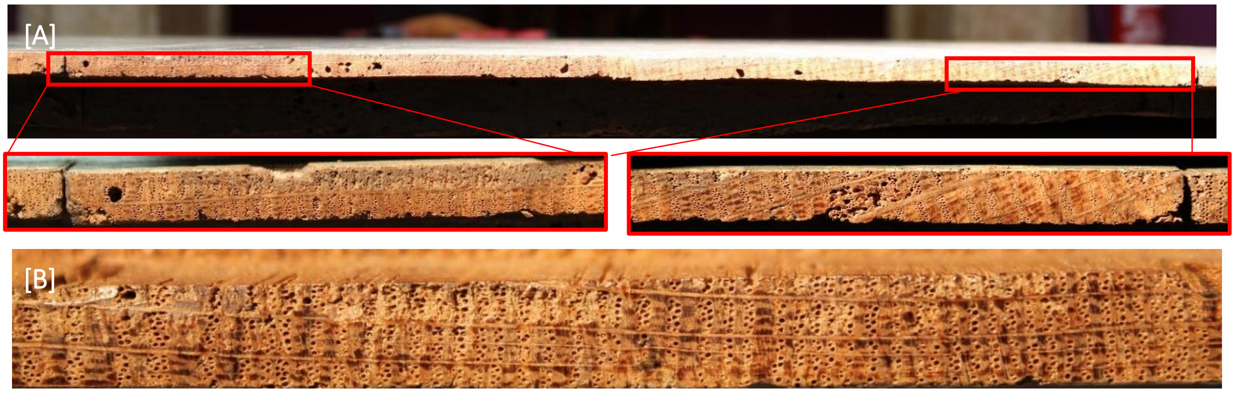


Figure 45. **[A]** Example of a board with the left edge as *full quarter* cutting and the right edge as *quarter* in *O Corpo de S. Tiago conduzido ao Paço da Rainha Loba* (21 Pint); and **[B]** Example of medullary rays slightly curved in *Cristo envia S. Tiago e S. João em missão apostólica* (22 Pint).

The external panels of all panels were assembled in accordance with the Flemish standard that was then in force and incorporated into the Portuguese workshops, with the oldest outer rings on the outer side of the panels. The only exception was in *Investidura de um Mestre da Ordem de Santiago* panel (19 Pint) (Figure 46).

Figure 46. Non-compliance with the rule, with earlier tree-rings at the edge. Transverse section of the left external board from the *Investidura de um Mestre da Ordem de Santiago* panel (19 Pint) [The white arrow indicates the direction of growth].

2.1.1.3. Dendrochronological study

2.1.1.3.1. Description of the dendrochronological sequences

The 22 boards from the eight panels allowed 21 tree ring measurement series since the left sideboard of the *Cristo envia S. Tiago e S. João em missão apostólica* panel (22 Pint) was very narrow and contained insufficient numbers of rings for dendrochronological purposes (Table 1). The tree-ring patterns reveal different growth rates from one board to the next one in a panel. In general, each panel displayed a set of boards with similar wood growth patterns, ranging from "very low" to "medium" annual growth rates (Table 19). Figure 47 details the irregularity of intra- and inter-board growth rings to a greater or lesser extent while also revealing a consistency in the panels chosen in each panel, as well as the altarpiece as a unique artwork. The *Conversão de Hermógenes* panel (20 Pint) consisted of three fast-growing boards (PCEF0102020152, PCEF0102020153 and PCEF0102020154 (Figure 47D), with an average ring width of almost 2.00 mm and a high standard deviation (1.85±0.62, 1.76±0.55 and 1.75±0.67, respectively) (Table 19). A similar example is found in the *Aparição da Virgem a um Mestre da Ordem de Santiago panel* (18 Pint) where the boards have more homogeneous growth patterns (PCEF0102020145, PCEF0102020146, PCEF0102020147 and PCEF0102020148) (Figure 47B), with an average ring width between 1.50 and 2.00 mm (1.59±0.38, 1.78±0.51, 1.83±0.46 and 1.65±0.36, respectively) (Table 19). The remaining panels show boards with a higher growth trend irregularity (Figures 47A, C, D and F). Of these boards, two examples stand out with a growth rhythm that is fast at the beginning, then progressively slows down with tree ageing until it slows down (PCEF0102020151, Figure 47C) or very slow (PCEF0102020142, Figure 47A). Slow-growing trends are found in two panels of the *O Corpo de S. Tiago conduzido ao Paço da Rainha Loba* panel (21 Pint) (PCEF0102020157 and PCEF0102020158) (Figure 47E), with an average ring width of less than 1.00 mm (0.98±0.31 and 0.92±0.26, respectively) (Table 19). In this case, a comparatively higher resistance to shrinkage or dilation deformation is to be expected, which means that these panels can have more stable support for the panels.

Table 19. Details of the tree ring measurement series of the 21 boards from the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection) [Wood Growth Rate: *very slow* – less than 1.00 mm; *slow* – between 1.00 and 1.20 mm; *medium* – between 1.20 and 2.00 mm; *fast* – greater than 2.00 mm].

PANEL [INVENTORY NUMBER]	BOARD (LABORATORY FILENAME)	TOTAL RINGS MEASURED	RING WIDTH (mm)			WOOD GROWTH RATE
			MIN	MAX	AVG±STDV	
Investidura de um Mestre da Ordem de Santiago [16 Pint]	PCEF0102020141	99	0.53	2.38	1.35±0.42	Medium
	PCEF0102020142	211	0.56	2.70	1.22±0.35	Medium
	PCEF0102020143	179	0.47	3.66	1.47±0.52	Medium
	PCEF0102020144	117	0.66	2.63	1.75±0.42	Medium
Aparição da Virgem a um Mestre da Ordem de Santiago [18 Pint]	PCEF0102020145	88	0.67	2.65	1.59±0.38	Medium
	PCEF0102020146	120	0.76	3.04	1.78±0.51	Medium
	PCEF0102020147	139	0.71	3.15	1.83±0.46	Medium
	PCEF0102020148	84	0.74	2.31	1.65±0.36	Medium
S. Tiago combatendo os mouros [19 Pint]	PCEF0102020149	164	0.55	2.58	1.29±0.39	Medium
	PCEF0102020150	113	0.39	2.13	1.30±0.39	Medium
	PCEF0102020151	164	0.55	2.60	1.35±0.43	Medium
Conversão de Hermógenes [20 Pint]	PCEF0102020152	121	0.74	3.77	1.85±0.62	Medium
	PCEF0102020153	114	0.72	3.90	1.76±0.55	Medium
	PCEF0102020154	121	0.57	3.71	1.75±0.67	Medium
O Corpo de S. Tiago conduzido ao Paço da Rainha Loba [21 Pint]	PCEF0102020155	92	0.76	2.74	1.63±0.40	Medium
	PCEF0102020156	154	0.83	3.32	1.92±0.64	Medium
	PCEF0102020157	156	0.41	2.13	0.98±0.31	Very slow
	PCEF0102020158	86	0.50	1.73	0.92±0.26	Very slow
Cristo envia S. Tiago e S. João em missão apostólica [22 Pint]	PCEF0102020159	170	0.43	2.33	1.28±0.35	Medium
	PCEF0102020160	140	0.48	3.27	1.59±0.52	Medium
	PCEF0102020161	108	0.84	2.90	1.78±0.42	Medium

The description of the "same-tree wood groups" was a preliminary step by visual and statistical analysis. Graphic visualisation and comparison of all tree-ring patterns revealed that there were boards between panels coming from the same tree (Figure 48). This is not uncommon in dendrochronological research, either in single panels or in an altarpiece (see subchapter 2.1.1. *Manufacture of wooden supports for Flemish and Portuguese panels*). To corroborate the final decision a set of seven combinations (hereinafter referred to as *dendrochronological sequence*) was formulated (PCEF0102020141-143-160, PCEF0102020142-159, PCEF0102020144-147-148-161, PCEF0102020145-155, PCEF0102020146-156, PCEF0102020149-151 and PCEF0102020152-153-154), based on the parameters set out in subchapter 1.2.3.1. Panels:

- Similar mean ring widths – 1.35 mm-1.47 mm-1.59 mm; 1.22 mm-1.28 mm; 1.75 mm-1.83 mm-1.65 mm-1.78 mm; 1.59 mm-1.63 mm; 1.78 mm-1.92 mm; 1.29 mm-1.35 mm-1.59 mm; and 1.85 mm-1.76 mm-1.75 mm (respectively) (Table 19);
- Nearly contemporaneous ring tree-ring patterns (begin and/or end) (Figure 48);
- Very high t_{BP} for seven combinations of dendrochronological sequences, ranging from 10.7 to 20.4 (Table 20).

The combination PCEF0102020152-153-154 applies to the only situation in which three boards of the same tree make up one panel (*Conversão de Hermogenes* panel, 20 Pint). The similarity between the graphs is remarkable (Figure 48G): very similar mean ring widths (Table 19); nearly contemporaneous tree-ring patterns (Figure 48G); and very high t_{BP} (between 12.3 and 17.6) (Table 20).

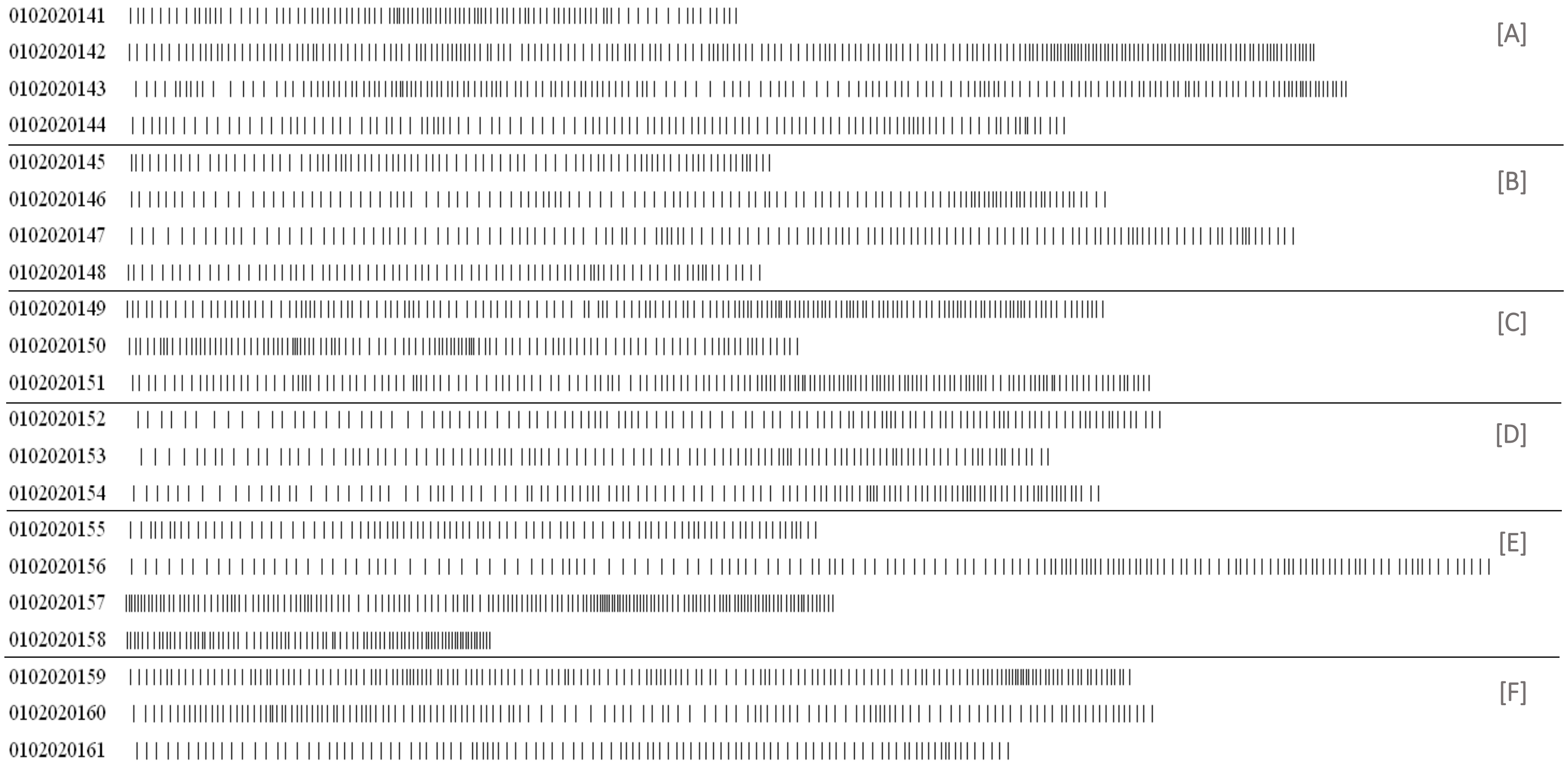


Figure 47. Grid beam graph representing the tree ring widths of the 21 boards from the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection): **[A]** *Investidura de um Mestre da Ordem de Santiago* (16 Pint); **[B]** *Aparição da Virgem a um Mestre da Ordem de Santiago* (18 Pint); **[C]** *S. Tiago combatendo os mouros* (19 Pint); **[D]** *Conversão de Hermógenes* (20 Pint); **[E]** *O Corpo de S. Tiago conduzido ao Paço da Rainha Loba* (21 Pint); and **[F]** *Cristo envia S. Tiago e S. João em missão apostólica* (22 Pint) [Graph by TSAP Win Scientific 4.64] .

Table 20. Matrix t_{BP} (white area) / overlap (grey area) obtained between the dendrochronological sequences of the 21 boards from the *Vida de S. Tiago* altarpiece, of unknown assignment (MNAA collection) [The unfilled spaces correspond to the absence of overlapping sequences].

	PCEF0102020141	PCEF0102020142	PCEF0102020143	PCEF0102020144	PCEF0102020145	PCEF0102020146	PCEF0102020147	PCEF0102020148	PCEF0102020149	PCEF0102020150	PCEF0102020151	PCEF0102020152	PCEF0102020153	PCEF0102020154	PCEF0102020155	PCEF0102020156	PCEF0102020157	PCEF0102020158	PCEF0102020159	PCEF0102020160	PCEF0102020161
PCEF0102020141		72	95			22	3		20	58	17					16	19		65	81	
PCEF0102020142	2.7		156	117	88	120	139	84	159	113	156	106	100	107	92	154	156	86	170	131	108
PCEF0102020143	**18.7**	4.5		66	39	106	87	31	104	113	101	51	45	52	44	100	103	81	149	140	70
PCEF0102020144		4.8	4.4		88	80	117	82	117	37	117	102	96	103	92	117	117	71	87	41	104
PCEF0102020145		4.5	3.4	4.1		53	88	80	88	10	88	88	88	88	87	88	88	44	60	44	77
PCEF0102020146	2.2	6.3	6.5	5.4	2.4		101	45	118	77	115	65	59	66	58	114	117	86	120	81	84
PCEF0102020147	1.4	6.1	4.6	**19.0**	5.0	6.6		83	139	58	139	103	97	104	92	139	139	86	108	62	108
PCEF0102020148		3.9	4.6	**11.3**	3.0	1.6	**10.7**		84	2	84	84	84	84	79	84	84	36	52	36	69
PCEF0102020149	0.1	5.9	2.6	4.9	4.7	8,0	6,0	3.1		75	161	111	105	112	92	154	156	86	125	79	108
PCEF0102020150	4.1	3.7	5.7	0.8	3.0	3.4	2.2		2.6		72	22	16	23	15	71	74	52	113	113	41
PCEF0102020151	1.5	5.1	3.2	5.9	4.2	7.2	5.8	4.2	**17.8**	2.6		114	108	115	92	154	154	86	122	76	108
PCEF0102020152		4.4	1.7	5,0	5.0	2.1	6.3	6.1	5.2	0.9	6,0		114	120	92	105	104	56	72	36	89
PCEF0102020153		4.1	3.1	5.7	5.1	2.6	6.1	6.6	6.	1.1	7.6	**16.0**		114	92	99	98	50	66	30	83
PCEF0102020154		4.0	2.7	4.9	4.2	2,0	5.3	6.7	5.4	1,0	6.1	**12.5**	**17.2**		92	106	105	57	73	31	90
PCEF0102020155		5.3	2.2	5.4	**15.0**	1.5	6.3	4.9	3.3	1.1	3.1	5.3	4.9	3.7		92	92	49	65	39	82
PCEF0102020156	0.5	5.8	5.9	6.9	3.5	**12.2**	7,0	5,0	7.0	3.5	7.7	3.6	4.5	4.5	3.6		153	86	121	75	108
PCEF0102020157	1.4	6.1	3,0	2.9	2.8	5.7	3.2	1.8	5.3	2.8	4.8	2.3	3.2	2.3	1.6	4.9		86	124	78	108
PCEF0102020158		5.3	2.5	2.6	3.1	4.7	4.2	0.6	5.0	3,0	5,0	3.5	3.7	2.9	2.6	3.3	6.8		86	56	75
PCEF0102020159	**3.3**	**16.8**	5.7	4,0	3.3	6.2	4.1	2.3	4.7	4.1	4.3	1.4	2.7	3.2	3.4	5.8	4.9	4.1		124	91
PCEF0102020160	**15.2**	4.4	**20.4**	1.5	2.7	5.4	2.6	0.5	2.7	5.1	2.1	2.2	4,0	2.9	1.2	3.9	3.2	2.4	5.9		45
PCEF0102020161		4.3	4.2	**16.5**	4.1	5.3	**14.5**	7.4	5.1	1.4	6.9	5.4	6.8	5.5	4.4	5.6	1.8	2,0	3.1	1.4	

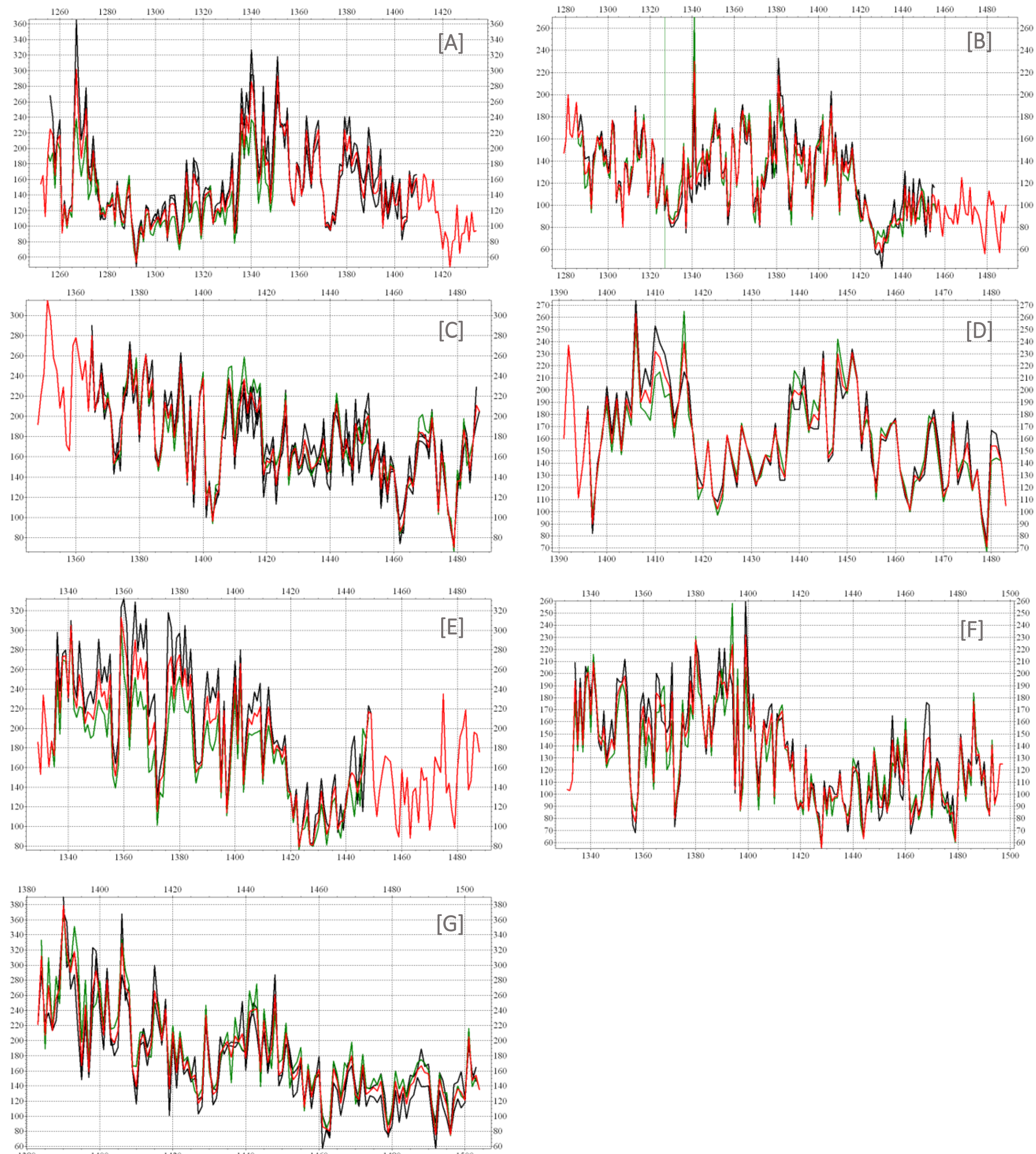


Figure 48. Visual synchronisation between tree-ring patterns with very high t_{BP} values (equal to or greater than 9.0) and considered as coming from the same tree: **[A]** PCEF0102020141-143-160; **[B]** PCEF0102020142-159; **[C]** PCEF0102020144-147-148-161; **[D]** PCEF0102020145-155; **[E]** PCEF0102020146-156; **[F]** PCEF0102020149-151; and **[G]** PCEF0102020152-153-154. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graphs by TSAP Win Scientific 4.64].

The tree-ring patterns of the "same-tree wood groups" were combined in their contemporary position to calculate the mean for each tree for subsequent dating. There are four instances in which two tree-ring patterns have similar characteristics (e.g., synchronisation, mean ring widths or/and almost contemporaneous sequences) but do not reach the level met before, namely high t_{BP} values – PCEF0102020146-149 (t_{BP}=7.8), PCEF0102020151-153 (t_{BP}=7.6), PCEF0102020151 -156 (t_{BP}=7.3) and PCEF0102020149-156 (t_{BP}=7.0) (Table 20). These combinations present nearly contemporaneous tree-ring patterns (Figure 49). However, there are differences in mean ring widths – 1.78 mm-1.29 mm, 1.35 mm-1.76 mm, 1.35 mm-1.92 mm and 1.29 mm-1.92 mm, respectively (Table 19), and visual synchronisation is not so evident (Figure 49). In these cases, the boards probably came from different trees that grew under similar conditions, for instance neighbouring trees in the same forest area.

Therefore, the 21 boards determine ten distinct dendrochronological sequences (PCEF0102020150, PCEF0102020157, PCEF0102020158, PCEF0102020141-143-160, PCEF0102020142-159, PCEF0102020144-147-148-161, PCEF0102020145-155, PCEF0102020146-156, PCEF0102020149-151 and PCEF0102020152-153-154), thus allowing the conclusion that they originated from ten distinct oak trees.

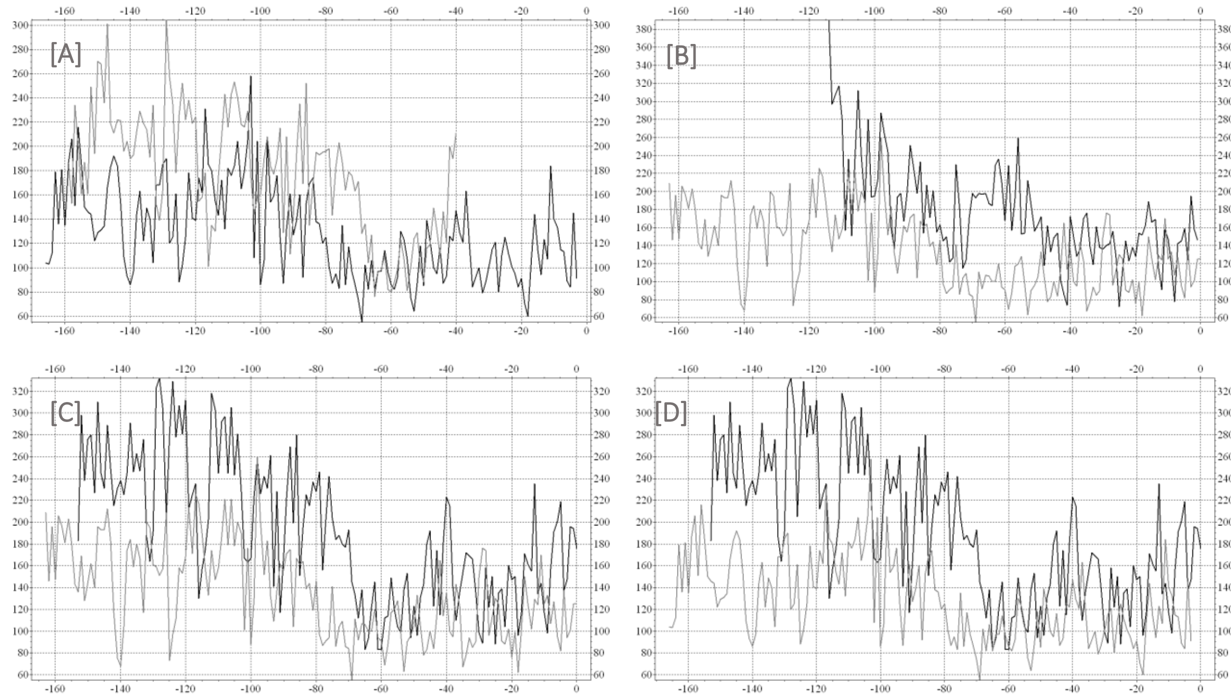


Figure 49. Visual synchronisation between tree-ring patterns with high t_{BP} values (between 7.0 and 9.0) and not considered as coming from the same tree: **[A]** PCEF0102020146-149; **[B]** PCEF0102020151-153; **[C]** PCEF0102020151-156; and **[D]** PCEF0102020149-156. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graphs by TSAP Win Scientific 4.64].

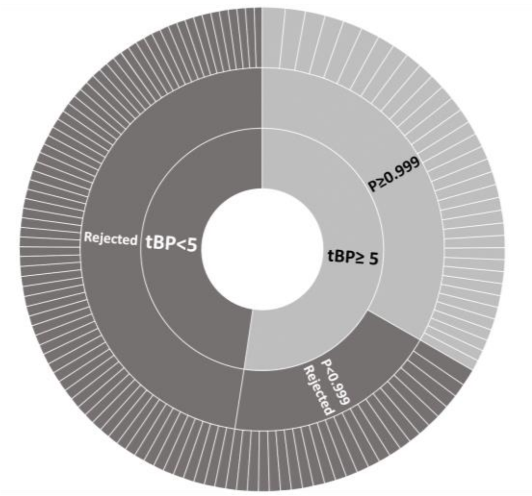
2.1.1.3.2. Dating of the dendrochronological sequences

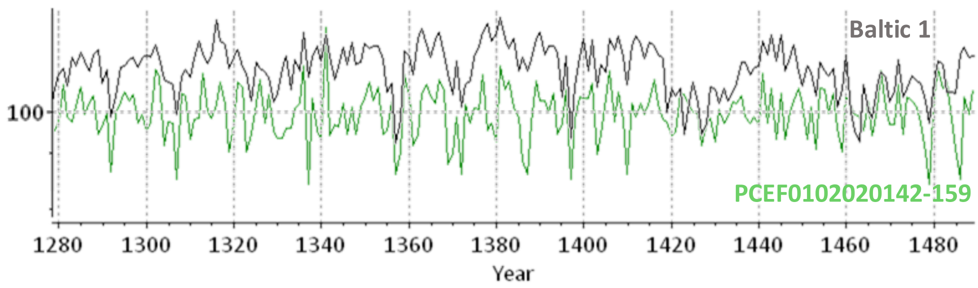
The year of formation of each ring and, by extension, the period during which the tree lived can be calculated by determining the exact position of a dendrochronological sequence. The altarpiece's ten dendrochronological sequences that provide absolute dating were successfully dated. All the chronologies that contribute to the dendrochronological date replication are from the *Quercus* genus (knowns as *teleconnection*) and come from various geographical locations.

Figures 50 to 53 illustrate the classification of dating quality for each dendrochronological sequence. Confidence for each proposed date is obtained by replicating the proposed date through a crossmatch with the independent chronologies set out in Table 14, given that extensive reproduction gives the proposed date a more effective date. The ANNEX 5-Table1 details the reference chronology assigned to each replication for a t_{BP} greater than 5.0 and *P*-value equal to or higher than 0.999. In summary, the data analysis allowed the identification of four distinct dating qualities:

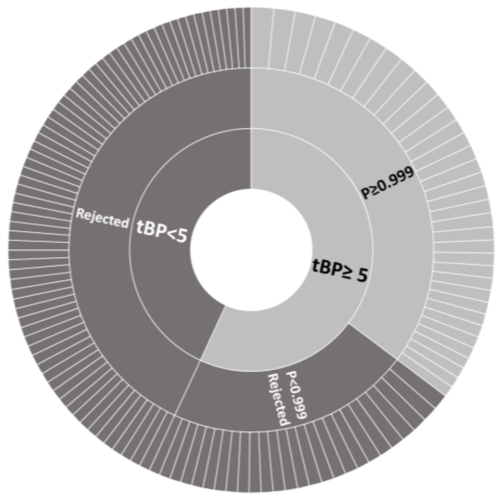
- Excellent quality dating (30%) – three dendrochronological sequences (PCEF0102020142-159, PCEF0102020149-151 and PCEF0102020152-153-154) present their best synchronisation rates achieved with master chronologies and t_{BP} values above 10.0 (Figure 50);
- High quality dating (40%) – four dendrochronological sequences (PCEF0102020141-143-160, PCEF0102020144-147-148-161, PCEF0102020145-155 and PCEF0102020146-156) report their best synchronisation rates with master chronologies and t_{BP} values ranging between 8.0 and 9.9 (Figure 51);
- Very good quality dating (10%)– one dendrochronological sequence (PCEF0102020157) presents its best synchronisation rates achieved with master chronologies and t_{BP} values ranging between 7.0 and 8.0 (Figure 52);
- Hypothetical dating (20%) – two dendrochronological sequences (PCEF0102020150 and PCEF0102020158) report their best synchronisation rates with master chronologies and t_{BP} values ranging between 5.0 and 7.0, but with very low replication (Figure 53).

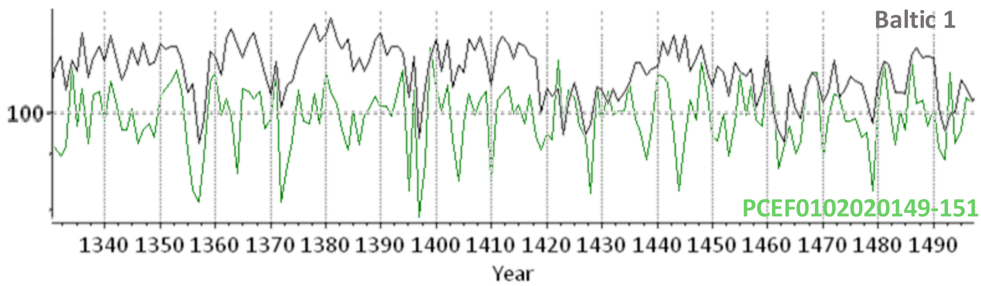
[A] The dendrochronological sequence **PCEF0102020142-159** gives excellent results. The proposed date **1279-1489** is given by several individual and master chronologies from BALTIC area – 59 for t_{BP}≥5.0 and 74 for t_{BP}<5.0 (graph I). The replication is notable since 35 of the 59 chronologies give the proposed date for *P*≥0.999. Special emphasis should be given to the excellent correlation between PCEF0102020142-159 and master chronology BALTIC 1 (t_{BP}=10.4) (graph II). A **dating of excellent quality** can be considered.



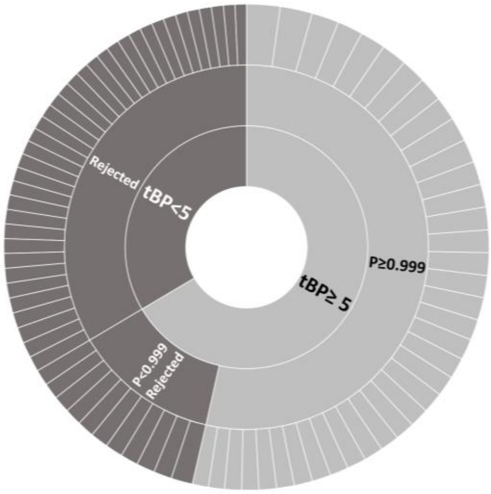


[B] The dendrochronological sequence **PCEF0102020149-151** gives excellent results. The proposed date **1331-1497** is given by numerous individual and master chronologies from BALTIC area – 62 for t_{BP}≥5.0 and 70 for t_{BP}<5.0 (graph I). The replication is notable since 36 of the 62 chronologies give the proposed date for *P*≥0.999. Two excellent correlations should be highlighted in particular – BALTIC 1 (t_{BP}=9.9) (graph II) and PCEF0604010008 index series (t_{BP}=10.4), which corresponds to a board of the *S. Brás* (ME 1523), attributed to the Flemish painter Frey Carlos, ME. A **dating of excellent quality** can be considered.





[C] The dendrochronological sequence **PCEF0102020152-153-154** provides excellent results. The proposed date **1383-1504** is granted by several individual and master chronologies from BALTIC area – 48 for t_{BP}≥5.0 and 37 for t_{BP}<5.0 (graph I). The replication is remarkable since 37 of the 48 chronologies give the proposed date for *P*≥0.999. Special attention should be given to two excellent correlations between PCEF01020152-153-154 and two master chronologies – NL BALTIC B (t_{BP}=10.2) and BALTIC 1 (t_{BP}=10.6) (graph II). A **dating of excellent quality** can be considered.



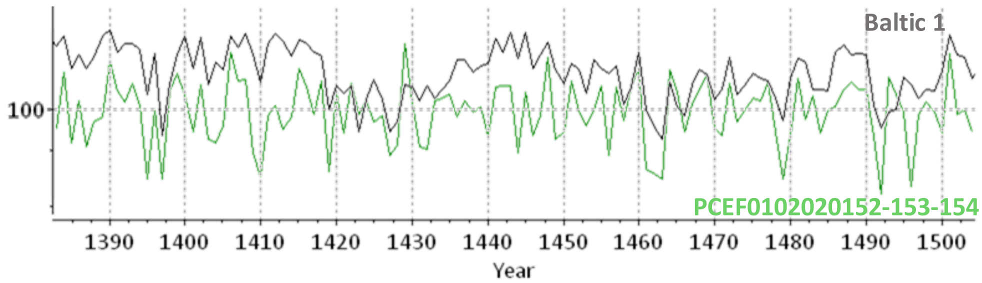
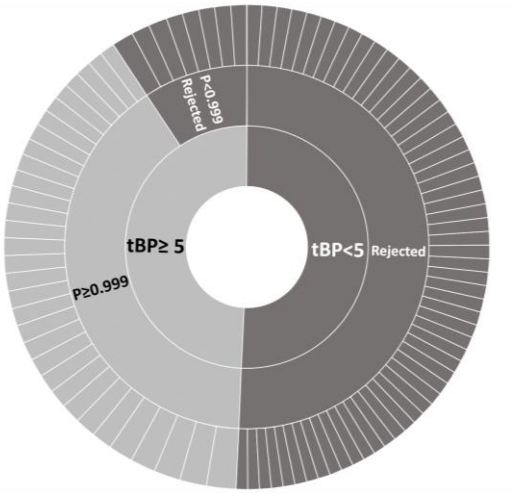
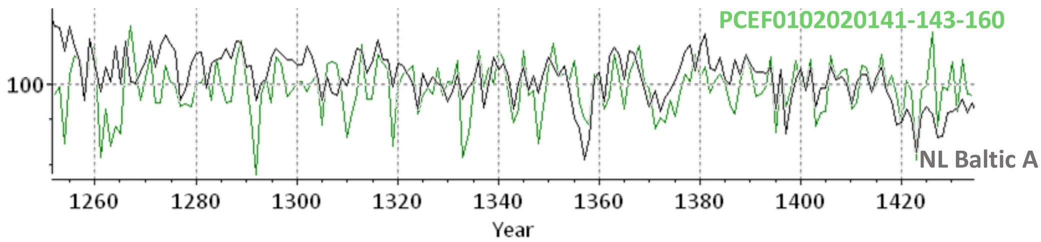


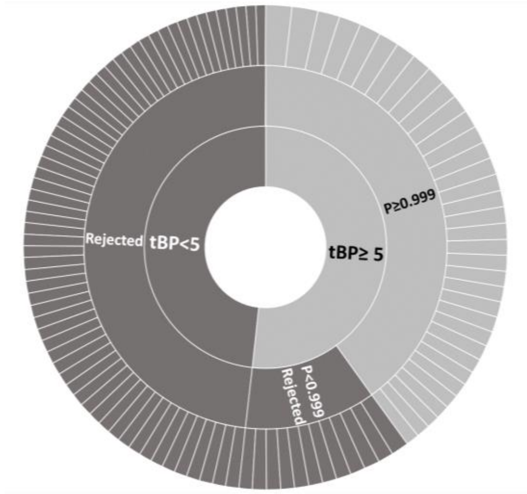
Figure 50. Excellent quality dating of the dendrochronological sequences from the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection), according the t_{BP} and *P* values, and respective brief interpretation: **[A]** PCEF0102020142-159; **[B]** PCEF0102020149-151; and **[C]** PCEF0102020152-153-154.

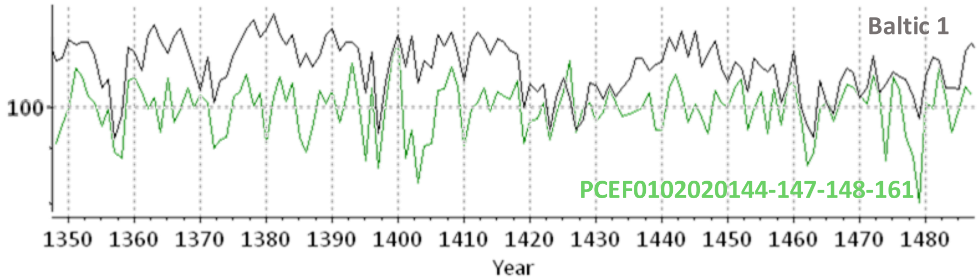
[A] The dendrochronological sequence **PCEF0102020141-143-160** gives excellent/very good results. The proposed date **1252-1434** is granted by several individual and master chronologies from BALTIC area – 40 for t_{BP}≥5.0 and 57 for t_{BP}<5.0 (graph I). The replication is particularly good since 32 of the 40 chronologies give the proposed date for *P*≥0.999, with the four best synchronisation rates achieved with four master chronologies – BALTIC 1 (t_{BP}=8.4), 0520006M (t_{BP}=8.6), 0520003M (t_{BP}=8.9) and NL BALTIC A (t_{BP}=9.7) (graph II). A dating of **high quality** can be considered.



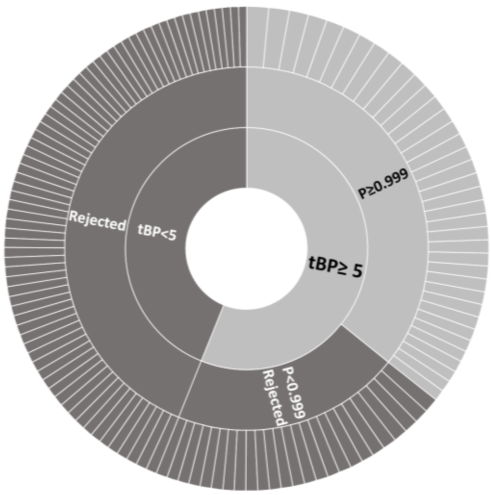


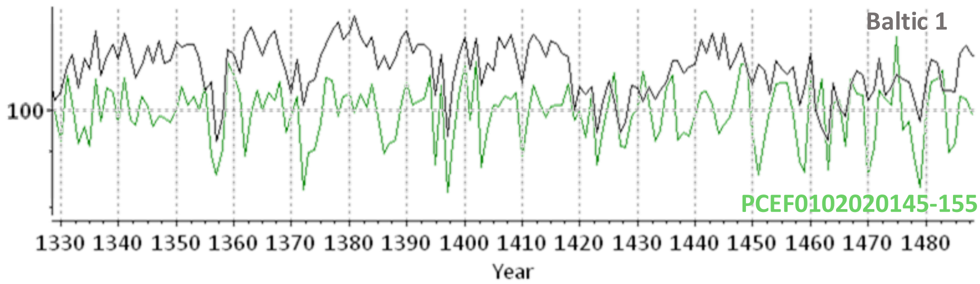
[B] The dendrochronological sequence **PCEF0102020144-147-148-161** gives excellent/very good results. The proposed date **1349-1487** is supplied by several individual and master chronologies from BALTIC area – 59 for t_{BP}≥5.0 and 74 for t_{BP}<5.0 (graph I). The replication is extremely good since 35 of the 59 chronologies give the proposed date for *P*≥0.999, with the four best synchronisation rates obtained with four master chronologies – BALTIC Import (t_{BP}=8.1), 0520003M (t_{BP}=8.1), NL BALTIC B (t_{BP}=9.7) and BALTIC 1 (t_{BP}=9.7) (graph II). A **dating of high quality** can be considered.



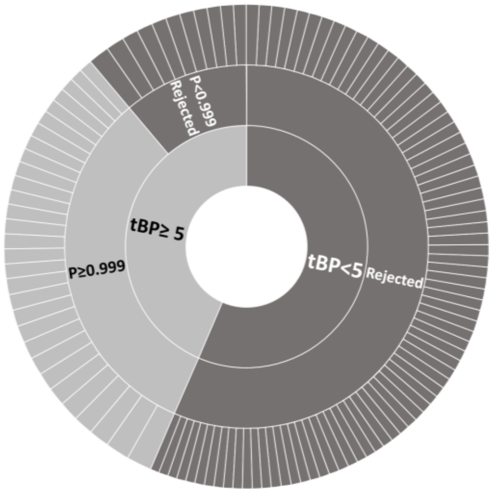


[C] The dendrochronological sequence **PCEF0102020145-155** gives excellent/very good results. The proposed date **1329-1488** is granted by several individual and master chronologies from BALTIC area – 62 for t_{BP}≥5.0 and 71 for t_{BP}<5.0 (graph I). The replication is extremely good since 37 of the 62 chronologies give the proposed date for *P*≥0.999, with the four best synchronisation rates obtained with five master chronologies – 0520003M (t_{BP}=8.1), NL BALTIC B (t_{BP}=8.4), NL BALTIC A (t_{BP}=8.7), BALTIC Import (t_{BP}=9.2), and BALTIC 1 (t_{BP}=9.9) (graph II). A **dating of high quality** can be considered.





[D] The dendrochronological sequence **PCEF0102020146-156** gives excellent/very good results. The proposed date **1348-1487** is provided by several individual and master chronologies from BALTIC area – 41 for t_{BP}≥5.0 and 78 for t_{BP}<5.0 (graph I). The replication is extremely good since 30 of the 41 chronologies give the proposed date for *P*≥0.999, with the four best synchronisation rates achieved with three master chronologies – 0520002M (t_{BP}=7.9), BALTIC 1 (t_{BP}=9.4) and NL BALTIC B (t_{BP}=9.7) (graph II). A **dating of high quality** can be considered.



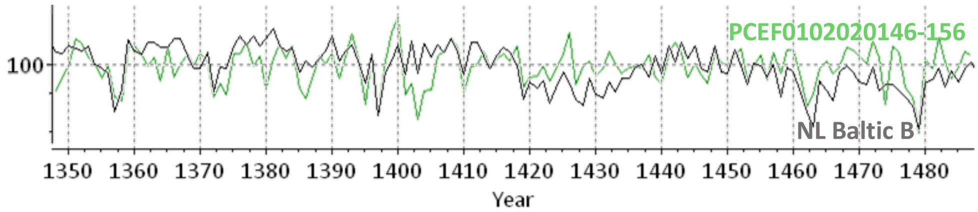
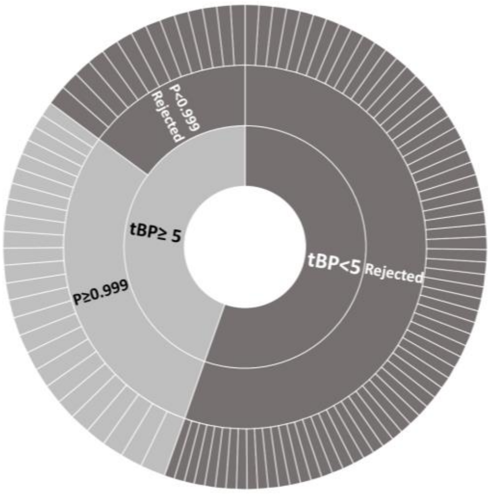


Figure 51. Hight dating quality of the dendrochronological sequences from the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection), according the t_{BP} and P values, and respective brief interpretation: **[A]** PCEF0102020141-143-160; **[B]** PCEF0102020144-147-148-161; **[C]** PCEF0102020145-155; and **[D]** PCEF0102020146-156.

The dendrochronological sequence **PCEF0102020157** gives very good results. The proposed date **1332-1487** is granted by several individual and master chronologies from BALTIC area – 39 for t_{BP}≥5.0 and 69 for t_{BP}<5.0 (graph I). The replication is very good since 25 of the 39 chronologies give the proposed date for *P*≥0.999, with the four best synchronisation rates achieved with four master chronologies – BOWHILL-B NL (t_{BP}=7.2), BALTIC Import (t_{BP}=7.5), BALTIC 1 (t_{BP}=7.8) and NL BALTIC A (t_{BP}=8.8) (graph II). A **dating of high quality** can be considered.



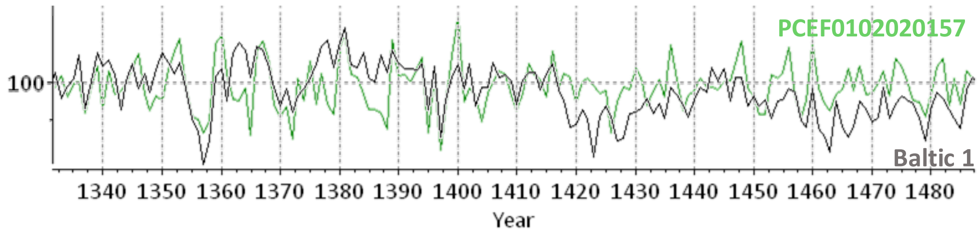
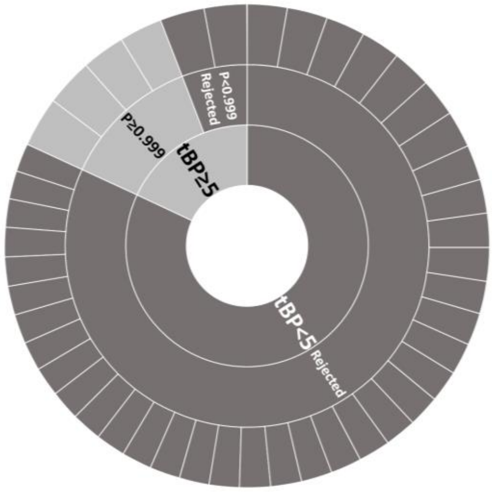
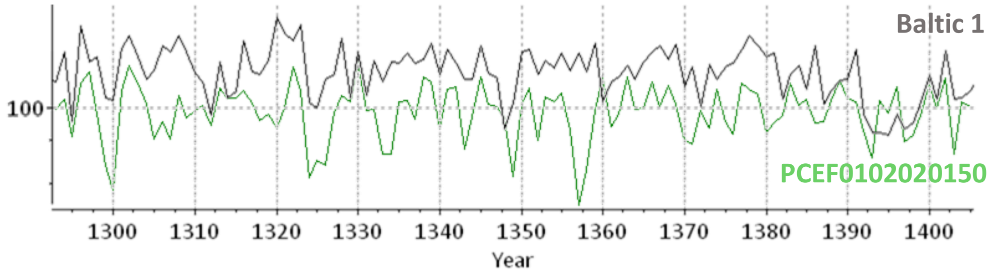


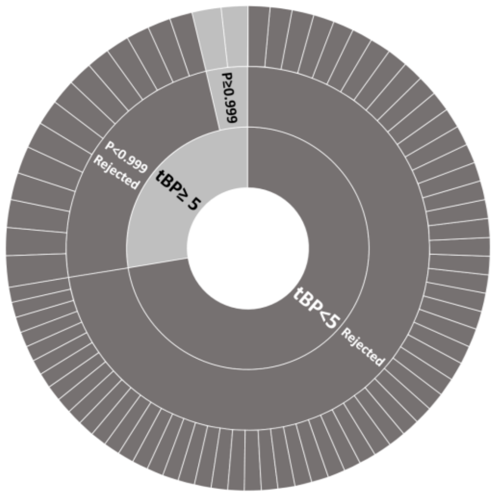
Figure 52. Very good quality dating of the PCEF0102020157 dendrochronological sequence from the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection), according the t_{BP} and *P* values, and respective brief interpretation.

[A] The dendrochronological sequence **PCEF0102020150** presents weak results. The proposed date **1293-1405** is supplied by several individual and master chronologies from BALTIC area – 7 for t_{BP}≥5.0 and 38 for t_{BP}<5.0 (graph I). However, the replication is low since only 5 of the 7 chronologies the proposed date for *P*≥0.999, with the two best synchronisation rates obtained with two individual index series – PCEF0604010010 (t_{BP}=5.7) and PCEF2310040085 (t_{BP}=6.0). These series correspond to two boards of distinct panels (*S. Cristóvão* (ME 1524), attributed to the Flemish painter Frey Carlos, ME, and *Descida da Cruz* (MASF20), attributed to workshop of Gerard David, MASF). A **hypothetic dating** should be considered.





[B] The dendrochronological sequence **PCEF0102020158** gives rather poor results. The proposed date **1354-1439** is provided by several individual and master chronologies from BALTIC area – 16 for t_{BP}≥5.0 and 61 for t_{BP}<5.0 (graph I). Just two chronologies replicate the proposed date with high probability (*P*≥0.999), one of them with a master chronology (BALTIC 1, t_{BP}=6.5). The results combined with the shortness of the dendrochronological sequence (86 tree rings) suggest that a **hypothetic dating** should be considered.



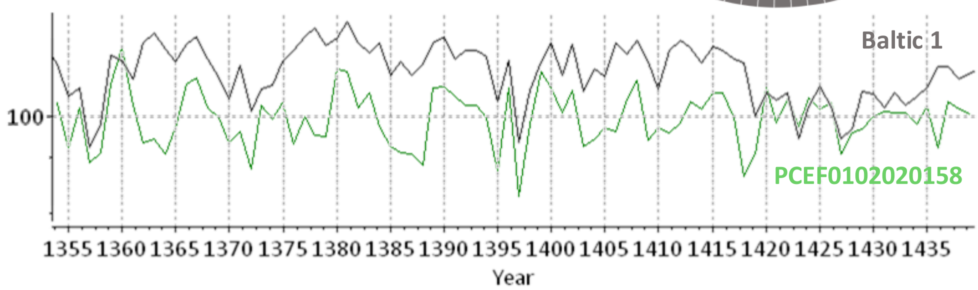


Figure 53. Hypothetical dating quality of the dendrochronological sequences from the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection), according the t_{BP} and *P* values, and respective brief interpretation: **[A]** PCEF0102020150; and **[B]** PCEF0102020158.

Synchronisation rate greater than 9.0 may be obtained on boards from the same tree, as can be suggested by the correlation between the dendrochronological sequence PCEF0102020149-151 and PCEF0604010008 index series (t_{BP}=10.4), which corresponds to a board of the *S. Brás* panel (ME 1523), attributed to the Flemish painter Frey Carlos, ME (Figure 50B). However, this is not the case for three main reasons: **(1)** there is not an evident graphical similarity between the two growth curves; **(2)** no agreement of pointer years, namely the years of 1363, 1381, 1406 and 1481; and **(3)** there is not a roughly of the beginning or end of both sequences (Figure 54).

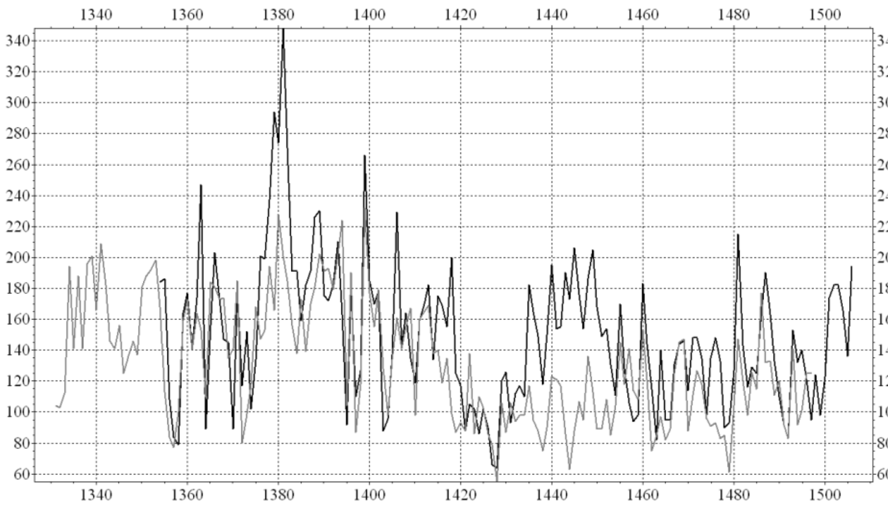


Figure 54. Visual synchronisation between dendrochronological PCEF0102020149-151 (grey line), belong to the *Vida S. Tiago* altarpiece, and PCEF0604010008 index series (black line), belong to *S. Brás* (ME 1523) panel, ME. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64].

2.1.1.3.3. Dating of the altarpiece

The youngest last tree ring identified (also defined as *dendrochronological date*) in the altarpiece in the sequence PCEF0102020152-153-154, positioned in *Conversão de Hermógenes* panel (20 Pint) refers to **1504** (Figure 55). The date obtained for the last measured ring on the support informs us about the tree felling period. This is determined with more or less precision, depending on the presence/absence of sapwood rings on the panel. No sapwood ring was identified on all the boards of the altarpiece. As a result, the dendrochronological dating is defined as "Type D", which means the dating quality classified as "*suspect*" according to BAILLIE (1982) (see subchapter 3.5. Types of dendrochronological dating in historical artefacts). The *terminus post quem* for the tree felling date can be determined from the three boards – PCEF0102020152, PCEF0102020153 and PCEF0102020154.

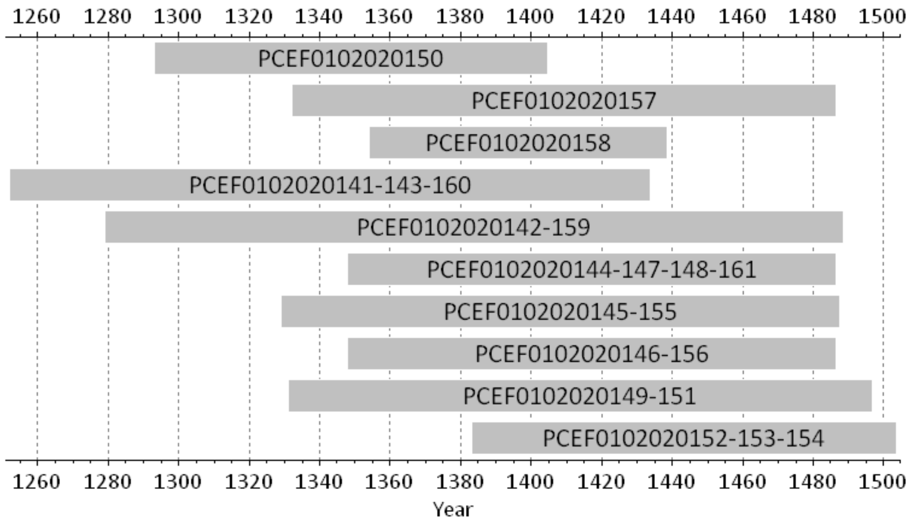


Figure 55. Chronological position of all dated dendrochronological sequences/combination of sequences obtained in the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection) [Graph by TSAP Win Scientific 4.64].

The minimum number of sapwood rings must be added to the heartwood/sapwood boundary. Considering that this parameter depends, among other factors, on the age of the tree, the estimated value to be considered for each board is variable. The *terminus post quem* for the earliest possible tree felling identified in the altarpiece is 1513, considering nine rings as sapwood estimate for boards with less than 200 years and 15 rings for the older ones from the eastern BALTIC region (KLEIN, 1998a; BAUCH, 2002) (Table 21). The time expected to complete the manufacture of the support must also be considered with a two-years period for wood stabilisation and transportation, and board preparation (see subchapter 1.2.3. *Dendrochronological dating*). The creation of the altarpiece appears to be possible from around **1515 onwards** (i.e., *terminus post quem* for support manufacturing) and agrees with its historical date of attribution (1520-1530 or 1520-1525). In this situation, the present dendrochronological analysis cannot offer clarification since all historical dates are probable.

Table 21. Dendrochronological dates of the 10 sequences/combination of sequences obtained the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection) [Laboratory filename – internal identification of each board; total rings – number of growth rings measured; sapwood rings (estimated number) – number of sapwood rings according to the tree's age (boards with less than 200 years - add 9 rings; boards with more than 200 years - add 15 rings); *terminus post quem* earliest possible tree felling – last preserved ring plus sapwood rings (estimated number); *terminus post quem* for the support manufacture – *terminus post quem* earliest possible tree felling plus 2 years of seasoning].

SEQUENCE / COMBINATION OF SEQUENCES	TOTAL RINGS MEASURED	FIRST PRESERVED RING	LAST PRESERVED RING	SAPWOOD RINGS (ESTIMATED NUMBER)	*terminus post quem* EARLIEST POSSIBLE TREE FELLING	*terminus post quem* FOR THE SUPPORT MANUFACTURE
PCEF0102020150	113	1293	1405	+9	1414	**1515 forward**
PCEF0102020157	156	1332	1487	+9	1496	
PCEF0102020158	86	1354	1439	+9	1448	
PCEF0102020141-143-160	183	1252	1434	+9	1443	
PCEF0102020142-159	211	1279	1489	+15	1504	
PCEF0102020144-147-148-161	140	1348	1487	+9	1496	
PCEF0102020145-155	160	1329	1488	+9	1497	
PCEF0102020146-156	140	1348	1487	+9	1496	
PCEF0102020149-151	167	1331	1497	+9	1506	
PCEF0102020152-153-154	122	1383	1504	+9	**1513**	

2.1.2. S. Francisco de Évora altarpiece

2.1.2.1. Assembly of the wood support

The boards of all panels are arranged parallel with each other with the grain parallel to length and in the same direction. Seven of the eleven panels analysed are made up of three boards, 24.3 cm to 33.5 cm in width and 1.22 m to 1.67 m in length (Table 22). The remaining four panels are mounted by four boards of a wider width (between 5.9 cm and 29.8 cm) and a similar length. There are significant differences in width between the top and bottom of the boards in some panels, e.g., in *Degolação dos Cinco Mártires de Marrocos* (89 pint) and *Descida da Cruz* (95 pint). The selection of uneven width between the tops and the bottoms of the boards may be justified for maximising the available timber.

The original thickness of all panels is roughly 15 mm, which corresponds to the spectrum of values shown by WADUM (1998). There is, however, a thinning of the edges in five panels to fit into the groove of the frame (Figure 56; Table 22) and, in these situations, a dendrochronological cross-section examination was conducted on boards with a thickness of approximately 6-8 mm.

In the seven panels made up of three boards, the centre board is larger than the other boards. The exceptions are in *Última Ceia* panel (94 Pint) and *Deposição de Cristo no Túmulo* panel (98 Pint) (Table

22). According to WADUM (1998) and DUNKERTON *et al.* (1999), this criterion indicated that wood craftsmen attempted, in most situations, to prevent the location of joints in the most important field of artistic composition to minimise the possibility of cracking in the central section by considering the material available.

Table 22. Description of the boards that compose the oak supports of the eleven panels studied on *S. Francisco de Évora* altarpiece, curated by the National Museum of Ancient Art, Lisbon [Type of cut - A: full radial (or full quarter); B: radial (or quarter); C: semi-radial (or false quarter); D: tangential (FRAITURE, 2011) (a) unmeasured].

NAME [INVENTORY NUMBER]	#	THICKNESS (mm)		TYPE OF CUT	WIDTH, cm	
		ORIGINAL	TO DENDRO		TOP LEVEL	LOWER LEVEL
Degolação dos Cinco Mártires de Marrocos [89 Pint]	4	15		A/B/A-B/B-C	24.0/10.0/28.4/ 25.0	26.0/10.9/23.7/25.0
Missa de São Gregório [91 Pint]	4	15	06-08	B-C/B /C/A	25.1/22.3/25.3/14.4	25.5/-/-/10.3
Apanha do Maná no Deserto [92 Pint]	3	15	6-8	B/B/B	27.6/33.2/27.5	26.5/33.5/28.0
Encontro de Abraão e Melquisedeque [93 Pint]	3	15		B/A-B/B	27.3/33.5/27.0	27.7/33.0/28.2
Última Ceia [94 Pint]	3	15	6-8	B/B/B	(a)	28.4/30.0/30.8
Descida da Cruz [95 pint]	3	15		B/A-B/A	28.8/32.2/26.7	32.0/29.1/26.2
Cristo a Caminho do Calvário [96 Pint]	4	15		A/B/B/B	29.8/27.3/5.9/ 24.6	28.0/28.0/5.9/25.6
Cristo no Horto [97 Pint]	3	15		B/A/B	30.6/32.8/24.3	28.8/32.4/26.2
Deposição de Cristo no Túmulo [98 Pint]	3	15		B/A/B	27.0/29.4/29.3	27.8/28.2/30.4
São Boaventura e São Luís de Tolosa [99 Pint]	3	15	6-8	A-B/A/B	25.1/33.4/28.7	23.5/35.0/27.0
São Bernardino de Siena e Santo António [293 Pint]	4	15	6-8	B/A/B/B	(a)	24.3/26.4/9.6/27.5

Figure 56. [A] Overview of the board I with the original thickness in *Encontro de Abraão e Melquisedeque* (93 Pint); and **[B]** Overview of the board II with bevelled edges in *São Boaventura e São Luís de Tolosa* (99 Pint).

Two types of board cuts were identified in the altarpiece – full quarter and quarter (Figure 57; Table 22). No board was classified with a distinctly false quarter and tangential cut. The choice for the two best kinds of cut boards shows the robustness and homogeneity of the panels that compose the altarpiece. Of the 37 boards analysed, 22% lead to a full quarter and 60% to quarter cut (Table 22). Six boards displayed an irregular alignment of the medullar rays between their edges (Figure 58), which could be predicted considering the wide width of the boards (between 24.3 cm and 30.8 cm). These observations are identical to those found in the *Vida de S. Tiago* altarpiece and other Flemish panels (FRAITURE, 2011).

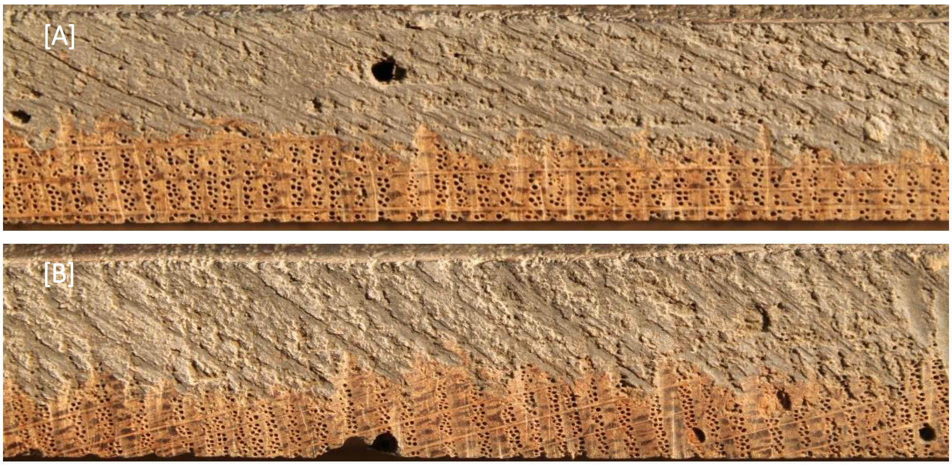


Figure 57. Type of boards' cut in *Cristo a Caminho do Calvário* (96 Pint): **[A]** *full quarter*; and **[B]** *quarter*.

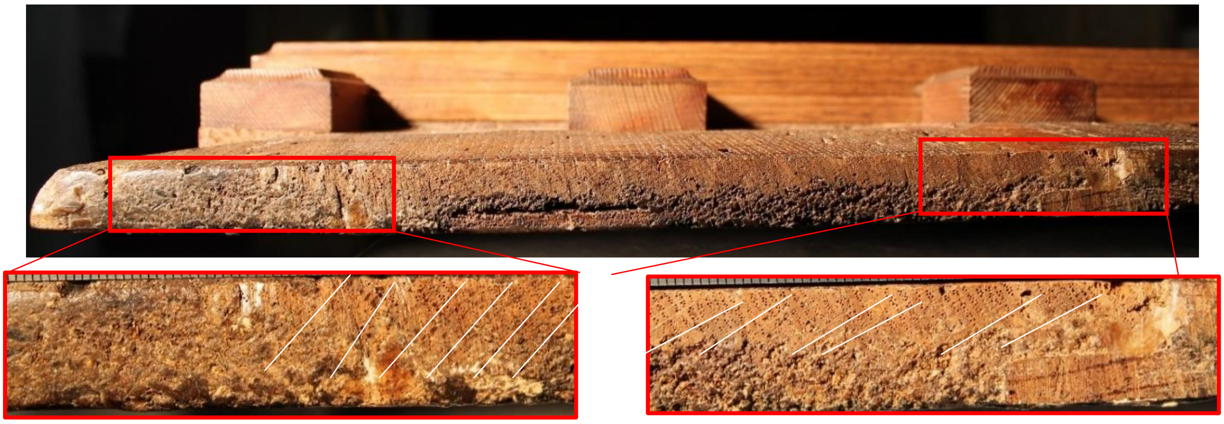


Figure 58. Example of a board with the left edge as *false quarter* cut and the right edge as *quarter* cut in *Degolação dos Cinco Mártires de Marrocos* (89 Pint).

The rule concerning the older tree-rings at the edge boards as applied by the Flemish workshops that were then in placed and adopted into the Portuguese workshops, was applied in eight of the eleven panels. Exceptions were found in three panels – *Missa de São Gregório* (91 Pint), *Encontro de Abraão e Melquisedeque* (93 Pint) and *Descida da Cruz* (95 Pint) (Figure 59).

Figure 59. Non-compliance with the rule on the older tree-rings at the edge of the external boards. Transverse section of the external boards from: **[A]** *Missa de São Gregório* (91 Pint); **[B]** *Encontro de Abraão e Melquisedeque* (93 Pint); and **[C]** *Descida da Cruz* (95 Pint) [The white arrow indicates the direction of growth].

2.1.2.2. Dendrochronological study

2.1.2.2.1. Description of the dendrochronological sequences

The visual inspection in the cross-section of the 11 panels permitted the identification of 37 panels. However, the dataset was reduced to 32 tree ring measurement series to date (Table 23) since five boards were not considered:

- *Degolação dos Cinco Mártires de Marrocos* (89 Pint) – on board III some discontinuities did not allow the continuous measurement of the rings; three of four boards were analysed.
- *Missa de São Gregório* (91 Pint) - on board II some discontinuities did not allow the continuous measurement of the rings; three of four boards were analysed.

- *Apanha do Maná no Deserto* (92 Pint) - on board I some discontinuities did not allow the continuous measurement of the rings; two of three boards were analysed.
- *Cristo a Caminho do Calvário* (96 Pint) - board III is very narrow, with few dating rings; three of four boards were analysed.
- *São Bernardino de Siena e Santo António* (293 Pint) –board IV is very damaged in the lower part, with no alternative of analysis in the upper part since it is a new wood.

Dendrochronological analysis allowed us to identify several boards from centenary oaks - nine boards with more than 200 rings (PCEF2802020123, PCEF2802020130, PCEF2802020136, PCEF2802020129, PCEF2802020131, PCEF2802020124, PCEF2802020125, PCEF2802020122 and PCEF2802020121) and two boards with more than 300 (PCEF2802020139 and PCEF2802020128). Two panels consist entirely of two-hundred-year-old boards – *Descida da Cruz* (95 pint) and *Cristo no Horto* (97 Pint) (Table 23).

The 32 tree-ring trends display growth rates that vary from one panel to another. In general, each panel provided a group of boards with common trends of wood growth, including one or two similar annual growth rates. Two panels show two uneven cases – *Última Ceia* (94 Pint) with fast and slow growth ring patterns, and *São Bernardino de Siena e Santo António* (293 Pint) with three distinct patterns (very slow, slow and medium) (Figure 60; Table 23). The very-slow-growing oak (with an average ring width of less than 1.00 mm) appears in the two older panels situated in two separate panels of the altarpiece – PCEF2802020128 (0.75±0.59) and PCEF2802020139 (0.81±0.46) (Figures 60G and K; Table 23). The slow-growing oak (with an average ring width between 1.00 and 1.20 mm) is identified in boards of differing sizes and positioned in separate panels. The extreme cases are the PCEF2802020110 tree-ring pattern with almost 10 cm wide, 91 tree-rings and an average ring width of 1.03 mm (Figure 60A; Tables 22 and 23), and the PCEF2802020121 tree-ring pattern with about 30 cm wide, 271 tree-rings and an average ring width of 1.08 mm (Figure 60E; Tables 22 and 23). A fast-growing trend is found in three distinct panels consisting of two separate panels: PCEF2802020117 and PCEF2802020119 from *Encontro de Abraão e Melquisedeque* (93 Pint), and PCEF2802020120 from *Última Ceia* (94 Pint) (Figures 60D and E; Table 22). The PCEF2802020117 and PCEF2802020120 tree-ring patterns with large and numerous rings (121 and 123, respectively) are supposed to originate from trees in an area favourable to higher annual growth, very different from standard forests in the BALTIC region. The PCEF2802020119 tree-ring pattern presumably refers to the innermost portion of a wider board due to its minimal number of rings. This fact exemplifies the tradition of using the sections of the boards to create the painting support to guarantee the complete width of the panel originally calculated. Three boards display a growth rhythm that is relatively fast at the beginning of growth, then steadily slows down with tree ageing (PCEF2802020125, PCEF2802020134 and PCEF2802020137) (Figures 60F, I and J).

Table 23. Details of the tree ring measurement series of the 32 boards from the *S. Francisco de Évora* altarpiece attributed to Francisco Henriques (MNAA collection) [Wood Growth Rate: *very slow* – less than 1.00 mm; *slow* – between 1.00 and 1.20 mm; *medium* – between 1.20 and 2.00 mm; *fast* – greater than 2.00 mm].

PANEL [INVENTORY NUMBER]	BOARD (LABORATORY FILENAME)	TOTAL RINGS MEASURED	RING WIDTH (mm)			WOOD GROWTH RATE
			MIN	MAX	AVG±STDV	
Degolação dos Cinco Mártires de Marrocos [89 Pint]	PCEF2802020109	161	0.44	3.96	1.57±0.76	Medium
	PCEF2802020110	91	0.32	1.76	1.03±0.40	Slow
	PCEF2802020111	96	0.72	2.85	1.45±0.50	Medium
Missa de São Gregório [91 Pint]	PCEF2802020112	151	0.50	2.27	1.08±0.57	Slow
	PCEF2802020113	97	0.60	3.31	1.48±0.70	Medium
	PCEF2802020114	95	0.66	2.79	1.43±0.51	Medium
Apanha do Maná no Deserto [92 Pint]	PCEF2802020115	102	0.63	2.69	1.62±0.48	Medium
	PCEF2802020116	190	0.49	2.97	1.27±0.57	Medium
Encontro de Abraão e Melquisedeque [93 Pint]	PCEF2802020117	121	0.71	3.84	2.18±0.72	Fast
	PCEF2802020118	187	0.66	2.99	1.66±0.49	Medium
	PCEF2802020119	59	1.21	4.32	2.45±0.67	Fast
Última Ceia [94 Pint]	PCEF2802020120	123	0.73	4.07	2.22±0.74	Fast
	PCEF2802020121	271	0.44	2.80	1.08±0.74	Slow
	PCEF2802020122	248	0.44	2.65	1.08±0.72	Slow
Descida da Cruz [95 pint]	PCEF2802020123	204	0.59	2.74	1.36±0.66	Medium
	PCEF2802020124	220	0.56	3.31	1.43±0.62	Medium
	PCEF2802020125	231	0.37	2.86	1.07±0.90	Slow
Cristo a Caminho do Calvário [96 Pint]	PCEF2802020126	149	0.82	3.86	1.91±0.66	Medium
	PCEF2802020127	156	0.86	3.17	1.68±0.56	Medium
	PCEF2802020128	325	0.31	1.34	0.75±0.59	Very slow
Cristo no Horto [97 Pint]	PCEF2802020129	207	0.33	2.33	1.25±0.66	Medium
	PCEF2802020130	204	0.76	2.68	1.55±0.40	Medium
	PCEF2802020131	216	0.60	1.89	1.08±0.61	Slow
Deposição de Cristo no Túmulo [98 Pint]	PCEF2802020132	193	0.44	2.34	1.20±0.60	Medium
	PCEF2802020133	132	0.62	2.14	1.25±0.52	Medium
	PCEF2802020134	194	0.68	3.25	1.47±0.80	Medium
São Boaventura e São Luís de Tolosa [99 Pint]	PCEF2802020135	159	0.57	3.07	1.35±0.66	Medium
	PCEF2802020136	204	0.69	2.77	1.46±0.55	Medium
	PCEF2802020137	142	0.83	2.50	1.59±0.55	Medium
São Bernardino de Siena e Santo António [293 Pint]	PCEF2802020138	185	0.61	1.79	1.09±0.30	Slow
	PCEF2802020139	305	0.33	1.39	0.81±0.46	Very slow
	PCEF2802020140	60	0.62	3.43	1.54±0.86	Medium

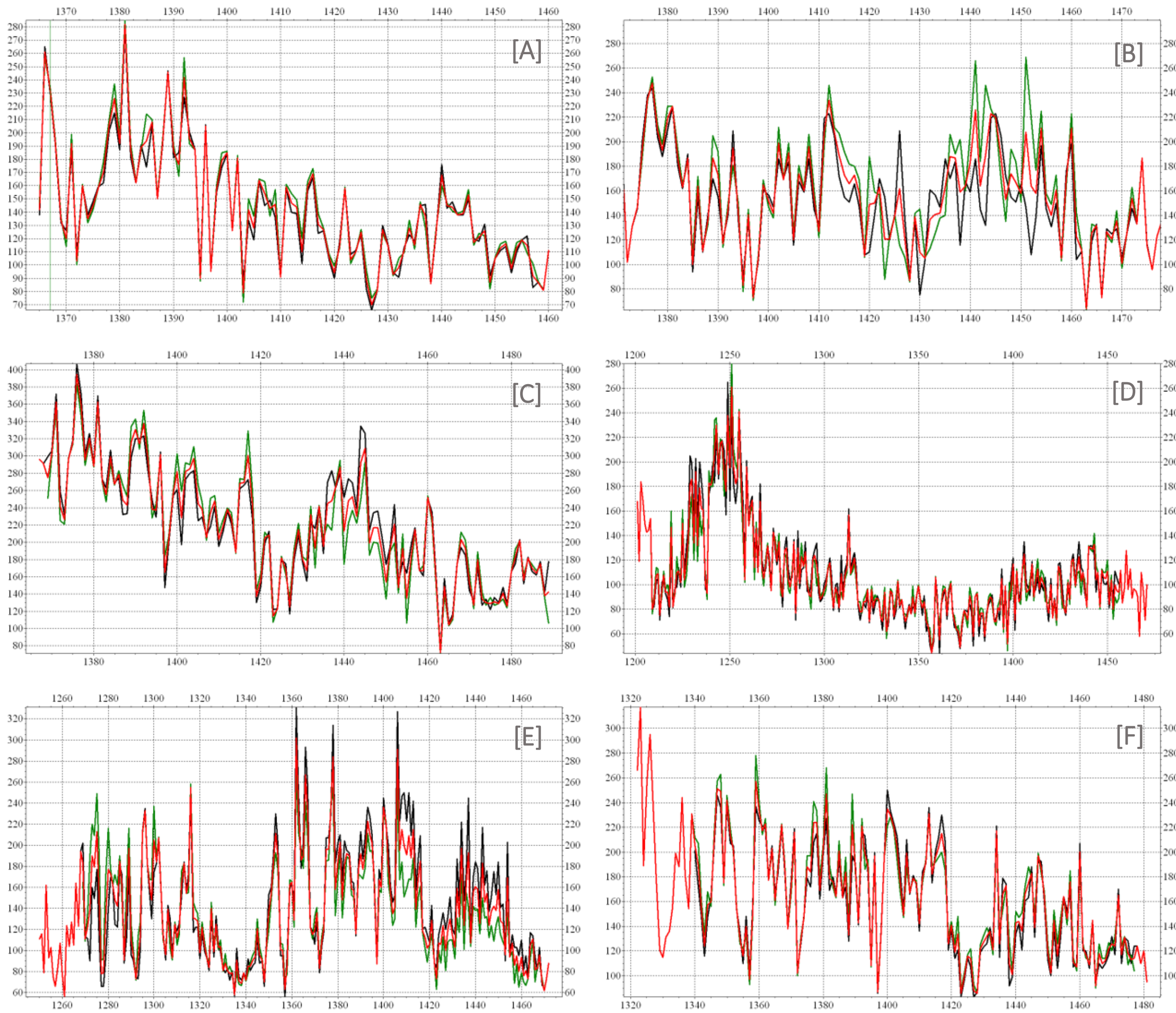
Figure 60. Grid beam graph representing the tree ring widths of the 32 boards from the *S. Francisco de Évora* altarpiece attributed to Francisco Henriques (MNAA collection): **[A]** *Degolação dos Cinco Mártires de Marrocos* (89 Pint); **(B)** *Missa de São Gregório* (91 Pint); **(C)** *Apanha do Maná no Deserto* (92 Pint); **(D)** *Encontro de Abraão e Melquisedeque* (93 Pint); **(E)** *Última Ceia* (94 Pint); **(F)** *Descida da Cruz* (95 pint); **(G)** *Cristo a Caminho do Calvário* (96 Pint); **(H)** *Cristo no Horto* (97 Pint); **(I)** *Deposição de Cristo no Túmulo* (98 Pint); **(J)** *São Boaventura e São Luís de Tolosa* (99 Pint); and **(K)** *São Bernardino de Siena e Santo António* (293 Pint) [Graph by TSAP Win Scientific 4.64].

Table 24. Matrix t_{BP} value (white area) / overlap (grey area) obtained between dendrochronological sequences of the 32 boards from the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection) [The unfilled spaces correspond to the absence of overlapping sequences].

	PCEF2802020109	PCEF2802020110	PCEF2802020111	PCEF2802020112	PCEF2802020113	PCEF2802020114	PCEF2802020115	PCEF2802020116	PCEF2802020117	PCEF2802020118	PCEF2802020119	PCEF2802020120	PCEF2802020121	PCEF2802020122	PCEF2802020123	PCEF2802020124	PCEF2802020125	PCEF2802020126	PCEF2802020127	PCEF2802020128	PCEF2802020129	PCEF2802020130	PCEF2802020131	PCEF2802020132	PCEF2802020133	PCEF2802020134	PCEF2802020135	PCEF2802020136	PCEF2802020137	PCEF2802020138	PCEF2802020139	PCEF2802020140
PCEF2802020109		91	96	145	97	95	102	155	107	161	59	109	157	142	158	155	144	139	154	154	158	161	155	152	92	161	150	161	136	159	160	60
PCEF2802020110	3.3		75	91	70	75	66	91	71	91	59	73	91	91	91	91	91	91	91	91	91	91	91	91	58	91	91	91	91	91	91	60
PCEF2802020111	6.4	4.2		95	91	95	87	96	92	64	59	94	96	92	96	96	96	96	96	96	96	96	96	96		96	96	96	96	96	96	60
PCEF2802020112	3.7	3.2	5.2		90	95	86	151	91	151	59	93	151	148	151	151	150	123	138	151	151	151	151	151	98	151	151	151	120	151	151	60
PCEF2802020113	8.0	0.6	3.8	1.8		90	93	97	97	97	59	97	97	87	97	97	89	97	97	97	97	97	97	97	37	97	97	97	97	97	97	60
PCEF2802020114	6.7	4.2	**23.1**	5.9	4.2		86	95	91	95	59	93	95	92	95	95	94	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60
PCEF2802020115	7.1	2.9	5.7	3.5	3.6	6.0		96	102	102	59	102	98	83	99	96	85	102	102	95	99	102	96	93		102	102	102	102	100	101	60
PCEF2802020116	6.9	2.5	6.4	3.8	4.0	6.8	4.6		101	177	59	103	190	177	190	190	179	133	148	189	190	188	190	187	137	186	159	190	130	181	190	60
PCEF2802020117	4.5	2.1	5.0	1.3	1.4	3.9	6.4	2.7		111	59	121	103	88	104	101	90	117	109	100	104	117	101	98	38	109	121	114	113	105	106	60
PCEF2802020118	5.4	4.9	4.9	4.7	2.0	5.3	8.3	2.8	5.0		59	113	179	164	180	177	166	143	156	176	180	187	177	174	114	185	159	187	140	181	182	60
PCEF2802020119	2.1	1.6	6.2	1.3	1.1	6.3	4.7	3.2	**13.2**	4.7		59	59	59	59	59	59	59	59	59	59	59	59	59		59	59	59	59	59	59	60
PCEF2802020120	5.4	2.6	6.6	2.0	2.7	6.1	7.5	4.5	**18.2**	5.5	**12.6**		105	90	106	103	92	119	111	106	106	119	103	100		111	123	116	115	107	108	60
PCEF2802020121	4.6	3.4	3.6	4.3	2.2	3.6	3.0	5.8	1.7	4.0	1.1	2.1		248	203	220	231	135	150	268	206	190	216	196	132	188	159	193	132	183	271	60
PCEF2802020122	5.7	3.4	3.0	2.9	0.8	3.2	2.9	5.7	1.9	3.8	1.5	2.1	**20.5**		188	207	229	120	135	248	191	175	203	186	132	173	159	178	117	168	248	60
PCEF2802020123	6.0	1.5	3.7	2.6	0.7	4.0	3.3	3.9	3.6	5.0	2.5	3.9	5.3	5.8		201	190	136	151	200	204	191	201	196	132	189	159	194	133	184	204	60
PCEF2802020124	5.6	1.7	3.4	2.4	1.5	3.8	2.8	4.3	2.8	4.5	1.9	2.9	5.0	4.8	**20.7**		209	133	148	219	204	188	216	196	132	186	159	191	130	181	220	60
PCEF2802020125	5.7	0.7	3.0	2.5	0.7	3.3	1.2	3.4	1.6	0.7	1.7	2.5	4.4	3.7	6.7	6.6		122	137	231	193	177	205	188	132	175	149	180	119	170	231	60
PCEF2802020126	5.5	2.9	5.7	2.9	1.3	5.4	4.0	4.2	4.1	6.0	2.2	4.2	3.0	4.1	5.7	5.2	3.9		141	132	136	149	133	130	70	141	146	146	142	137	138	60
PCEF2802020127	6.9	2.8	7.8	4.8	3.5	6.8	5.8	5.4	5.6	5.8	5.1	6.7	6.0	5.5	5.5	4.8	3.5	5.6		147	151	156	148	145	81	156	159	156	138	152	153	60
PCEF2802020128	2.1	0.4	0.7	2.3	1.4	1.0	1.9	0.3	0.7	3.5	0.2	0.7	3.6	2.7	1.8	2.1	0.2	3.3	0.6		203	187	215	196	132	185	159	190	129	180	299	60
PCEF2802020129	5.0	1.5	3.6	2.5	1.9	3.8	4.8	4.7	4.2	1.9	3.1	5.1	4.9	5.5	6.9	5.0	6.3	2.2	2.8	0.3		191	204	196	132	189	159	194	133	184	207	60
PCEF2802020130	5.5	2.7	6.5	5.0	2.5	6.4	5.9	4.6	5.2	6.0	5.5	5.9	5.1	4.2	4.7	3.2	3.0	5.4	6.8	3.0	3.5		188	185	125	194	159	201	142	185	193	60
PCEF2802020131	2.0	0.6	1.8	3.2	1.6	2.4	1.8	1.9	1.7	4.8	3.0	1.6	3.5	4.5	3.6	3.8	3.6	2.2	2.7	2.0	4.3	2.4		196	132	186	159	191	130	181	216	60
PCEF2802020132	4.0	1.8	4.0	2.5	2.3	4.0	3.0	3.4	3.5	2.7	2.1	4.2	4.8	5.8	6.3	5.5	4.8	4.8	4.6	2.6	4.7	6.0	5.0		132	183	132	188	127	178	196	60
PCEF2802020133	4.2	1.9		2.9	2.3			2.2	3.0	5.2			5.1	4.4	7.2	5.0	3.6	4.8	5.1	2.8	2.5	3.8	4.9	4.8		132	159	128	67	118	132	60
PCEF2802020134	6.3	3.6	7.9	3.7	3.3	7.4	7.2	5.1	4.2	6.7	5.0	5.6	4.0	3.7	5.0	5.6	3.8	5.3	**10.2**	2.5	2.7	6.3	1.5	3.5	3.4		159	194	138	185	191	60
PCEF2802020135	1.9	0.6	0.7	0.9	0.4	0.6	0.7	1.4	0.3	0.2	0.5	0.3	0.7	1.1	1.7	1.6	0.7	0.2	0.4	0.3	0.5	0.9	2.3	0.2	0.6	0.1		159	142	159	159	60
PCEF2802020136	3.9	2.2	1.7	4.3	0.5	2.1	2.8	2.4	1.9	3.1	0.6	1.9	4.5	3.9	7.1	6.7	3.6	4.5	3.3	1.8	3.7	4.3	5.0	6.2	4.8	2.5	0.1		142	185	196	60
PCEF2802020137	5.9	3.1	7.8	4.4	4.0	7.7	5.7	5.2	5.9	5.4	5.5	7.7	5.3	4.6	6.0	5.3	3.5	5.8	**25.6**	0.8	3.0	6.9	1.3	4.9	5.8	9.5	0.1	3.1		134	135	60
PCEF2802020138	5.3	3.8	3.7	2.9	2.3	3.5	4.4	5.4	2.2	3.8	2.8	3.1	6.0	3.6	4.3	4.3	4.0	3.6	3.3	2.2	6.2	6.3	2.8	6.1	3.7	3.5	1.3	4.7	4.0		185	60
PCEF2802020139	2.7	0.4	1.6	1.4	1.8	1.6	5.1	0.8	3.6	4.8	1.1	2.9	3.6	3.1	1.7	2.8	0.5	3.1	1.7	**11.2**	1.7	5.9	0.1	2.7	1.8	4.2	1.9	0.9	2.0	2.4		60
PCEF2802020140	0.7	1.9	0.9	0.6	0.2	0.7	1.3	0.2	0.5	1.2	0.4	0.9	1.1	0.1	0.5	0.3	0.9	0.1	1.7	2.1	0.7	1.3	0.7	1.4	0.1	2.6	1.7	0.1	0.2	0.3	0.3	

According to the growth ring patterns, certain boards in various parts of the altarpiece are made from the same tree, as can be seen in the *Vida de S. Tiago* altarpiece. Previous graphic visualisation (Figure 61) has raised the hypothesis of a dataset of seven growth ring pattern combinations (PCEF2802020111-114, PCEF2802020115-118, PCEF2802020117-120, PCEF2802020121-122, PCEF2802020123-124, PCEF2802020127-137 and PCEF2802020128-139) based on the parameters set out in subchapter 1.2.3.1. *Panels*:

- Similar mean ring widths – 1.45 mm-1.43 mm; 1.62 mm-1.66 mm; 2.18 mm-2.22 mm; 1.08 mm-1.08 mm; 1.36 mm-1.43 mm; 1.68 mm-1.59 mm; and 0.75 mm-0.81 mm (respectively) (Table 23);
- Nearly contemporaneous ring tree-ring patterns (begin and/or end) (Figure 61);
- Very hight t_{BP} values for the seven combinations of dendrochronological sequences, ranging from 10.2 to 25.6 (Table 24).



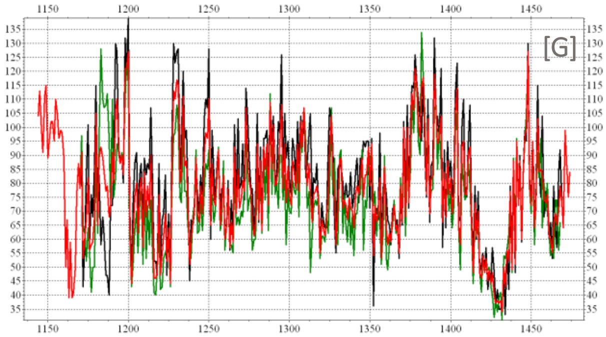
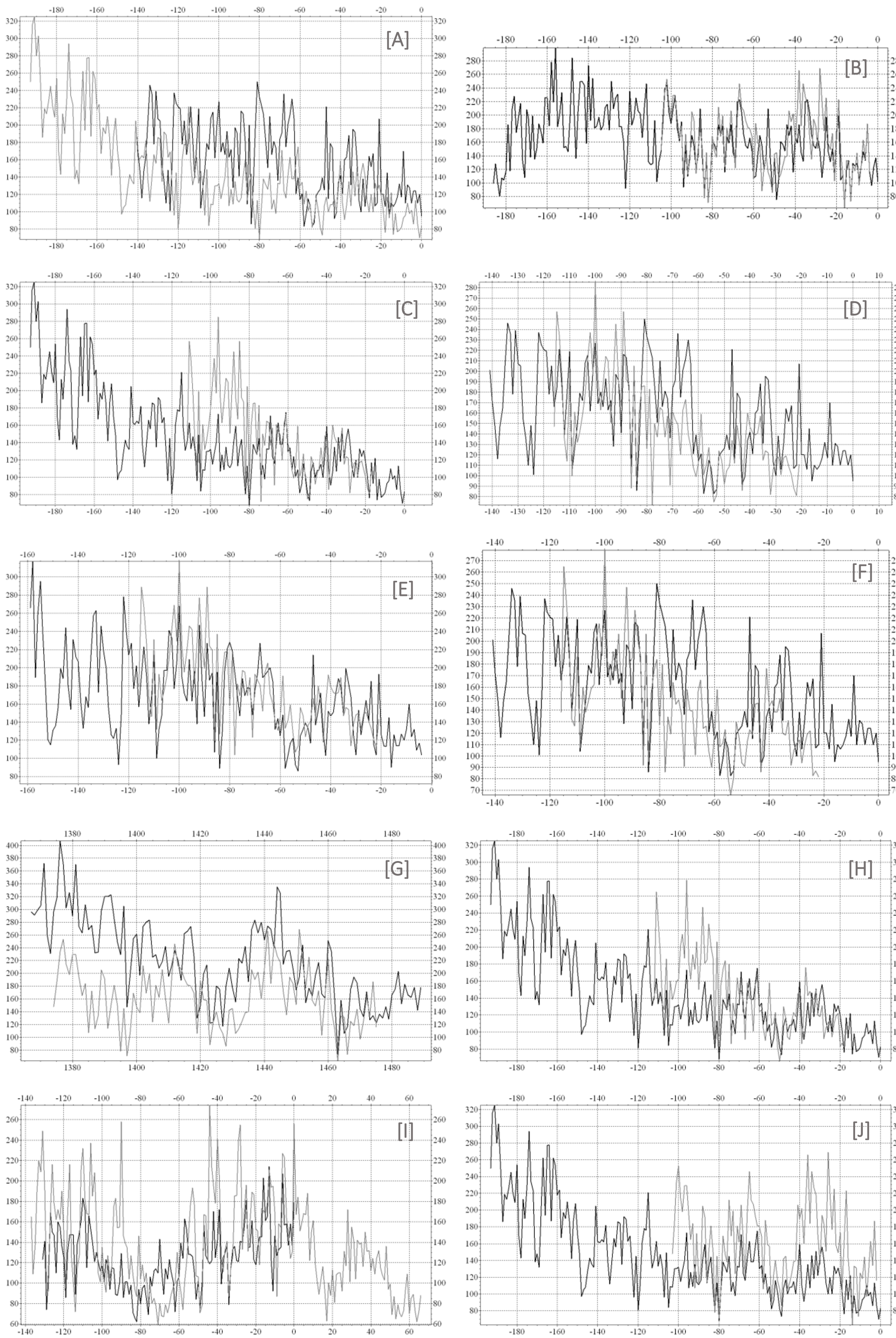


Figure 61. Visual synchronisation between growth ring patterns to consider as coming from the same tree: **[A]** PCEF2802020111-114; **[B]** PCEF2802020115-118; **[C]** PCEF2802020117-120; **[D]** PCEF2802020121-122; **[E]** PCEF2802020123-124; **[F]** PCEF2802020127-137; and **[G]** PCEF2802020128-139. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graphs by TSAP Win Scientific 4.64].

As seen in the *Vida de S. Tiago* altarpiece, there were several occasions where two growth ring patterns had identical characteristics (e.g., synchronisation, mean ring widths or/and almost contemporary sequences) but without such high t_{BP} values. Twelve combinations of combinations of dendrochronological sequences registered strong t_{BP} values, greater than 7.0 – PCEF2802020137-134 (t_{BP}=9.5); PCEF2802020115-118 (t_{BP}=8.3); PCEF2802020111-134 (t_{BP}=7.9); PCEF2802020111-137 (t_{BP}=7.8); PCEF2802020111-127 (t_{BP}=7.8); PCEF2802020114-137 (t_{BP}=7.7); PCEF2802020115-120 (t_{BP}=7.5); PCEF2802020114-134 (t_{BP}=7.4); PCEF2802020123-133 (t_{BP}=7.2); PCEF2802020115-134 (t_{BP}=7.2); PCEF2802020109-115 (t_{BP}=7.1) and PCEF2802020123-136 (t_{BP}=7.1) (Table 24). Mean ring widths varied only slightly in one combination – PCEF2802020137-134 (1.47 mm-1.59 mm); PCEF2802020115-118 (1.62 mm-1.66 mm); PCEF2802020111-134 (1.45 mm-1.47 mm); PCEF2802020111-137 (1.45 mm-1.59 mm); PCEF2802020111-127 (1.45 mm-1.68 mm); PCEF2802020114-137 (1.43 mm-1.59 mm); PCEF2802020115-120 (1.62 mm-2.22 mm); PCEF2802020114-134 (1.43 mm-1.47 mm); PCEF2802020123-133 (1.36 mm-1.25 mm); PCEF2802020115-134 (1.62 mm-1.47 mm); PCEF2802020109-115 (1.36 mm-1.46 mm); and PCEF2802020123-136 (1.57 mm-1.62 mm) (Table 23). However, visual synchronisation was not as obvious in most cases and did not reveal contemporaneous growth ring trends (begin/end) (Figure 62). As mentioned earlier, the boards most likely came from different trees growing in the same conditions, probably nearby trees in the same forest. Thus, of the 37 boards that make up the altarpiece, it can be claimed that at least 25 individual oak trees have been used in the creation of this incredible artwork.


[A]
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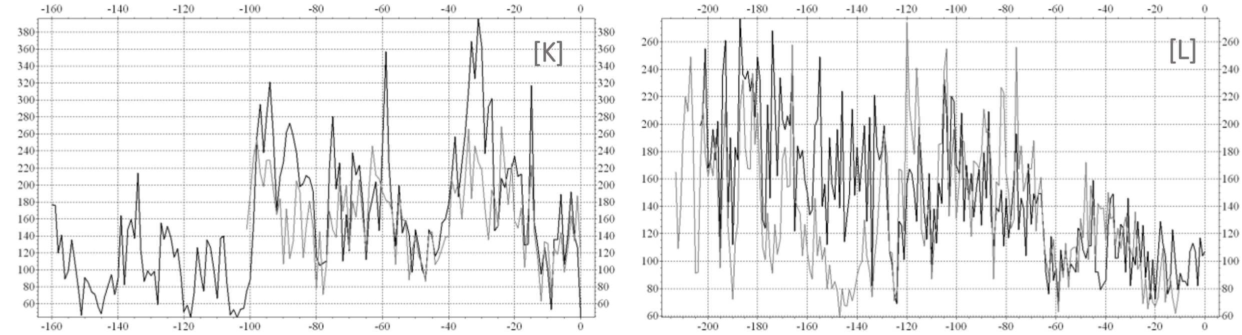


Figure 62. Visual synchronisation between growth ring patterns with high t_{BP} values (between 7.0 and 9.0) and not considered as coming from the same tree: **[A]** PCEF2802020137-134; **[B]** PCEF2802020115-118; **[C]** PCEF2802020111-134; **[D]** PCEF2802020111-137; **[E]** PCEF2802020111-127; **[F]** PCEF2802020114-137; **[G]** PCEF2802020115-120; **[H]** PCEF2802020114-134; **[I]** PCEF2802020123-133; **[J]** PCEF2802020115-134; **[K]** PCEF2802020109-115; and **[L]** PCEF2802020123-136. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graphs by TSAP Win Scientific 4.64].

2.1.2.2.2. Dating of the dendrochronological sequences

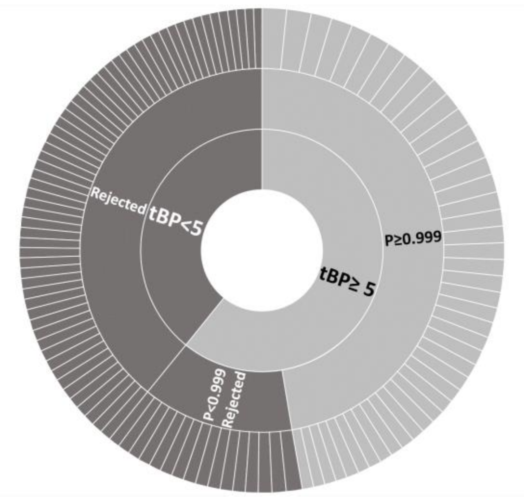
Twenty-one of the 25 final dendrochronological sequences is correctly dated, resulting in an 84% success rate. In four different panels (*Degolação dos Cinco Mártires de Marrocos* (89 Pint), *Missa de São Gregório* (91 Pint), *São Boaventura e São Luís de Tolosa* (99 Pint), and *São Bernardino de Siena e Santo António* (293 Pint)), four dendrochronological sequences could not be dated absolutely (PCEF2802020110, PCEF28020201113, PCEF2802020135 and PCEF2802020140, respectively). The third one, with 159 growth rings, has a good chance of succeeding. All dated chronologies were replicated using *Quercus* genus chronologies (defined as teleconnection) from various geographical regions.

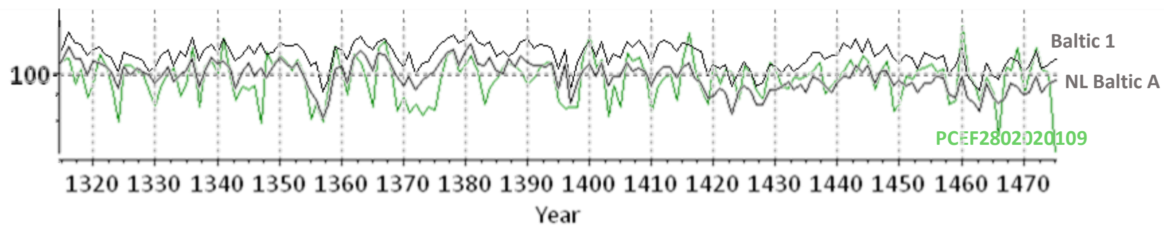
Figures 63 to 67 indicate the dating quality of each dendrochronological sequence, including an independent brief analysis. The confidence for each proposed date was obtained by its replication through the crossmatch with independent chronologies set out in Table 14. The ANNEX 5-Table 2 outlies the reference chronologies identification assigned to each replication with a t_{BP} equal or greater than 5.0 and a *P*-value equal or higher than 0.999. In summary, the data analysis allowed the identification of five distinct dating qualities:

- Excellent quality dating (43%) – nine dendrochronological sequences (PCEF2802020109, PCEF2802020116, PCEF2802020130, PCEF2802020111-114, PCEF2802020115-118, PCEF2802020117-120, PCEF2802020121-122, PCEF2802020123-124 and PCEF2802020127-137) report their best synchronisation rates with master chronologies and t_{BP} values above 10.0, reaching an excellent value of 16.3 (Figure 63);

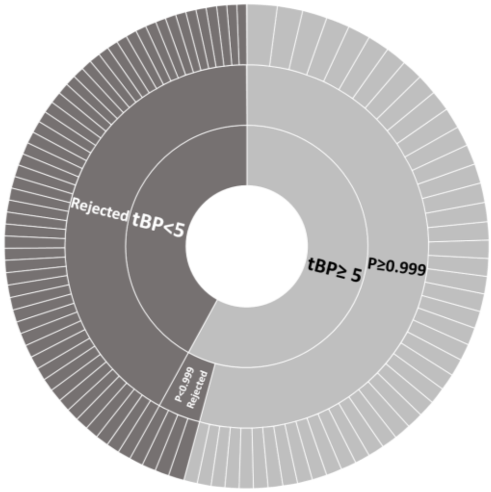
- High quality dating (10%) – two dendrochronological sequences (PCEF2802020126 and PCEF2802020132) display their best synchronisation rates with master chronologies and t_{BP} values ranging between 8.0 and 9.9 (Figure 64);
- Very good quality dating (19%) – four dendrochronological sequences (PCEF2802020133, PCEF2802020134, PCEF2802020136 and PCEF2802020138) report their best synchronisation rates with master chronologies and t_{BP} values ranging between 7.0 and 8.0 (Figure 65);
- Good quality dating (14%) – two dendrochronological sequences (PCEF2802020125, and PCEF2802020129) present their best synchronisation rates with master chronologies t_{BP} values ranging between 6.0 and 7.0. Despite presenting a high rate of synchronization with a master chronology (BALTIC 1, t_{BP}=8.7), the dating of the chronological sequence PCEF0102020128-139 is classified just as good given its low replication (Figure 66);
- Medium quality dating (14%) – four dendrochronological sequences (PCEF2802020112, PCEF2802020119, PCEF2802020128-139 and PCEF2802020131) report their best synchronisation rates with master chronologies and t_{BP} values ranging between 6.0 and 7.0, but with lower replication (Figure 67).

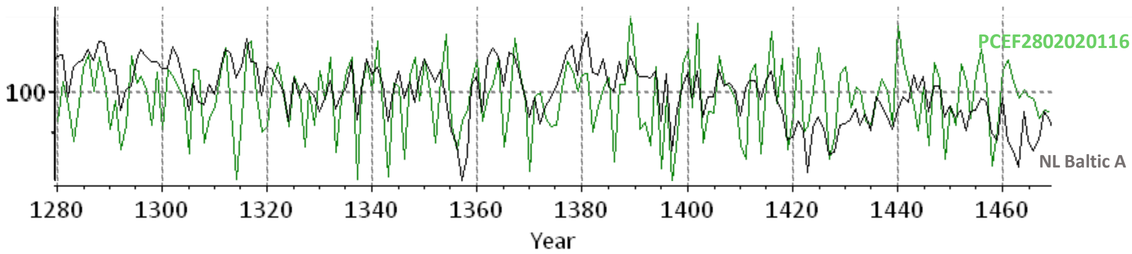
[A] The dendrochronological sequence **PCEF2802020109** gives excellent results. The proposed date **1315-1475** is given by several individual and master chronologies from BALTIC area – 60 for t_{BP}≥5.0 and 60 for t_{BP}<5.0 (graph I). The replication is notable since 44 of the 60 chronologies give the proposed date for *P*≥0.999. It should be given a special attention of the two best correlations of PCEF2802020109 with two master chronologies – BALTIC 1 and NL BALTIC A (both with t_{BP} = 10.8) (graph II). A **dating of excellent quality** can be considered.



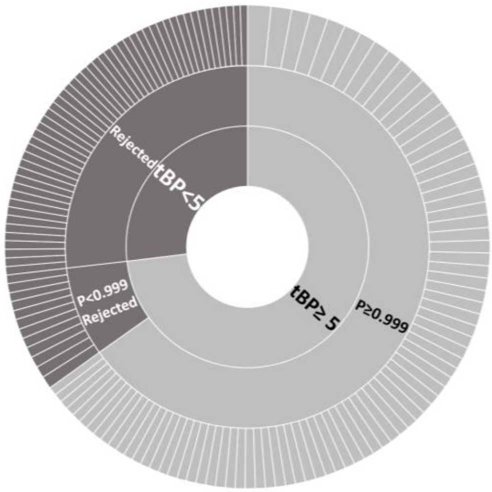


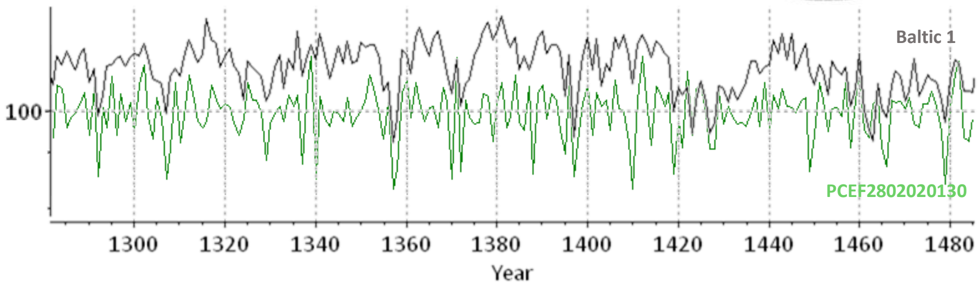
[B] The dendrochronological sequence **PCEF2802020116** gives excellent results. The proposed date **1280-1469** is granted by several individual and master chronologies from BALTIC area – 49 for t_{BP}≥5.0 and 54 for t_{BP}<5.0 (graph I). The replication is notable since 45 of the 49 chronologies give the proposed date for *P*≥0.999. It should be given a special attention of the two best correlations of PCEF2802020116 with the master chronology NL BALTIC A (t_{BP}=11.2) (graph II). A **dating of excellent quality** can be considered.



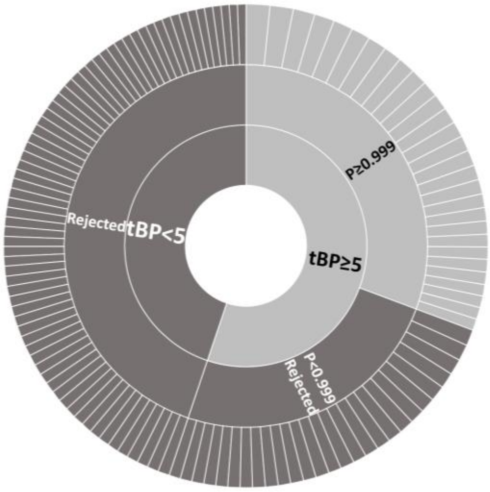


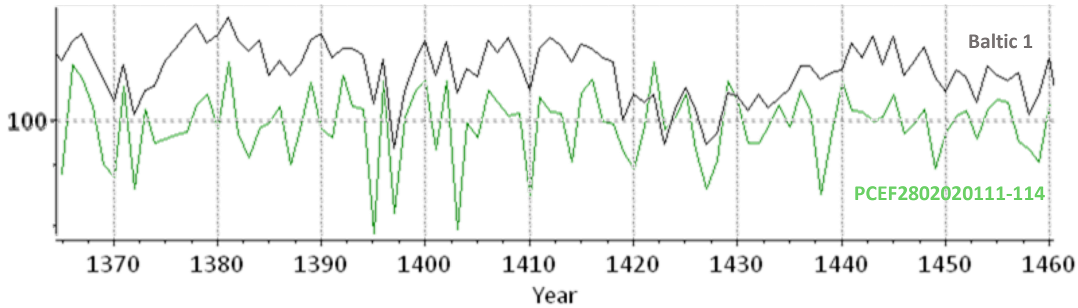
[C] The dendrochronological sequence **PCEF2802020130** gives extraordinary results. The proposed date **1282-1485** is granted by several individual and master chronologies from BALTIC area – 95 for t_{BP}≥5.0 and 52 for t_{BP}<5.0 (graph I). The replication is remarkable since 83 of the 95 chronologies give the proposed date for *P*≥0.999, with the five best correlations of PCEF2802020130 with five master chronologies – BALTIC Import (t_{BP}=10.4), NL BALTIC A (t_{BP}=10.4), BOWHILL-B (t_{BP}=10.7), NL BALTIC B (t_{BP}=12.0) and BALTIC 1 (t_{BP}=13.3) (graph II). A **dating of excellent quality** can be considered.



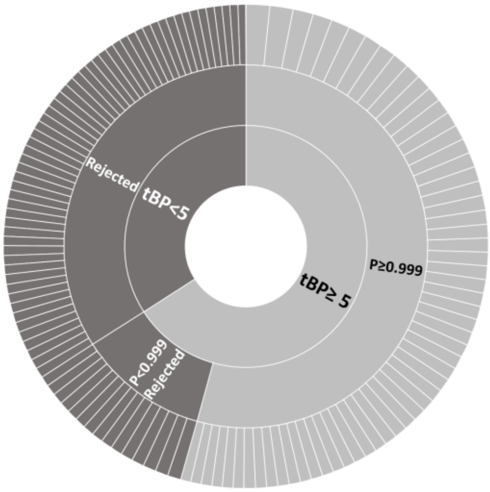


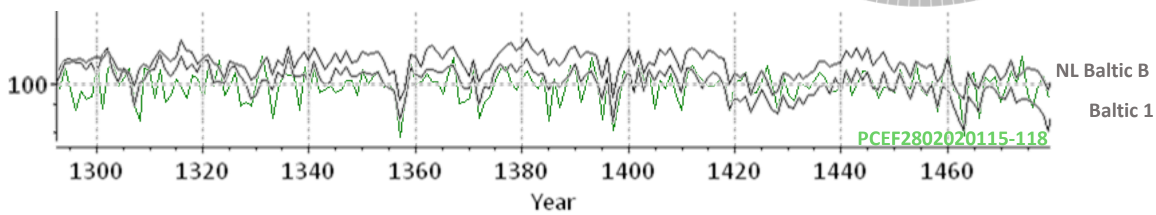
[D] The dendrochronological sequence **PCEF2802020111-114** gives excellent results. The proposed date **1365-1460** is given by several individual and master chronologies from BALTIC area – 56 for t_{BP}≥5.0 and 69 for t_{BP}<5.0 (graph I). The replication is notable since 29 of the 56 chronologies give the proposed date for *P*≥0.999. It should be given a special attention of the two best correlations of PCEF2802020111-114 with two master chronologies – BALTIC Import (t_{BP}=10.1) and BALTIC 1 (t_{BP}=10.4) (graph II). A **dating of excellent quality** can be considered.



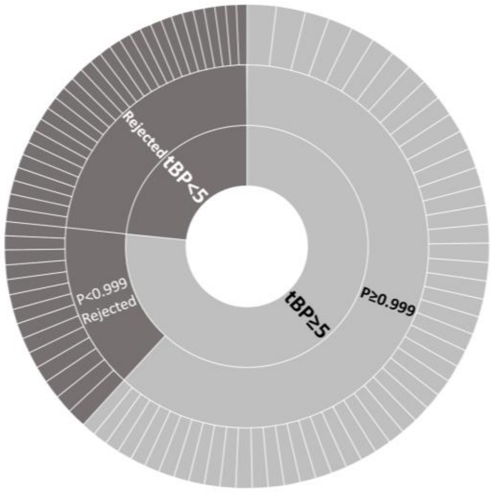


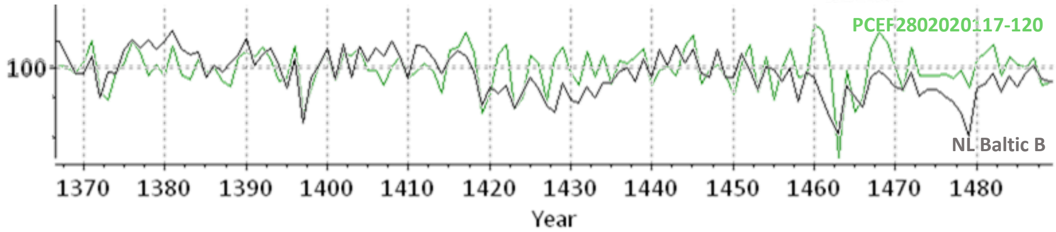
[E] The dendrochronological sequence **PCEF2802020115-118** gives excellent results. The proposed date **1293-1479** is awarded by several individual and master chronologies from BALTIC area – 74 for t_{BP}≥5.0 and 57 for t_{BP}<5.0 (graph I). The replication is notable since 59 of the 74 chronologies give the proposed date for *P*≥0.999. It should be given a special attention of the two best correlations of PCEF2802020115-118 with two master chronologies – NL BALTIC B and BALTIC 1 (both with t_{BP}=11.6) (graph II). A **dating of excellent quality** can be considered.



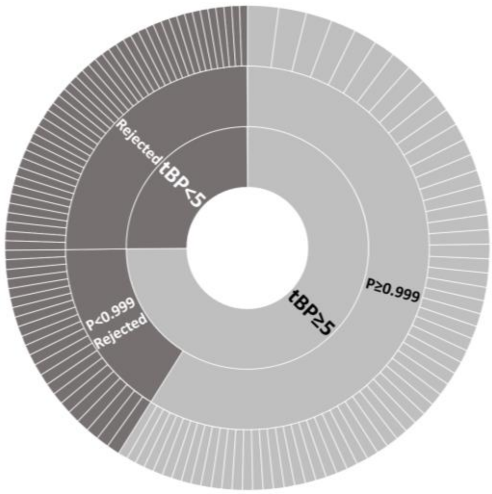


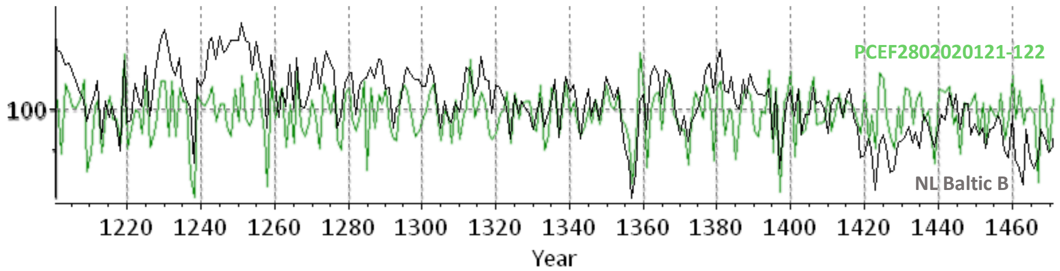
[F] The dendrochronological sequence **PCEF2802020117-120** gives excellent results. The proposed date **1367-1489** is granted by several individual and master chronologies from BALTIC area – 65 for $t_{BP}\geq5.0$ and 29 for $t_{BP}<5.0$ (graph I). The replication is notable since 51 of the 65 chronologies provide the proposed date for $P\geq0.999$. It should be given a special attention of the two best correlations of PCEF2802020117-120 with two master chronologies – BALTIC 1 (t_{BP}=10.1) and NL BALTIC B (t_{BP}=10.3) (graph II). A **dating of excellent quality** can be considered.



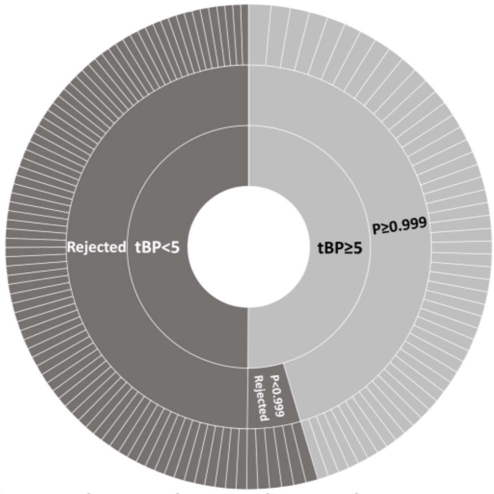


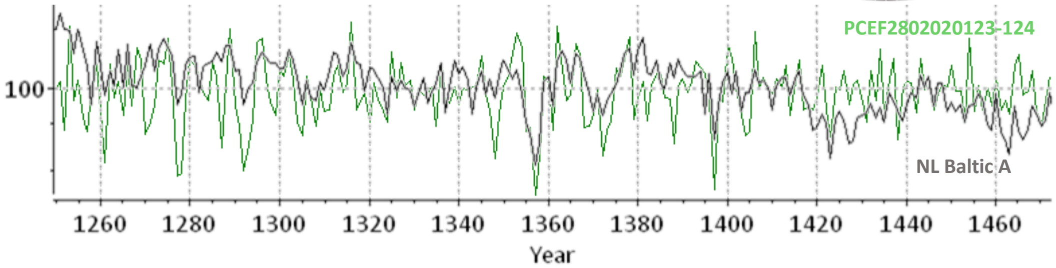
[G] The dendrochronological sequence **PCEF2802020121-122** gives extraordinary results. The proposed date **1201-1471** is given by several individual and master chronologies from BALTIC area – 86 for $t_{BP}\geq5.0$ and 44 for $t_{BP}<5.0$ (graph I). The replication is remarkable since 64 of the 86 chronologies provide the proposed date for $P\geq0.999$. A special attention should be given to the eight best correlations of PCEF2802020121-122 with five master chronologies and three index series – PCEF1603010018-20 (t_{BP}=10.0), P0202010195 (t_{BP}=10.6), P1604020131 (t_{BP}=11.1), BALTIC Import (t_{BP}=12.1), BALTIC 1 (t_{BP}=13.2), 0520006M (t_{BP}=13.4), 0520003M (t_{BP}=14.6) and NL BALTIC A (t_{BP}=16.3) (graph II). The first three were obtained in three distinct panels – *Assunção da Virgem* (2520 P50), attributed to the Portuguese painter Vicente Gil, MNMC; *S. Jerónimo* (287 Pint), of unknown attribution, MNAA; *Apresentação da Virgem no Templo* (ME 1504), attributed to workshop of Gerard David, ME, respectively. A **dating of exceptional quality** can be considered.



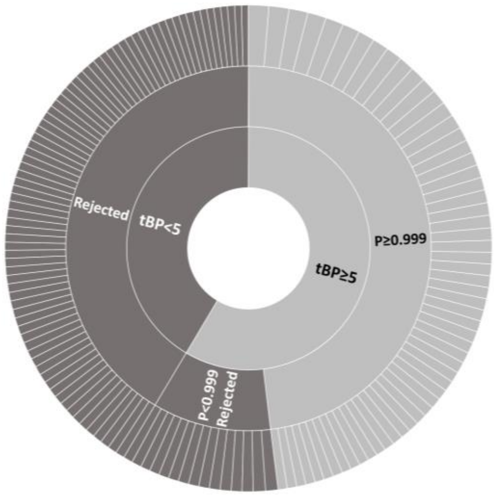


[H] The dendrochronological sequence **PCEF2802020123-124** gives excellent results. The proposed date **1250-1472** is given by several individual and master chronologies from BALTIC area – 57 for t_{BP}≥5.0 and 82 for t_{BP}<5.0 (graph I). The replication is noteworthy since 51 of the 57 chronologies provide the proposed date for *P*≥0.999, with the highest synchronisation rate obtained with the master chronology NL BALTIC A (t_{BP}=10.2) (graph II). A **dating of excellent quality** can be considered.





[I] The dendrochronological sequence **PCEF2802020127-137** gives excellent results. The proposed date **1322-1481** is provided by several individual and master chronologies from BALTIC area – 73 for t_{BP}≥5.0 and 78 for t_{BP}<5.0 (graph I). The replication is notable since 58 of the 73 chronologies provide the proposed date for *P*≥0.999. The three highest and excellent correlations should be given special attention as well – NL BALTIC A (t_{BP}=10.0), and PCEF3001010222 index series (t_{BP}=10.6) (it corresponds to a board of a Flemish panel belong to a private collection) and BALTIC 1 (t_{BP}=10.9) (graph II). A **dating of excellent quality** can be considered.



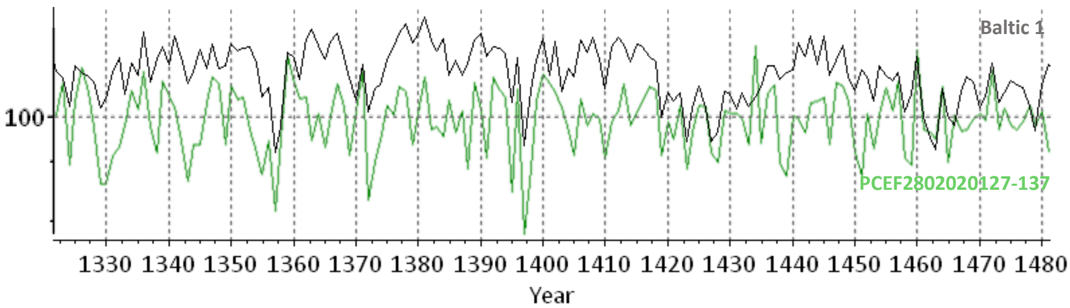
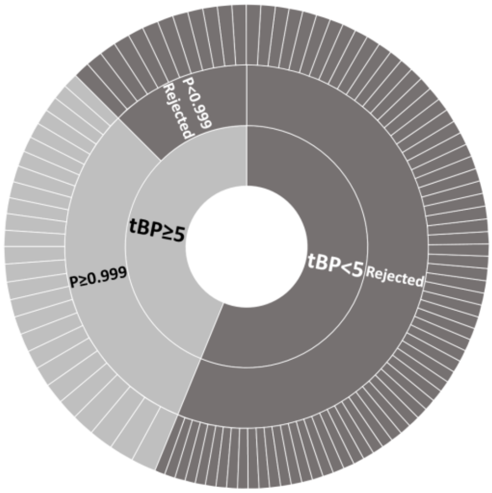
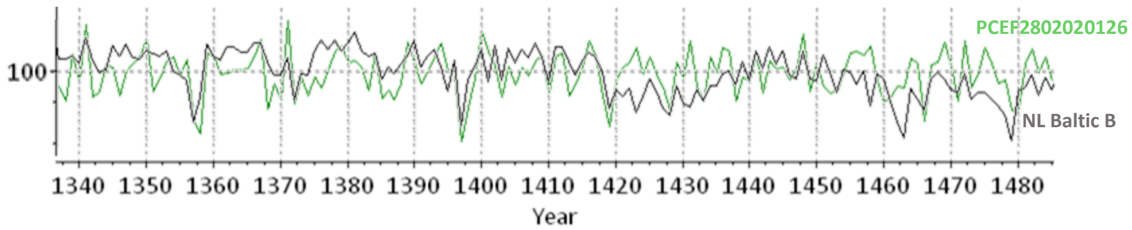


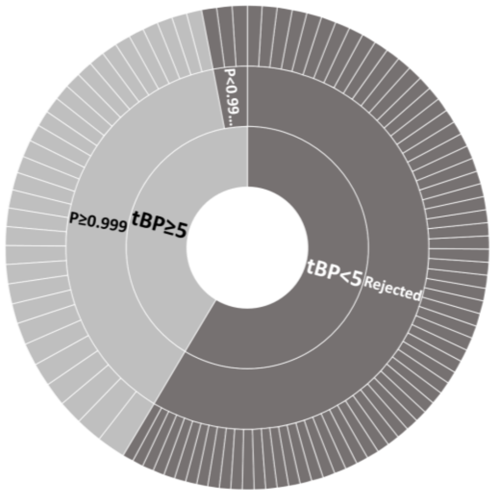
Figure 63. Excellent dating quality of the dendrochronological sequences from the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection), according to the t_{BP} and *P* values, and respective brief interpretation: **[A]** PCEF2802020109; **[B]** PCEF2802020116; **[C]** PCEF2802020130; **[D]** PCEF2802020111-114; **[E]** PCEF2802020115-118; **[F]** PCEF2802020117-120; **[G]** PCEF2802020121-122; **[H]** PCEF2802020123-124; and **[I]** PCEF2802020127-137.

[A] The dendrochronological sequence **PCEF2802020126** gives very good results. The proposed date **1377-1485** is given by several individual and master chronologies from BALTIC area – 38 for t_{BP}≥5.0 and 70 for t_{BP}<5.0 (graph I). The replication is very good since 26 of the 38 chronologies give the proposed date for P≥0.999, with the four best synchronisation rates achieved with four master chronologies – NL BALTIC A (t_{BP}=7.9), BALTIC 1 (t_{BP}=8.3), BALTIC Import (t_{BP}=8.3) and NL BALTIC B (t_{BP}=8.6) (graph II). A **dating of high quality** can be considered.





[B] The dendrochronological sequence **PCEF2802020132** provides very good results. The proposed date **1271-1466** is given by several individual and master chronologies from BALTIC area – 73 for t_{BP}≥5.0 and 78 for t_{BP}<5.0 (graph I). The replication is very good since 31 of the 59 chronologies give the proposed date for P≥0.999, with high synchronisation rates obtained with six master and one index series – 0520003M (t_{BP}=7.3), 0520006M (t_{BP}=7.4), P0202010190 (t_{BP}=7.7), BALTIC Import (t_{BP}=7.7), BALTIC 1 (t_{BP}=8.0), BOWHILL-B (t_{BP}=8.7) and NL BALTIC A (t_{BP}=9.5) (graph III). The P0202010190 index series corresponds to a board of the Portuguese panel *Pregação de São João Baptista* (49 Pint), of unknown attribution, MNAA. A **dating of high quality** can be considered.



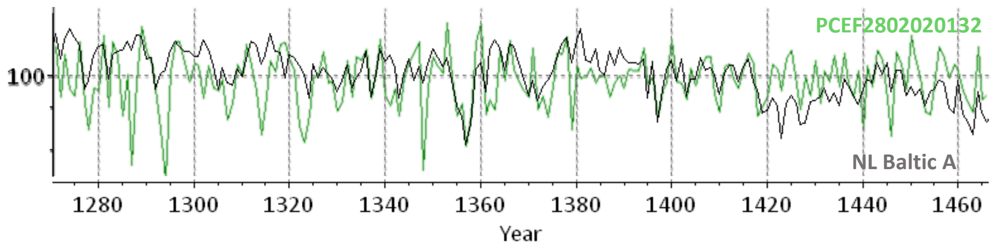
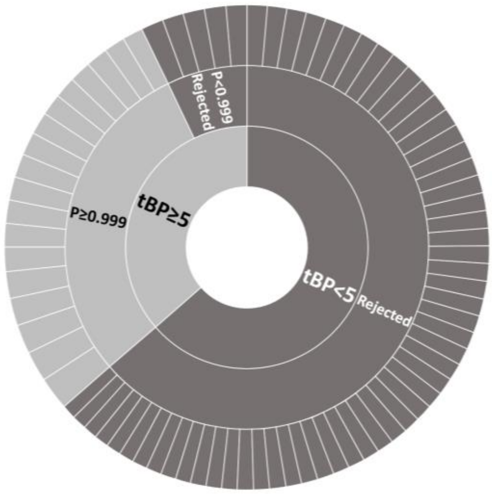
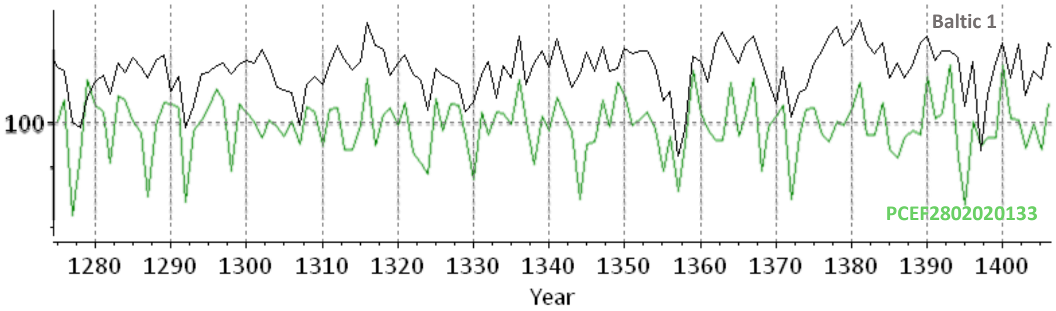


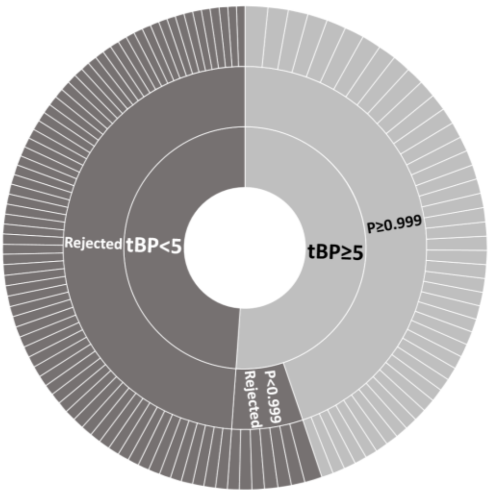
Figure 64. High dating quality of the dendrochronological sequences from the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection), according to the t_{BP} and P values, and respective brief interpretation: **[A]** PCEF2802020126; and **[B]** PCEF2802020132.

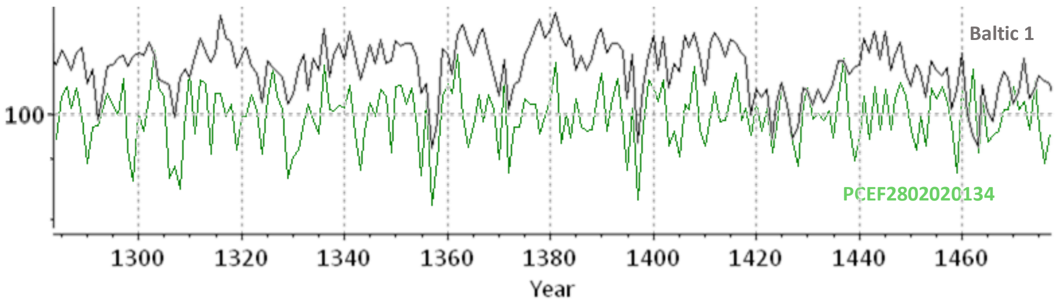
[A] The dendrochronological sequence **PCEF2802020133** gives very good results. The proposed date **1275-1406** is granted by several individual and master chronologies from BALTIC area – 23 for t_{BP}≥5.0 and 56 for t_{BP}<5.0 (graph I). The replication is good since 18 of the 23 chronologies provide the proposed date for *P*≥0.999, with the highest synchronisation rates obtained with master chronologies – NL BALTIC A (t_{BP}=7.1), NL BALTIC B (t_{BP}=7.4) and BALTIC 1 (t_{BP}=8.1) (graph II). A **dating of very good quality** can be considered.



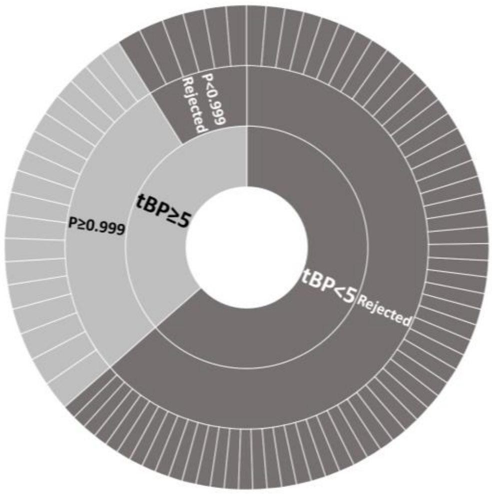


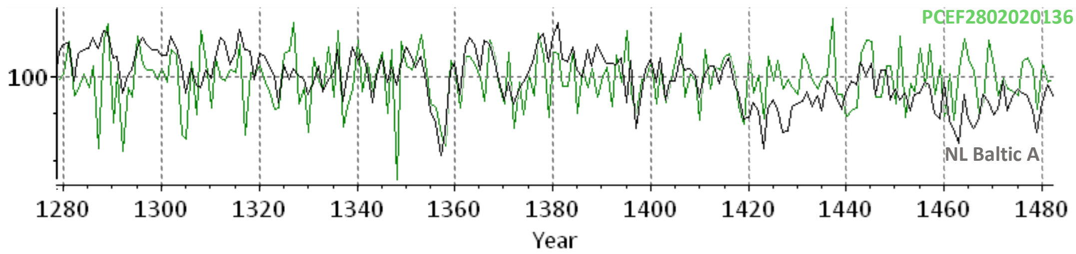
[B] The dendrochronological sequence **PCEF2802020134** gives very good results. The proposed date **1284-1477** is granted by several individual and master chronologies from BALTIC area – 52 for t_{BP}≥5.0 and 73 for t_{BP}<5.0 (graph I). The replication is very good since 45 of the 52 chronologies provide the proposed date for *P*≥0.999, with the highest synchronisation rates obtained with two master chronologies – BALTIC Import (t_{BP}=8.6) and BALTIC 1 (t_{BP}=9.6) (graph II). A **dating of very good quality** can be considered.



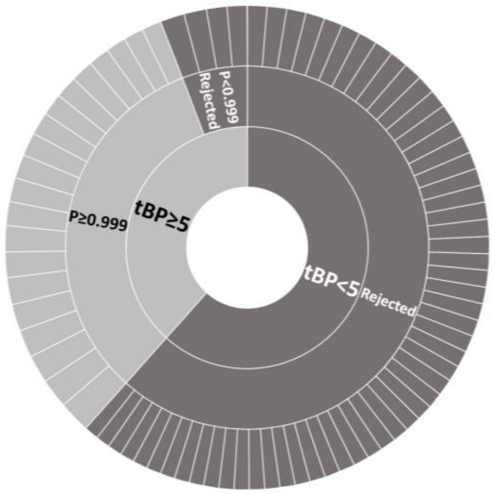


[C] The dendrochronological sequence **PCEF2802020136** gives very good results. The proposed date **1279-1482** is given by several individual and master chronologies from BALTIC area – 24 for t_{BP}≥5.0 and 60 for t_{BP}<5.0 (graph I). The replication is good since 18 of the 24 chronologies give the proposed date for *P*≥0.999, with the three highest synchronisation rates obtained with three master chronologies – BOWHILL-B (t_{BP}=7.0), BALTIC 1 (t_{BP}=7.1) and NL BALTIC A (t_{BP}=7.5) (graph II). A **dating of very good quality** can be considered.





[D] The dendrochronological sequence **PCEF2802020138** provides very good results. The proposed date **1289-1473** is provided by several individual and master chronologies from BALTIC area – 24 for t_{BP}≥5.0 and 56 for t_{BP}<5.0 (graph I). The replication is good since 20 of the 24 chronologies give the proposed date for *P*≥0.999, with the two highest synchronisation rates obtained with two master chronologies – BALTIC Import (t_{BP}=7.4) and NL BALTIC A (t_{BP}=8.0) (graph II). A **dating of very good quality** can be considered.



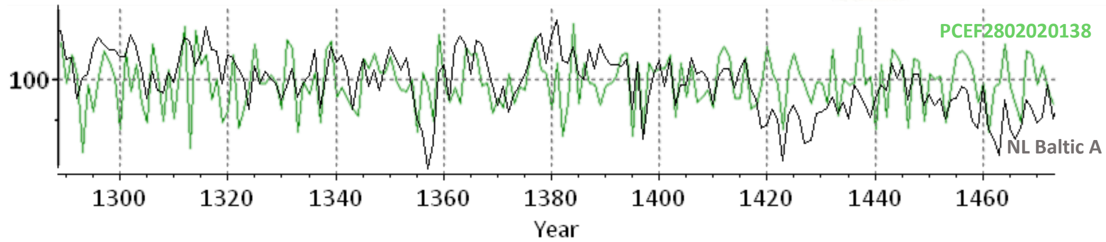
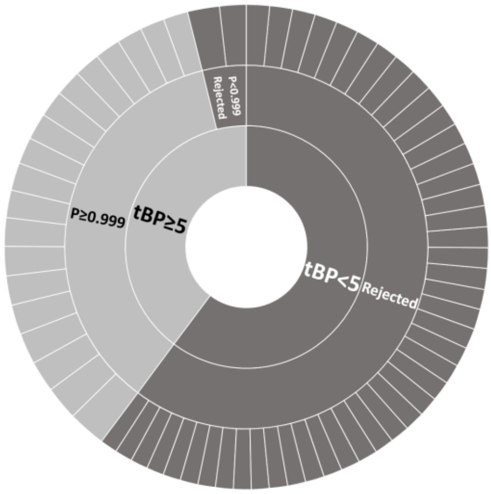
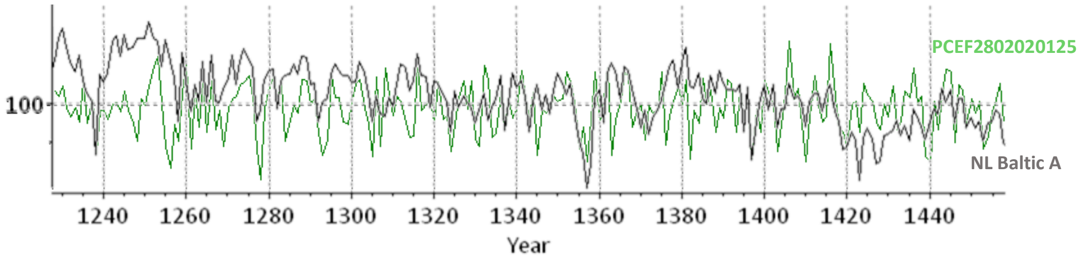


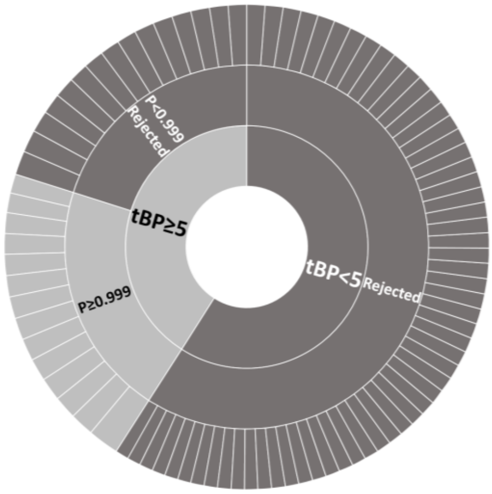
Figure 65. Very good dating quality of the dendrochronological sequences from the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection), according to the t_{BP} and *P* values, and respective brief interpretation: **[A]** PCEF2802020133; **[B]** PCEF2802020134; **[C]** PCEF2802020136; and **[D]** PCEF2802020138.

[A] The dendrochronological sequence **PCEF2802020125** gives good results. The proposed date **1228-1458** is provided by several individual and master chronologies from BALTIC area – 21 for t_{BP}≥5.0 and 45 for t_{BP}<5.0 (graph I). The replication is good since 19 of the 21 chronologies give the proposed date for *P*≥0.999, with the highest synchronisation rates achieved with an index series and a master chronology – PCEF0604010012 (t_{BP}=6.9) and NL BALTIC A (t_{BP}=7.7) (graph II). The PCEF0604010012 index series corresponds to a board of the Portuguese panel *S. Cristóvão* (ME 1524), attributed to the Flemish painter Frey Carlos, ME. A **dating of good quality** can be considered.





[B] The dendrochronological sequence **PCEF2802020129** gives good results. The proposed date **1266-1472** is supplied by several individual and master chronologies from BALTIC area – 29 for t_{BP}≥5.0 and 59 for t_{BP}<5.0 (graph I). The replication is good since 14 of the 29 chronologies give the proposed date for *P*≥0.999, with the three highest synchronisation rates obtained with three master chronologies – 0520003M (t_{BP}=6.3), NL BALTIC A (t_{BP}=6.4) and BALTIC 1 (t_{BP}=8.4) (graph II). A **dating of good quality** can be considered.



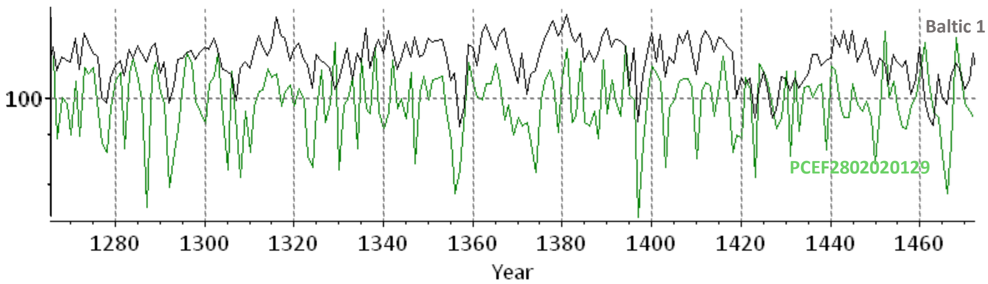
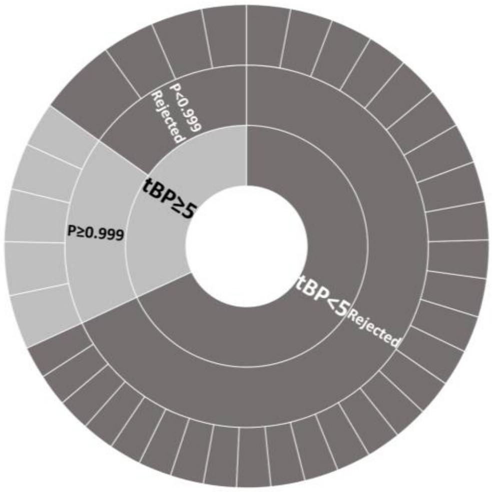
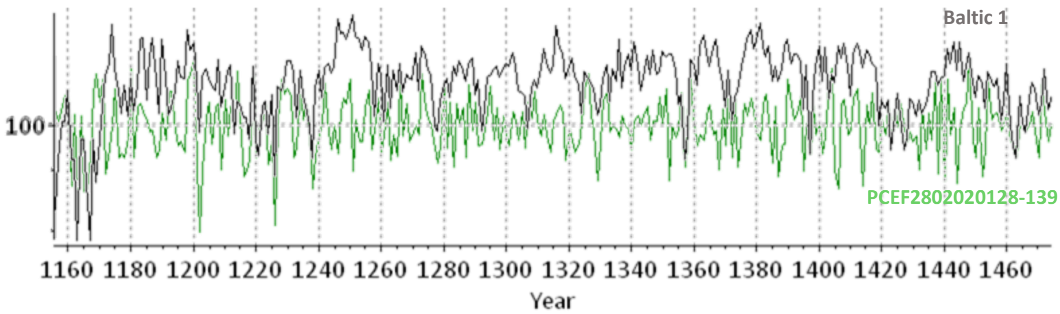


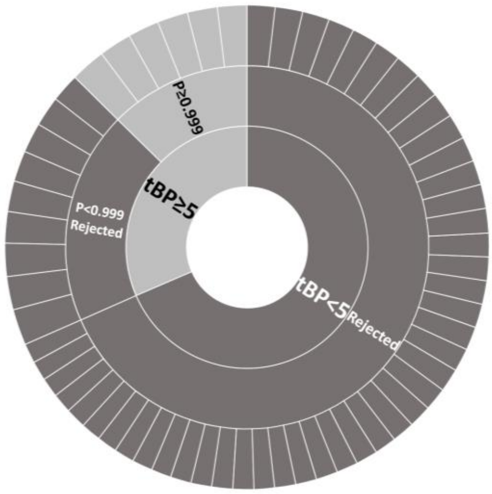
Figure 66. Good dating quality of the dendrochronological sequences from the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection), according to the t_{BP} and *P* values, and respective brief interpretation: **[A]** PCEF2802020125; and **[B]** PCEF2802020129.

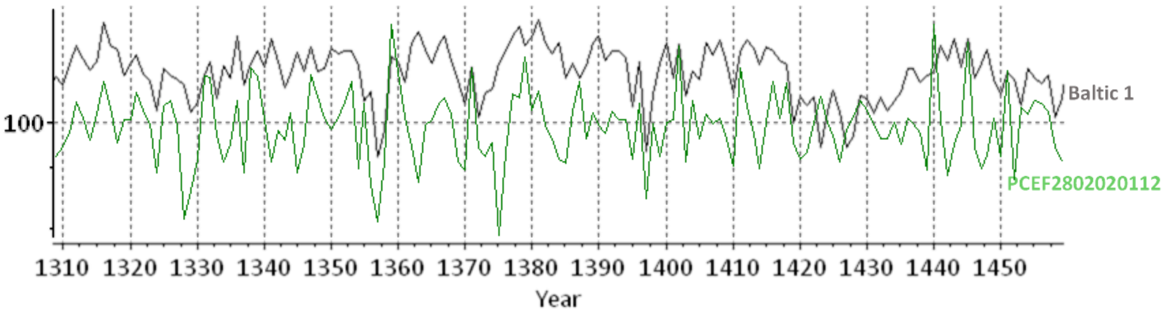
[A] The dendrochronological sequence **PCEF2802020128-139** presents good-acceptable results. The proposed date **1144-1474** is supplied by some individual and master chronologies from BALTIC area – 9 for t_{BP}≥5.0 and 28 for t_{BP}<5.0 (graph I). The replication is low since only 5 of the 9 chronologies provide the proposed date for *P*≥0.999. However, the two highest synchronisation rates are obtained with two master chronologies – BOWHILL-B (t_{BP}=6.1) and BALTIC 1 (t_{BP}=8.7) (graph III). A **dating of good quality** can be considered.



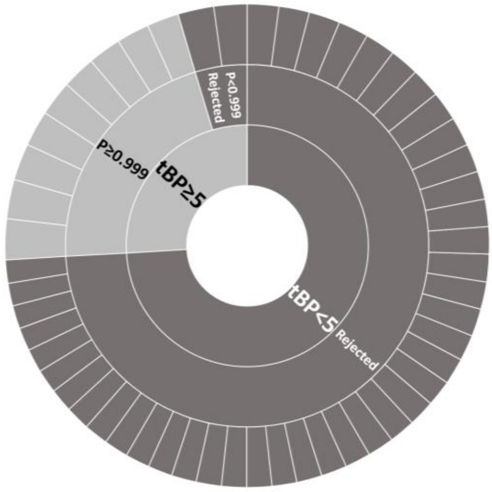


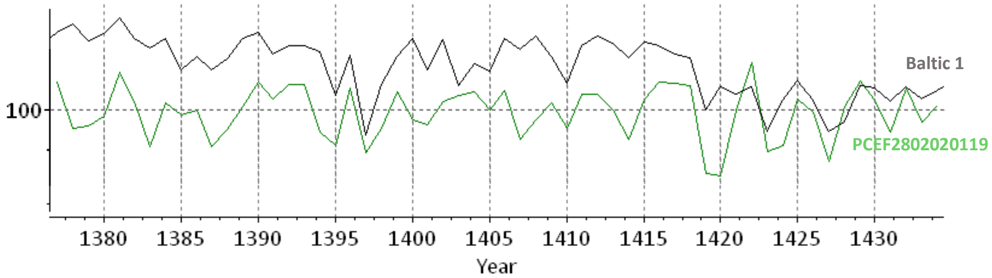
[B] The dendrochronological sequence **PCEF2802020112** presents acceptable results. The proposed date **1309-1459** is provided by some individual and master chronologies from BALTIC area – 15 for t_{BP}≥5.0 and 45 for t_{BP}<5.0 (graph I). The replication is low since only 6 of the 15 chronologies provide the proposed date for *P*≥0.999, with the two best synchronisation rates achieved two master chronologies – NL BALTIC B (t_{BP}=5.6) and BALTIC 1 (t_{BP}=6.1) (graph II). A **dating of medium quality** can be considered.



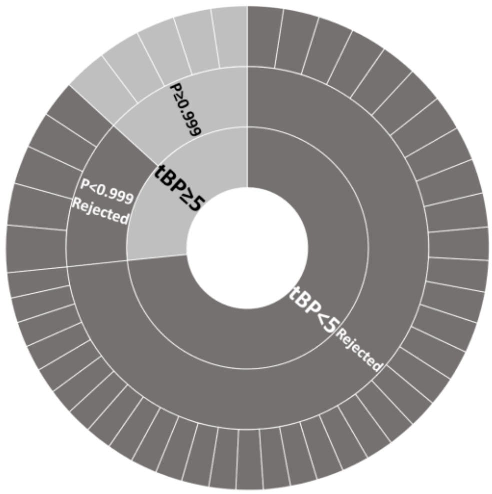


[C] The dendrochronological sequence **PCEF2802020119** provides acceptable results. The proposed date **1377-1434** is provided by several individual and master chronologies from BALTIC area – 11 for t_{BP}≥5.0 and 42 for t_{BP}<5.0 (graph I). The replication is low since 9 of the 11 chronologies give the proposed date for *P*≥0.999. However, the four best synchronisation rates achieved with four master chronologies – BALTIC Import (t_{BP}=5.2), 0520006M (t_{BP}=5.5), NL BALTIC B (t_{BP}=6.1) and BALTIC 1 (t_{BP}=6.4) (graph II). Although the shortness of the sequence (59 tree rings) may justify the high number of rejected dates, a **dating of medium quality** can be considered.





[D] The dendrochronological sequence **PCEF2802020131** gives acceptable results. The proposed date **1254-1469** is provided by several individual and master BALTIC chronologies – 10 for t_{BP}≥5.0 and 37 for t_{BP}<5.0 (graph I). The replication is low once 5 chronologies of the 10 chronologies provide the proposed date for *P*≥0.999. Nevertheless, there are two correlations of good quality – BALTIC 1 (t_{BP}=5.7) (graph III) and OS0833ar (t_{BP}=5.9). A **dating of medium quality** can be considered.



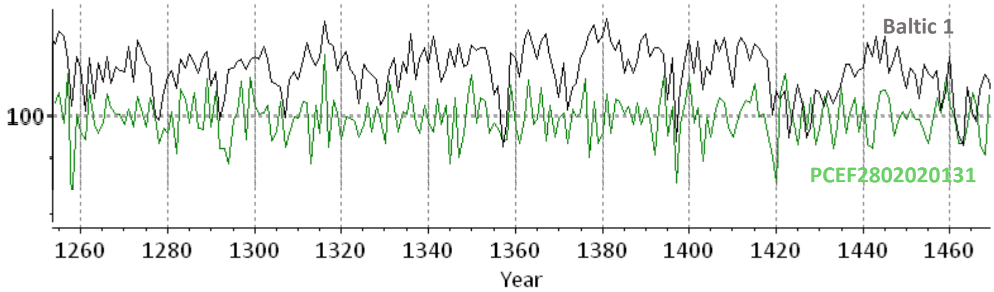


Figure 67. Medium dating quality of the dendrochronological sequences from the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection), according to the t_{BP} and *P* values, and respective brief interpretation: **[A]** PCEF2802020128-139; **[B]** PCEF2802020112; **[C]** PCEF2802020119; and **[D]** PCEF2802020131.

A synchronisation rate greater than 9.0 may be obtained on boards from the same tree (see subchapter 1.2.2. Dendrochronological dating), as suggested by the correlation between the dendrochronological sequence PCEF2802020121-122 and three individual chronologies – PCEF1603010018-20 (t_{BP}=10.0), P0202010195 (t_{BP}=10.6), P1604020131 (t_{BP}=11.1). These three boards correspond to three distinct panels belongs to distinct Museums – *Assunção da Virgem* (2520 P50), attributed to the Portuguese painter Vicente Gil, MNMC; *S. Jerónimo* (287 Pint), of unknown attribution, MNAA; *Apresentação da Virgem no Templo* (ME 1504), attributed to the workshop of Gerard David, ME, respectively. However, there is no evident graphical similarity between the different growth patterns (Figure 63), and it can then be presumed that these four boards come from the same region and the same wood dealer in Portugal has supplied different workshops with the same wood lot. This assumption is in line with one of the rules mentioned in the manuscript *Livro dos Regimentos* on joiner's regulations (CORREIA, 1926): "*36. – (…) nenhũa pessoa de qualquer condição que seia atrauessaraa mdr.ª que de fora do rejno vier nem madeira do rjeino que ao dito officio pertença sem primr.º o fazer saber aos juízes do dito officio se querem algũa parte para repartirem pelos afficiaes pelo preço que lhe custar* (…)"[72].

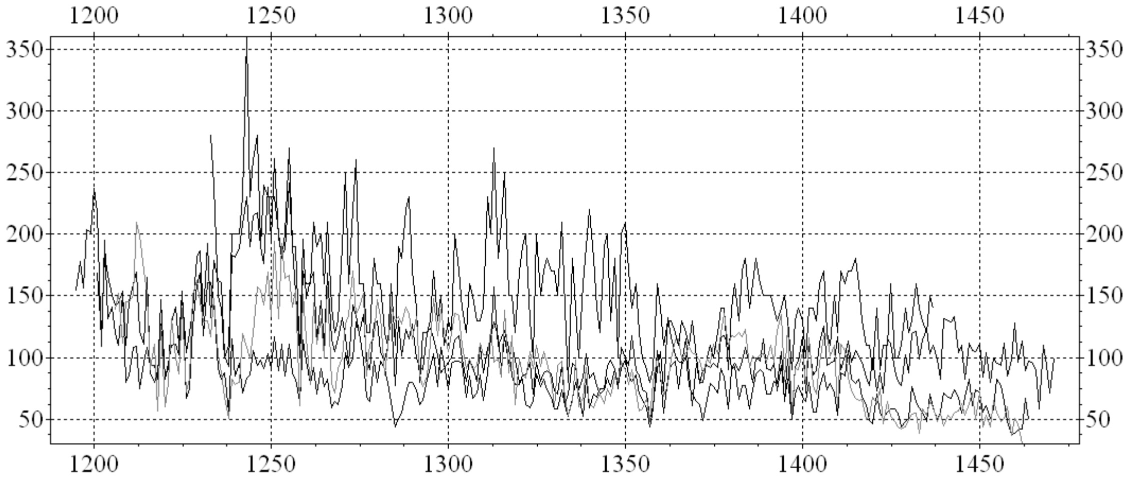


Figure 68. Visual synchronisation between PCEF2802020121-122 dendrochronological sequence (grey line), belong to the *S. Francisco de Évora* altarpiece, and the individual sequences PCEF1603010018-20, P0202010195 and P1604020131 (black lines). X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64].

[72] Author's free translation: *"36. – Item no one, regardless of condition, will hoard wood from outside the kingdom or wood from within the kingdom that belongs to the referred craft without first letting the judges of the referred craft know if they want some of it to be distributed among the officials at the price it costs (…)".*

2.1.2.2.3. Dating of the altarpiece

The dates of the last measured ring (also defined as *dendrochronological date*) from the 21 sequences range from 1406 (PCEF2802020133) and 1489 (PCEF2802020117-120) (Figure 69). This means that the most recent tree ring found in the altarpiece corresponds to the year 1489, collected from the mean series of two boards (PCEF2802020117-120) placed in separate panels – *Encontro de Abraão e Melquisedeque* (93 Pint) and *Última Ceia* (94 Pint).

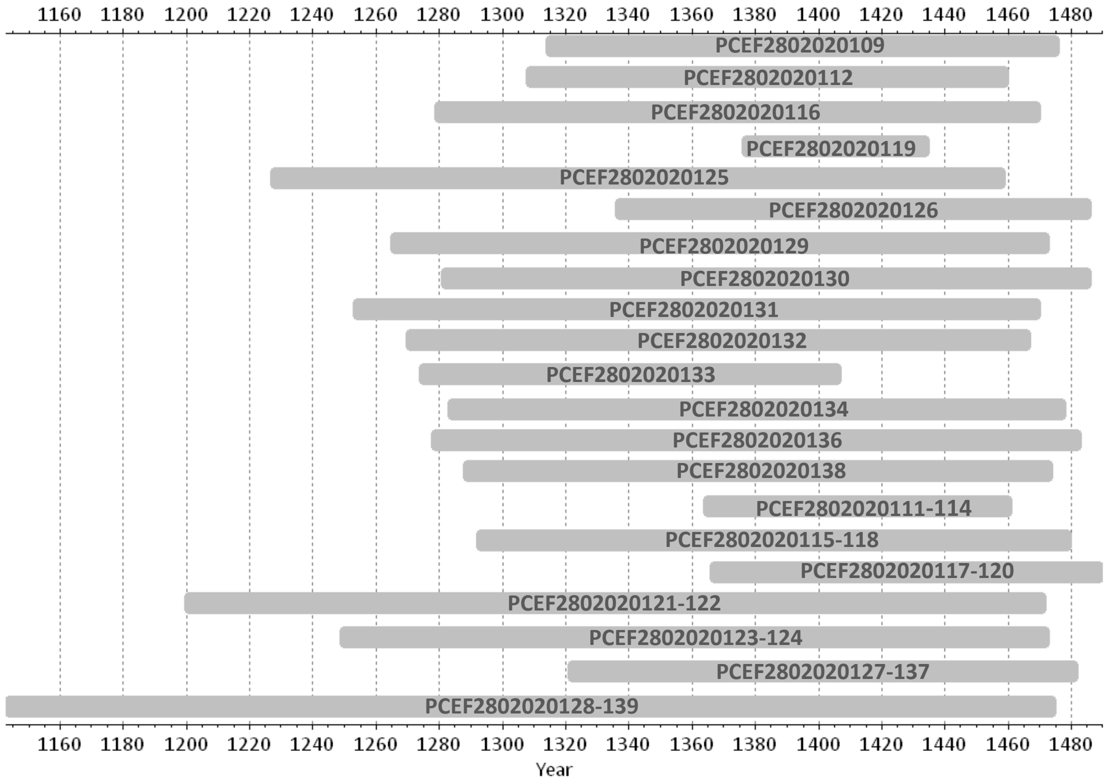


Figure 69. Chronological position of all dated dendrochronological sequences/combination of sequences obtained in the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection) [Graph by TSAP Win Scientific 4.64].

The sapwood was fully removed during the production of the altarpiece. While this technique decreased the final measurements of the boards, it increased the protection from the possible biological degradation. In this case, and as described above, it is only possible to set the *terminus post quem* for the tree felling date. A certain number of sapwood rings need to be added to the heartwood/sapwood border. Considering that this parameter depends, among other things, on the age of the tree, the approximate value to be considered for each board is variable. The *terminus post quem* for the earliest possible tree felling identified in the altarpiece is 1500, considering nine rings as sapwood estimate for boards with less than 200 years and 15 rings for the older ones from the eastern Baltic region (KLEIN, 1998a; BAUCH, 2002) (Table 25). Considering two years for the stabilisation and transport of wood and the preparing of boards, the construction of an altarpiece seems possible from about **1502 onwards**[73] (i.e., *terminus post quem* for the support manufacture). The present dendrochronological analysis is consistent with the allocation of historical dates 1508-1511.

Table 25. Dendrochronological dates of the 21 sequences/combination of sequences obtained in the *S. Francisco de Évora* altarpiece attributed to Francisco Henriques (MNAA collection) [Laboratory filename – internal identification of each board; total rings – number of growth rings measured; sapwood rings (estimated number) – number of sapwood rings according to the tree's age (boards with less than 200 years – add 9 rings; boards with more than 200 years – add 15 rings); *terminus post quem* earliest possible tree felling – last preserved ring plus sapwood rings (estimated number); *terminus post quem* for the support manufacture – *terminus post quem* earliest possible tree felling plus 2 years of seasoning].

SEQUENCE / COMBINATION OF SEQUENCES	TOTAL RINGS	FIRST PRESERVED RING	LAST PRESERVED RING	SAPWOOD RINGS (ESTIMATED NUMBER)	***terminus post quem*** **EARLIEST POSSIBLE TREE FELLING**	***terminus post quem*** **FOR THE SUPPORT MANUFACTURE**
PCEF2802020109	161	1315	1475	+9	1484	**1502 forward**
PCEF2802020112	151	1309	1459	+9	1468	
PCEF2802020116	190	1280	1469	+9	1478	
PCEF2802020119	59	1377	1434	+9	1443	
PCEF2802020125	231	1228	1458	+15	1473	
PCEF2802020126	149	1337	1485	+9	1494	
PCEF2802020129	207	1266	1472	+15	1487	
PCEF2802020130	204	1282	1485	+15	**1500**	
PCEF2802020131	216	1254	1469	+15	1484	
PCEF2802020132	193	1271	1466	+9	1475	
PCEF2802020133	132	1275	1406	+9	1415	
PCEF2802020134	194	1284	1477	+9	1486	
PCEF2802020136	204	1279	1482	+15	1497	
PCEF2802020138	185	1289	1473	+9	1482	
PCEF2802020111-114	96	1365	1460	+9	1469	
PCEF2802020115-118	187	1293	1479	+9	1488	
PCEF2802020117-120	123	1367	1489	+9	1498	
PCEF2802020121-122	271	1201	1471	+15	1486	
PCEF2802020123-124	223	1250	1472	+15	1487	
PCEF2802020127-137	160	1322	1481	+9	1490	
PCEF2802020128-139	331	1144	1474	+15	1489	

[73] Note: the dendrochronological dating is based on the paintings that are currently in the Museu Nacional de Arte Antiga, in Lisbon. The remaining four paintings belonging to the same altarpiece that are presently in the Casa-Museu dos Patudos, in Alpiarça, were not included in this study.

2.1.3. Development of a new local chronology

The two datasets obtained in the dendrochronological study of the *Vida de S. Tiago* and the *S. Francisco de Évora* altarpieces allowed the development of two local chronologies (PORTMNAAVST and PORTMNAASFE, respectively). Since several dendrochronological sequences belong to the same tree in each dataset (Tables 21 and 25), the development of each chronology is based on the individual dated dendrochronological sequences, corresponding to each dated board. It means that each chronology's development begins with 21 and 28 sequences, respectively (Table 26).

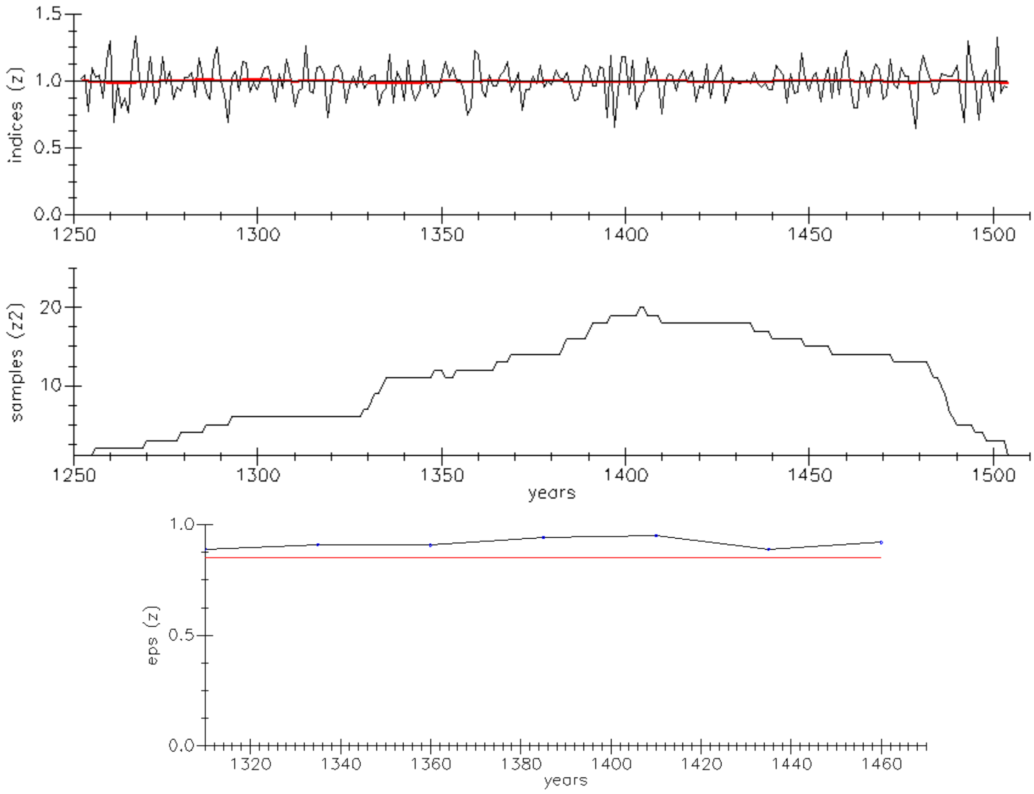
The 21 index growth series from the *Vida de S. Tiago* altarpiece initially included in the analysis are schematised in ANNEX 6-Tabel 1. They present a good crossmatch between them. The chronology PORTMNAAVST (1252-1504) is of good quality, considering $\bar{r}$=0.63 and only 2% of lower correlated segments (Figure 70A; Table 26).

The 28 index growth series from the *S. Francisco de Évora* altarpiece included initially in the analysis are schematised in ANNEX 6-Tabel 2, but they present a poorly crossmatch between each other. The chronology PORTMNAASFE (1144-1489) presents a questionable quality since 13% of the total segments present a low correlation beside $\bar{r}$=0.53 (Table 26). Four sequences were excluded to obtain the final chronology, resulting in 24 sequences of 17 trees covering the period between 1201 and 1489 (Figure 71A; Table 26).

Table 26. PORTMNAAVST, PORTMNAASFE and PORTMNAAVSTSFE chronologies statistics [$\bar{r}$ – average correlation between each growth index and the mean chronology resulting from all sequences excluding the comparative growth index; r_i^k– correlation between gi and the mean chronology resulting from all sequences excluding g_i in 50-years intervals; c_{eff} – Effective number of sequences/tree; $\bar{r}_{bt}$ – between-tree signal; $\bar{r}_{wt}$ – within-tree signal; $\bar{r}_{eff}$ – effective chronology signal; EPS – Expressed Population Signal; SE – Standard Error; * EPS values calculated in 50 years segments, using lags of 25 years].

	PORTMNAAVST	**PORTMNAASFE**		**PORTMNAAVSTSFE**
		INITIAL	**FINAL**	
Number of tree (t)	10	21	17	27
Number of sequences	21	32	24	45
Number of rings	2740	5126	4021	6761
Length (years)	253	346	289	304
First year	1252	1144	1201	1201
Last year	1504	1489	1489	1504
$\bar{r}$	0.63	0.53	0.57	0.59
$r_i^k \leq 0.32$	2%	13%	6%	3%
c_{eff}	1.69	-	1.20	1.34
$\bar{r}_{bt}$	0.51	-	0.37	0.41
$\bar{r}_{wt}$	0.91	-	0.89	0.90
$\bar{r}_{eff}$	0.53	-	0.38	0.42
EPS [min-max*]	0.91 [0.89-0.95]	-	0.92 [0.80-0.94]	0.95 [0.85-0.97]
SE [min-max*]	0.22 [0.02-0.15]	-	0.19 [0.01-0.18]	0.14 [0.01-018]

Figures 70C and 71C show the EPS values for both chronologies analysed in short intervals, revealing that most values are higher than the 0.85 criteria of WIGLEY *et al*. (1984). The only exception is the period 1260-1285 in the PORTMNAASFE chronology, which consists of five series, with an EPS of 0.80 and a SE value greater than the 0.15 recommended threshold (Table 26). Increasing the number of series in this chronology for this period could strengthen EPS while lowering the SE by 0.15 or less. However, theoretically, it would be valid to state that the two chronologies represent the hypothetical perfect chronologies.



[A]

[B]

[C]

Figure 70. [A] PORTMNAAVST chronology related to the *Vida de S. Tiago* altarpiece of unknown assignment (MNAA collection); **[B]** Sample depth; and **[C]** EPS values (50-years intervals, lag=25) [Graph by ARSTAN (version 49v1b_MRWE)].

[A]

[B]

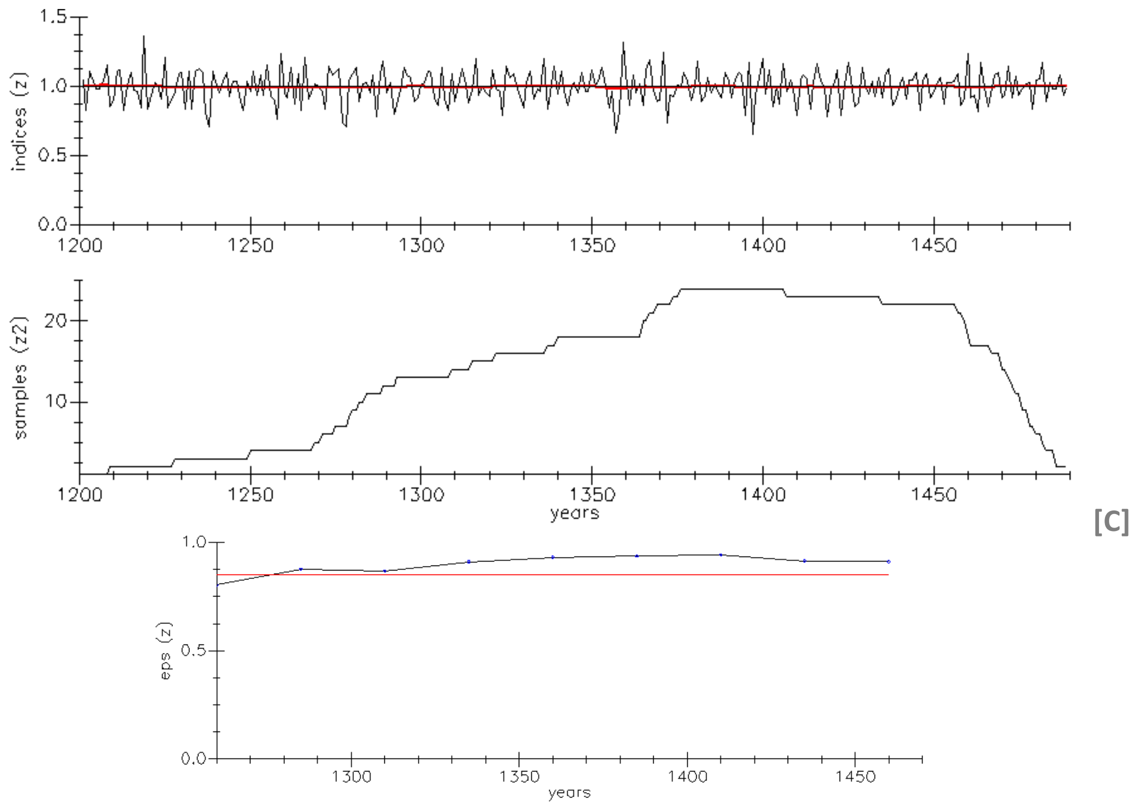


Figure 71. [A] PORTMNAASFE chronology related to the *S. Francisco de Évora* altarpiece, attributed to Francisco Henriques (MNAA collection); **[B]** Sample depth; and **[C]** EPS values (50-years intervals, lag=25) [Graph by ARSTAN (version 49v1b_MRWE)].

The crossmatch between PORTMNAAVST and PORTMNAASFE chronologies revealed a perfect visual synchronisation (Figure 72) and high statistical correspondence – t_{BP}=11.6, Glk=67%, an overlap of 238 years and a *P*-value greater than 0.999.

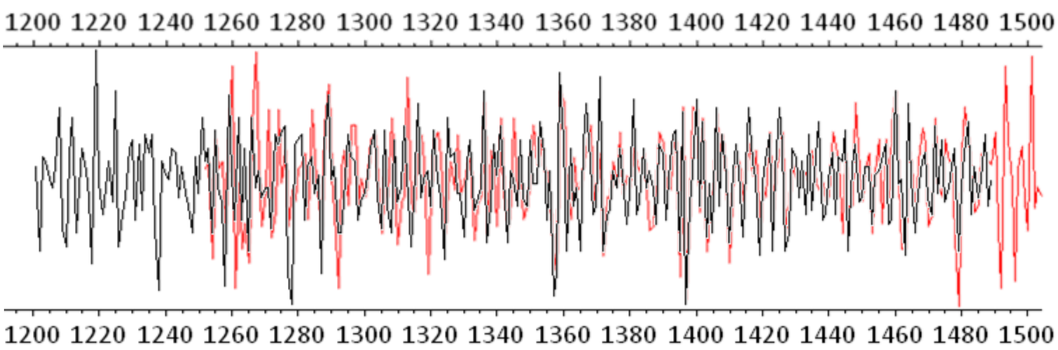


Figure 72. Visual comparation between PORTMNAAVST chronology (red line) and PORTMNAASFE chronology (black line) [Graph by TSAP Win Scientific 4.64].

The combination of the two chronologies, resulting in PORTMNAAVSTSFE (Figure 73A), yields the highest EPS (0.95) and the lowest SE (0.14) values (Table 26), as well as EPS values always greater than 0.85 when analysed in short intervals (Figure 73C). It means that the ring-width variations in PORTMNAAVSTSFE are less marked by exogenous and endogenous factors than in PORTMNAAVST and PORTMNAASFE. No statistical objection exists against averaging the PORTMNAAVST and PORTMNAASFE chronologies into a new one (PORTMNAAVSTSFE), which it will be useful for the future purposes of dating.

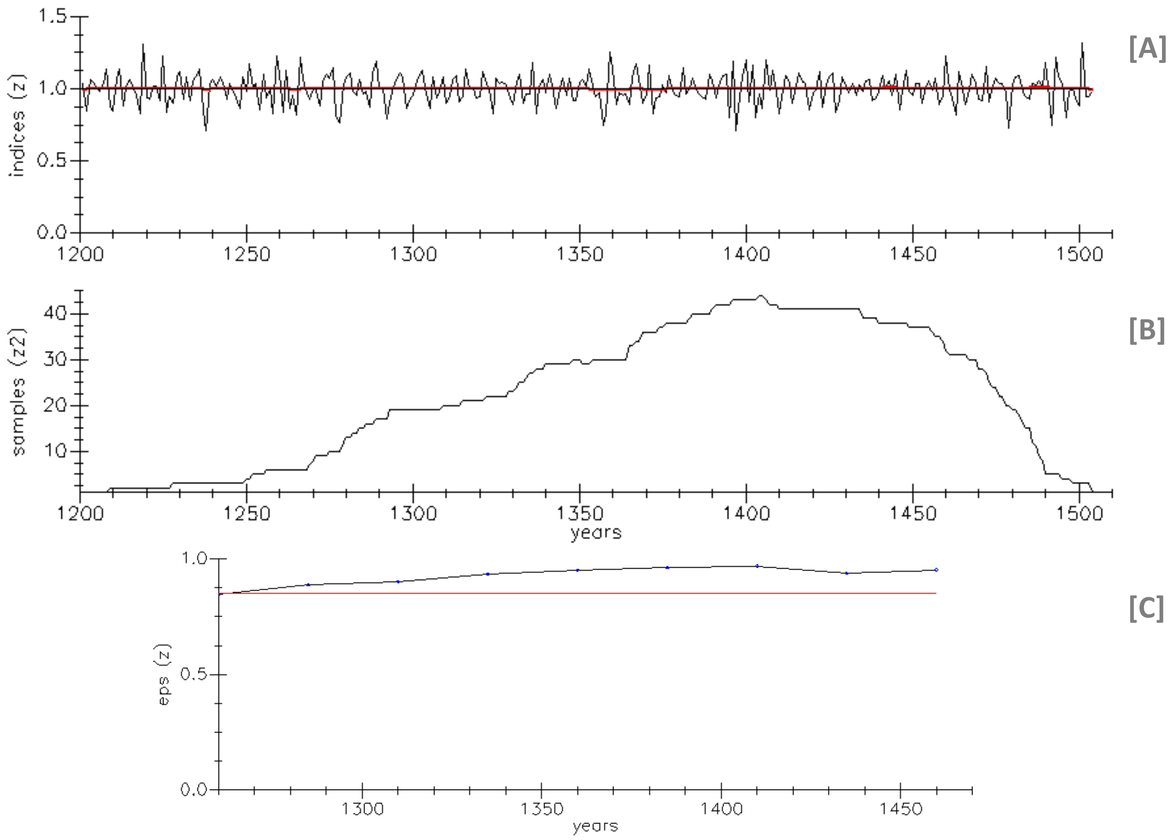


Figure 73. [A] PORTMNAAVSTSFE average chronology; **[B]** Sample depth; and **[C]** EPS values (50-years intervals, lag=25) (1201-1504) [Graph by ARSTAN (version 49v1b_MRWE)].

2.1.4. Dendroprovenance

The three chronologies based on historical objects (PORTMNAAVST, PORTMNAASFE and PORTMNAAVSTSFE) that were established in the previous subchapter were compared with independent chronologies listed in Table 14. The goal was to determine the wood source area used to make the two Portuguese altarpieces. The cross-date provided strikingly close and better statistical results and visual matching in all three cases (Table 27). For these purposes, the emphasis is given below on the average chronology. The PORTMNAAVSTSFE chronology was remarkably well correlated with many Baltic chronologies (BALTIC 1, NL BALTIC Import, NL BALTIC A, NL BALTIC B and BOWHILL-B), with t_{BP} range values from 5.6 to 24.0. The Netherlands-based chronology NL Baltic A and the UK-based chronology BALTIC1 given the most definitive matches with t_{BP} values of 20.1 and 24.0 (Table 27). The PORTMNAAVSTSFE chronology distinguishes the "pointer years" characteristic of the BALTIC1 master-chronology (narrow rings in 1357 and 1358, and narrow-wide-narrow in 1395-1397) (Figure 74). These results are naturally in line with the output for the individual dating of the dendrochronological sequences presented in subchapters 2.1.1.3.2. and 2.1.2.2.2..

Table 27. Best statistical matches between PORTMNAAVST, PORTMNAASFE and PORTMNAAVSTSFE chronologies and independent chronologies mentioned in Table 10 [LT – Lithuania; PL – Poland].

GROUP/ REGION	PORTMNAAVST				PORTMNAASFE				PORTMNAAVSTSFE			
	OVL	Glk	t_{BP}	P ≥ than	OVL	Glk	t_{BP}	P ≥ than	OVL	Glk	t_{BP}	P ≥ than
Imported wood												
BALTIC1	249	75	15.2	0.999	289	83	24.1	0.999	304	83	24.0	0.999
NL BALTIC IMPORT	249	72	12.0	0.999	289	76	15.5	0.999	304	76	15.2	0.999
BOWHILL-B	228	66	10.3	0.999	283	77	13.4	0.999	283	74	13.3	0.999
GRIMSBY1	150	62	5.7	0.998	205	68	6.0	0.999	205	69	6.6	0.999
NL Baltic A	249	75	12.5	0.999	289	80	23.3	0.999	304	81	20.1	0.999
NL Baltic B	249	72	11.2	0.999	289	76	11.2	0.999	304	78	11.6	0.999
0520003M	249	73	12.1	0.999	289	77	18.0	0.999	304	80	17.3	0.999
0520004M	142	67	5.7	0.970	127	71	6.4	0.999	142	71	5.6	0.999
0520006M	236	73	11.6	0.999	289	75	16,2	0.999	291	75	16.7	0.999
Known source												
LT - MEMEL	217	65	7.7	0.999	202	62	7.0	0.999	217	67	8.4	0.999
LT - VILQURO1	153	61	5.1	0.997	201	64	5.7	0.999	201	64	5.9	0.999
PL - Pola006	249	56	5.1	0.970	289	63	6.2	0.999	304	61	6.9	0.999
PL - 0670108M	249	58	5.8	0.994	289	62	6.5	0.999	304	61	7.5	0.999

The Baltic chronologies in Table 14 were built with index series from a wide area, but their correspondence with the PORTMNAAVSTSFE chronology does not provide reliable details regarding the geographical source of the timbers used in the *Vida de S. Tiago* and the *S. Francisco de Évora* altarpieces. Cross dating the PORTMNAAVSTSFE chronology with four site chronologies compiled with wood samples from historical buildings in Lithuania and Poland yielded strong statistical results (MEMEL, VILQURO1, Pola006 and 0670108M) – t_{BP} between 5.9 and 8.4; Glk between 61% and 67%; *P*-value equal or greater than 0.999 (Table 27). To suggest a more restricted source of the timbers used in both altarpieces, accurate and rigorous replication of dates with the independent site and local chronologies from these territories would be needed. There are drawbacks to the current experiments in dendroprovenance related to artwork studies. Oak had become very valuable but too costly for local consumers in the Middle Ages (WAZNY, 2010). In Lithuania, for example, one of the main challenges in creating new chronologies for this region is the lack of historic oak woods

(VITAS and ZUNDE, 2007). The use of wood samples from historic buildings in the sense of recent chronological developments does not ensure that they derive from local sources, as is the case with the Polish Pola006 chronology. According to ECKSTEIN and WROBEL (2007), there is no certainty that it is solely made from northern Poland, even indicating that the present Ukraine is a potential source of timber. Dendrochronological research, on the other hand, will back up historical arguments regarding the use of local forests in historic buildings. The MEMEL chronology is the case, with samples obtained from historical buildings in Lithuania (BRAZAUSKAS, 2005). According to the author, the timber used in the MEMEL chronology construction was of local origin since residents of the city were authorised to cut wood for construction and shipbuilding but not for sale.

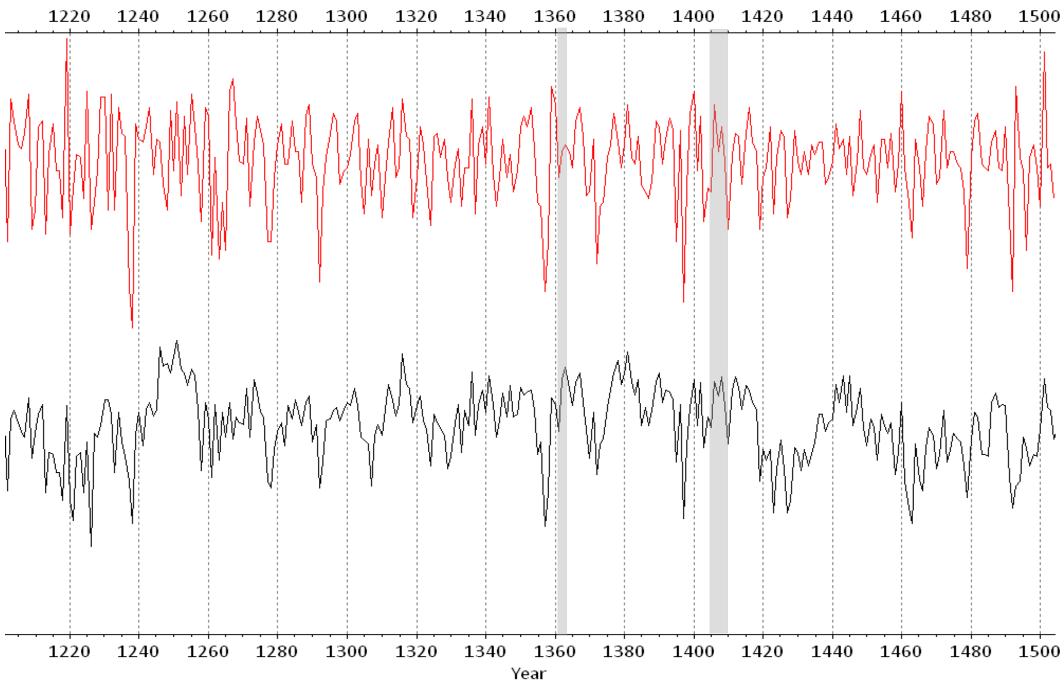


Figure 74. Synchronization (in common overlap) between the PORTMNAAVSTSFE average chronology (1201-1504) (red line) and BALTIC1 master-chronology (black line). Gray areas correspond to the pointer years typical from BALTIC1 [Graph by TSAP Win Scientific 4.64].

Even if it was not feasible to suggest the wood origins in greater detail, the dendrochronological findings provided in this study are an outstanding example of long-distance timber transport. The results also corroborate the historical research on wood trade between Portugal and Europe discussed in this study (see subchapter 1.1. *The wood trade between Portugal and Europe_XV and XVI centuries*). The imported timber was specifically meant for shipbuilding, according to MARQUES (1959) and GOMES (2016), as shown by the historical record given in Figure 2 on the transport of ship's wood from Poland to Lisbon. The present research complements historical documents and unmistakably shows the use of wood in works of art, illustrating the historical record given in Figure 3 on the shipment of oak planks from many Hanseatic cities of the League to Lisbon. WAZNY (2010) noted the frequent trade in timber between Baltic and Atlantic Europe since imports of non-native timber during the XV and XVI centuries were well documented in several dendrochronological studies. However, the author recognized that dendroprovenance discoveries in the Mediterranean region are at an early stage compared to the northern half of Europe.

2.2. Dendrochronological research of Flemish panels (ARTICLE)

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The art trade between Flanders and Madeira Island in the 15th and 16th centuries – The contribution of dendrochronology to the history of Portuguese heritage

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ABSTRACT

Flemish paintings from the 15th and 16th centuries, now preserved in public and private collections on Madeira Island, provide unequivocal witness to the trade link that existed between Flanders and this Portuguese territory. This article focuses on a dendrochronological approach to date fifteen paintings from thirteen artworks ascribed to several Flemish artists working in the 15th and 16th century and currently exhibited in the Museum of Sacred Art of Funchal (Madeira Island). The dendrochronological results consolidate the historical and iconographic dates reported in the museum catalogue for fourteen paintings, also allowing a more precise dating of one of the studied artworks assigned to Joos van Cleeve's workshop. Furthermore, new knowledge has been added to the panel attributed to Marinus van Reymerswaelle, indicating that it was painted after the historical dating, in the painter's late years. This study has resulted in the construction of a new historical oak chronology for the Baltic region, covering the period 1157–1599 and based on chronological series acquired from several research studies of Portuguese and Flemish paintings carried out over the previous decades. The new chronology can be considered as a valuable new tool for future research into Portuguese and Flemish paintings, sculptures, and furniture from Portuguese cultural heritage collections.

1. Introduction

Madeira Island has a remarkable collection of paintings from the 15th and 16th centuries, either sourced from Portuguese workshops working in the Flemish and Italian styles or acquired directly from Flanders. In the golden age of the sugar trade, during the transition from the 15th to the 16th century, Madeira and Flanders developed a close relationship that allowed the purchase of the best artwork to the island.

Flemish artwork is very rarely signed (Carita, 2006). Until now, no historical documentation was found to identify which artists or workshops were commissioned to produce the remarkable collection of paintings at Madeira Island. However, for some of these panels, stylistic comparisons with documented or assigned works have suggested workshops of the following renowned artists who were active during the 15th and 16th centuries: Gerard David, Joos Van Cleve, Jan Provoost, Pieter Coecke van Aelst, Jan Gossarte, and Marinus Van Reymerswaele. Connections to the anonymous masters known as the Master of the Holy Blood, the Master of the Morrison Triptych, and the Master of the *Adoração do Machico* were also suggested (Baptista Pereira and Clode, 1997).

The exact dating of these artworks is an essential and substantial tool for their artistic attribution, and dendrochronology is well suited for the dating of wooden supports of paintings. Dating of artworks through dendrochronology began in Europe in the 1960′s, was developed further (Fletcher, 1976; Bauch and Eckstein, 1981; Klein, 1981, Klein, 1994a, Klein, 1994b, Klein, 1998), and has seen an increased use in recent decades (Bernabei et al., 2007; Fraiture, 2002, Fraiture, 2009, Fraiture, 2011; Jansma et al., 2004; Klein, 2008; Kuniholm, 2000; Läänelaid and Nurkse, 2006; Rodríguez-Trobajo and Domínguez-Delmás, 2015).

Dendrochronology was also applied to artwork in Portugal in this context (Klein and Esteves, 1999; Leefang and Klein, 2006; Antunes et al., 2016; Cruz et al., 2020). The ***Painéis de São Vicente de Fora*** polyptych (or the 'Saint Vincent Panels') is an excellent example of the contribution of dendrochronology to multidisciplinary research carried

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Fig. 1. The analyzed Flemish panels belonging to the Museum of Sacred Art of Funchal (Madeira Island) **[A]** *Anunciação*. Central panel of the Triptych Bom Jesus (inventory number MASF35), assigned to Joos van Cleeve & collaborators **[B]** *S. Pedro*. Central panel of the Triptych Encarnação (inventory number MASF27), assigned to Joos van Cleeve & collaborators **[C]** *Anunciação e o Mistério da Encarnação*. Central panel of the Triptych São Pedro, São Paulo e Santo André (inventory number MASF32), assigned to Joos van Cleeve & collaborators **[D]** *Santiago Menor e S. Filipe*. Central panel of the Triptych Santiago Menor e São Filipe (inventory number MASF40) assigned to Pieter Coecke van Aelst & collaborators **[E]** *Calvário* (inventory number MASF55), assigned to Pieter Coecke van Aelst & collaborators **[F]** *Nossa Senhora do Amparo* (inventory number MASF39), assigned to workshop of Jan Gossart (Mabuse). For details see Supplementary Figs. 1 to 6 (photos credits: Museum of Sacred Art of Funchal archive).

out over the years. The six paintings of this polyptych, currently in the collection of the National Museum of Ancient Art (Lisbon), are attributed to Nuno Gonçalves (1420–1490), the royal painter of King Afonso V. All these paintings were examined earlier, focusing on their age, attribution, as well as the iconographic and iconological identifications of the figures (de Almeida and de Albuquerque, 2000; Baptista Pereira, 2010). The dendrochronological dating conducted by Peter Klein identified a specific time limit, thereby confirming the relationship of this polyptych to other panels from the same workshop (Baptista Pereira, 2010).

The present work aims to date the wooden support structures of fifteen paintings from thirteen artworks attributed to several Flemish painters from the 15th and 16th centuries, curated at the Museum of Sacred Art of Funchal (Madeira Island).

2. Socio-cultural and commercial relations between Flanders and Madeira Island during the 15th and 16th centuries

The commercial and cultural relations between the Kingdom of Portugal and the Duchy of Burgundy, part of the rich territory of Flanders, developed considerably through the marriage between Infanta D. Isabel, daughter of King João I, and Philip III 'The Good' of Burgundy, at the beginning of the second quarter of 15th century (Baptista Pereira and Sousa, 2017). Before his third marriage, in 1421, Philip III decided to renew the privileges granted to the Portuguese by his father, John I, 'The Fearless,' and his first wife, Micaela de Valois, by giving safe conduct to Portuguese merchants and sailors (Paviot, 1992). In 1429, Infanta D. Isabel left for Burgundy. At that time, Portugal was in full expansion with the addition of new territories, namely of Madeira and Azores Islands, Ceuta, and the first leagues of the African coast.

The settlement of Madeira Island introduced wheat and grapevine crops and, at a later stage, sugar cane imported from the Island of Sicily (MNAA, 1992). Across Europe, there had been a large-scale increase in the consumption of this 'white gold', changing eating habits and even some medicinal practices (Baptista Pereira and Sousa, 2017). In order to control the European trade of goods from the Kingdom and its overseas colonies, a Portuguese trading post (*feitoria*) was established in Flanders (initially in Bruges and then in Antwerp) to centralize the supply of goods. Preference was given to goods for which speculation and risk were associated with high-potential profits: sugar, spices and dyes (Pohl, 1991). From Portugal to Flanders, ships carried mainly salt for the salting of herring, as well as sugar, fruit, wine and cork (MNAA, 1992). The importance of Madeira's sugar trade in Antwerp was so vital that local names were still evident at the beginning of the 20th century, as evidenced by the 'Canal du Sucre' (Baptista Pereira and Clode, 1997; Carita, 2006).

The Crown was responsible for the maintenance of religious worship on Madeira Island and, as a result, many sacred artifacts – namely paintings, sculptures and gold objects – originated in export-oriented artistic centers in Flanders (Couto, 1955; MNAA, 1992; Carita, 2015;

Fig. 2. The analyzed Flemish panels belonging to the Museum of Sacred Art of Funchal (Madeira Island) **[A]** *Sta. Maria Madalena* (inventory number MASF29), assigned to Jan Provoost **[B]** *Descida da Cruz*. Central panel of the Triptych Descida da Cruz (inventory number MASF20), assigned to Gérard David & collaborators **[C]** *Natividade*. Central panel of the Triptych from Capela dos Reis Magos (Inventory number MASF30), assigned to Master of the Morrison Triptych **[D]** *Descida da Cruz* [Central panel of the Triptych from Ribeira Brava] *Nicodemos* [Left wing] *Maria Madalena* [Right wing] (inventory number MASF43), assigned to Workshop of Master of the Holy Blood **[E]** *Encontro de S. Joaquim e Sta Ana junto da porta dourada* (inventory number MASF26), assigned to Master of Adoração do Machico **[F]** *São Nicolau* (inventory number MASF25), assigned to Master of Adoração do Machico **[G]** *São Jerónimo* (inventory number MASF107), assigned to Marinus van Reymerswaelle. For details see Supplementary Figs. 7–13 (photos credits: Museum of Sacred Art of Funchal archive).

Baptista Pereira and Sousa, 2017). The same scenario occurred with major private chapels on the island, when "*the Crown also made it and thus worthy of being followed*" was popular belief (Carita, 2015). The overseer, the King's trusted man, played an active role as an economic agent. There were also diplomats who, at the request of the monarch, court, clergy and private landlords, were intermediaries in the acquisition of paintings, jewels, precious textiles, furs and furniture (Pohl, 1991; MNAA, 1992; Baptista Pereira and Clode, 1997).

In the second half of the 15th century and in the 16th century paintings could be acquired in Flanders at art markets organized by producers and consumers, with or without the presence of dealers, where high-quality paintings were almost exclusively aimed at local and foreign elites and institutions. At the same time, open markets for paintings of lower quality also attracted more socially diverse customers (Vermeylen, 2001).

This art-market system, which targets on mass production, focused primarily on export and price competition. Techniques such as the standardization of models and patterns were adopted by artists to save time and money (Vermeylen, 2001; Deceulaer and Diels, 2007). These new strategies allowed the production of paintings, triptychs, and altarpieces to be produced at competitive prices, ensuring the survival of the workshops. To this end, the workshops needed to be well organized and gave work to a large number of workers, namely apprentices, assistants, journeymen, and masters (Vermeylen, 2001; Deceulaer and Diels, 2007; Leeflang, 2015). The Flemish guilds normally provided for relatively short apprenticeships – two to three years – although this period could be longer, which was usually negatively correlated with the value of the 'learning payment' to the master. Apprentices could be rich or poor, living with the master or in their own home, and working in a long-term or short-term relationship. The journeymen could apply for master's status or choose to work on a lifetime salary. They could have a loose relationship with a larger group of masters, working based on labour needs or, in some cases, working independently by selling their own paintings. Therefore, maintaining a skilled workforce was a problem, and there are examples of masters who recognized the importance of their experienced collaborators, offering financial rewards to keep them in their workshops (Deceulaer and Diels, 2007). The production of many excellent works of art over the decades in the Low Countries, which supplied the national and international markets, shows that lower-ranking artists and craftsmen also were held in high regard and were considered an important asset in the workshops.

3. Material

Fifteen paintings from thirteen artworks belonging to the Museum of Sacred Art of Funchal (Madeira Island) and attributed to several Flemish painters from the 15th and 16th centuries were analysed (Figs. 1 and 2; Table 1). Except for the Triptych *Ribeira Brava* (MASF43), assigned to

Table 1
General description and wood supports characterization of the 13 artworks, in a total of 15 paintings analyzed, attributed to several Flemish painters from the 15th and 16th centuries and belonging to the Museum of Sacred Art of Funchal (Madeira Island) (h = height; w = width; t = thickness, in cm; 1 central panel; 2 left wing; 3 right wing; Type of cut: A = full radial or full quarter; B = radial (or quarter); C = semi-radial (or false quarter); D = tangential (Fraiture, 2011); **(a)** Plank not analyzed; n.a. = not applicable).

ARTWORK [INVENTORY NUMBER]	ATTRIBUTION	HISTORICAL DATE	PAINTING ANALYZED		NUMBER OF BOARDS	WIDTH (cm)	TYPE OF CUT	ORIENTATION OF THE EXTREME SIDE BOARDS	
			NAME	DIMENSIONS, cm (h × w × t)				←	→
Triptych *Bom Jesus* [MASF35]	Joos Van Cleeve & collaborators	1500–1510	Anunciação[1]	194 × 204 × 2.2	9	15.5 / 28.2 / 17.5 / 23.4 / 22.3 / 18.0 / 26.8 / 25.0 / 27.2	B / A / B / B / C / B / A / B / B	Pith	Bark
Triptych *São Pedro, São Paulo e Santo André* [MASF27]		1520	S. Pedro[1]	178 × 116 × 2.5	4	27.5 / 27.8 / 31.5 / 29.5	A / B / B / A	Pith	Pith
Triptych *Encarnação* [MASF32]		1510–1515	Anunciação e o Mistério da Encarnação[1]	282 × 153 × 1.5	6	26.4 / 27.8 / 27.2 / 27.3 / 17.0 / 27.5	B / A / A / B / B / B	Pith	Pith
Triptych *Santiago Menor e São Filipe* [MASF40]	Pieter Coecke van Aelst & collaborators	1528–1531	Santiago Menor e S. Filipe[1]	164 × 115 × 1.5	5	16.1 / 23.3 / 23.4 / 27.5 / 25.0	B / B / A / A / A	Pith	Pith
Calvário [MASF55]		1533–1534	Calvário	251 × 140 × 2.2	6	20.0 / 26.5 / 23.6 / 23.5 / 26.7 / 19.9	B / B / B / B / A / B	Pith	Pith
Nossa Senhora do Amparo [MASF39]	Workshop of Jan Gossart (*Mabuse*)	*ANNO DO 1543*	Nossa Senhora do Amparo	244 × 221 × 2.0	9	30.3 / 21.4 / 21.6 / 21.2 / 28.3 / 20.8 / 23.0 / 23.0 / 31.4	(a) / B / B / A / B / B / A / B / B	(b)	Pith
Sta Maria Madalena [MASF29]	Jan Provoost	1524–1526	Sta. Maria Madalena	260 × 122 × 1.0	5	28.7 / 24.0 / 28.0 / 28.0 / 14.0	A / (a) / A / B / B	Pith	Pith
Triptych *Descida da Cruz* [MASF20]	Gérard David & collaborators	1518–1527	Descida da Cruz[1]	204 × 121 × 2.0	5	21.5 / 24.7 / 31.5 / 23.0 / 20.5	B / B / B / B / B	Pith	Pith
Triptych from *Capela dos Reis Magos* [MASF30]	Master of the Morrison Triptych	1510–1515	Natividade[1]	218 × 140 × 1.5	6	4.0 / 30.9 / 27.1 / 26.3 / 28.3 / 24.3	A / B / B / B / B / A	Pith	Pith
Triptych from *Ribeira Brava* [MASF43]	Workshop of Master of the Holy Blood	1515–1520	Descida da Cruz[1] & Nicodemos[2] & Maria Madalena[3]	97 × 79 × 1.0	3	30.0 / 20.5 / 28.2	B / A / B	Pith	Pith
				97 × 34 × 0.7	1	33.9	A	n.a.	
	3			97 × 34 × 0.7	1	33.5	B	n.a.	
Encontro de S. Joaquim e Sta. Ana junto da porta dourada [MASF26]	Master of *Adoração do Machico*	Final 15th century	Encontro de S. Joaquim e Sta. Ana junto da porta dourada	51 × 39 × 0.8	1	39	C	n.a.	
São Nicolau [MASF25]		Early 16th century	São Nicolau	127 × 91 × 0.7	4	28.0 / 28.5 / 7.7 / 28.0	B / (a) / (a) / B	Pith	Pith
São Jerónimo [MASF107]	Marinus van Reymerswaelle	1521–1540	São Jerónimo	27.5 × 34.5 × 0.7	1	34.5	B	n.a.	

the workshop of the Master of the Holy Blood, it was not possible to study the lateral panels of the remaining triptychs because the frames could not be removed.

The *Anunciação* painting (MASF35) has not retained its original dimensions (Baptista Pereira and Clode, 1997; IJF/DGPC, 2015). Except for the left side, the artwork has been cut on all sides (Baptista Pereira and Clode, 1997). According to these authors, the right side lacks the pilaster that would have framed the original composition together with the one on the left side (Supplementary Fig. 1). The missing part would also have allowed for a complete display of the prie-dieu and book. Due to the cutting of the painting's boards in height, the mitre and angels were decreased at the top, and the clothes of the two major figures were reduced at the bottom.

The *Natividade* painting (MASF30) does not have the original dimensions. In view of the renovation of the original location, the central panel was adapted with the rounding of the top and a slight trimming of both sides (Supplementary Fig. 9) (Baptista Pereira and Clode, 1997).

The wood support of the *São Jerónimo* (MASF107) painting has a chamfer on the lower edge and on the right side. However, it is absent on the left and upper side edges and may be indicative of cuts in these areas (IJF/DGPC, 2015). Two illegible inscriptions painted in black can be identified on the back (Supplementary Fig. 13B).

4. Methods

4.1. Wood preparation and tree-ring measurement

The transverse cross-section of each board generally allows the identification of the growth rings as it is usually not painted and hidden by the frame. The dendrochronological analysis was performed on high resolution images of the cross-sections of sixty-two boards which were smoothed with a blade to make the cell structure and ring boundaries visible. The selection of the upper or lower section of the painting for dating depended on the state of conservation of the wood and on the part of the board which contained more growth rings.

Macro-photographs of the cross-section of each board were taken

Table 2
Reference chronologies and tree-ring series of *Quercus* sp. used to date the Flemish paintings from the Museum of Sacred Art of Funchal (Madeira Island, Portugal) ((a) unpublished chronologies, kindly provided by Peter Klein, which were developed by Josef Bauch, Dieter Eckstein and Peter Klein of the Institute of Wood Science, University of Hamburg; [1] Paintings on Baltic wood made in Portugal).

	FIRST YEAR	LAST YEAR	REFERENCE
REFERENCE CHRONOLOGIES (IDENTIFICATION CODE)			
BALTIC 1	1156	1597	Hillam and Tyers (1995)
BALTIC 2	1257	1615	Hillam and Tyers (1995)
NL BALTIC IMPORT	1167	1637	Jansma et al. (2004)
NL Baltic A	1030	1602	Jansma (unpublished)
NL Baltic B	1167	1544	Jansma (unpublished)
0520001 M	1173	1619	(a)
0520002 M	1199	1635	(a)
0520003 M	1115	1643	Eckstein et al. (1975)
0520004 M	1363	1643	(a)
0520006 M	1146	1491	(a)
BOWHILL-B	1161	1483	Groves (2002)
PAINTINGS BELONG TO THE PORTUGUESE CULTURAL HERITAGE [NR. SERIES]			
Portuguese[1] [89]	1157	1593	Instituto José de Figueiredo (Direcção Geral do Património Cultural)
Flemish [47]	1041	1536	(unpublished)
Portuguese[1] [98]	1144	1599	Forest Research Centre, School of Agriculture, University of Lisbon
Flemish [52]	1186	1553	(unpublished)

with a CANNON EOS 1100D digital camera. The growth rings were measured using Analysis software (version 3.2, AnalySIS Soft Imaging System GmbH, Munster, Germany). It is the most sustainable method in art research since it allows independent re-analysis and re-evaluation of research results (Fraiture, 2011) and avoids re-handling for follow-up tree-ring studies.

4.2. *Statistical analysis*

4.2.1. *Calculation of dendrochronological dates*

For data conversion, software package TRiCYCLE was used (Brewer et al., 2011). The statistical analyses was carried out using software packages TSAP Win Scientific 4.64 (Rinn, 2008) and COFECHA (Holmes, 1983) and the dendrochronological dates were established according to three statistical parameters commonly used in dendrochronology: (1) t-value Baillie-Pilcher, t_{BP} (Baillie and Pilcher, 1973); (2) percentage of parallel variation, also termed *Gleichläufigkeit*, Glk (Eckstein and Bauch, 1969); and (3) significance level, based on the percentage of parallel variation, P (Jansma, 1995).

4.2.2. *Interpretation of dendrochronological data*

The criterion used to determine whether different boards belong to the same single tree was set at $t_{BP}>9$ (Baillie and Pilcher, 1973; Susperregi et al., 2017) and with a visual graph match. In this case, the tree-ring series were averaged.

For the dendrochronological dating to be acceptable, a t_{BP} value>5 is considered as preferable, with a significance level lower than 0.001, as well as an absolute replication with independent chronologies and tree-ring series.

The dating was carried out by comparison with a wide range of European oak chronologies, namely Baltic region (Germany, Poland, Estonia, Latvia, Lithuania, and Finland), and Scandinavia (Denmark, Norway, and Sweden). Oak reference chronologies were obtained from private databases, scientific publications, reports, and a set of tree-ring series of Portuguese and Flemish paintings from public and private collections (Table 1).

The dendrochronological date, defined as the 'possible creation date,' was derived from the identification of the board's youngest ring, with two additional parameters: (1) an estimated number of missing sapwood rings, which were purposefully removed from oak boards in Flemish workshops in the 15th and 16th centuries due to their vulnerability to biological degradation (Fraiture, 2002; Haneca et al., 2005; Bernabei et al., 2007); and (2) the time span between felling a tree in the forest and the use of its wood as a painting support in the main Flemish workshops.

4.2.3. *Building a new chronology*

The first oak chronology, termed PORTHER01, was compiled using the newly dated series together with tree-ring data gathered during previous decades of dendrochronological research of Baltic oak used in Portuguese and Flemish paintings belonging to Portugal's cultural heritage (Table 2).

The statistical analyses were performed with COFECHA (Holmes, 1983) and ARSTAN (Cook et al., 1990) software. To remove age trend, the tree-ring series were detrended and transformed into growth indices using a 128-yr spline with 50% variance cut-off (Cook et al., 1990).

To compile the average tree-ring chronology, the degree of similarity between the underlying growth indices was estimated according to the value of the correlation coefficient (r_i) obtained between each growth index (g_i) and the average chronology of all other series in the data group except g_i. If the mean correlation value ($\bar{r}$, i.e., the average of all r_i) was lower than 0.50, specific growth indices were rejected to allow the increase of $\bar{r}$ using the following procedure:

[1] calculate the correlation coefficient (r) between g_i and the average chronology resulting from all growth indices excluding g_i in 50-years comparison intervals shifting in 25 years intervals (r_i^k, with k ranging from 1 to the number of 50-years intervals contained in g_i);

[2] since $r_i^k \leq 0.32$ are not statistically significant, reject the growth index with more than two intervals with $r_i^k \leq 0.32$ (Jansma, 1995).

The strength of the common signal of the resulting chronology was estimated using the Expressed Population Signal (EPS) defined by Wigley et al. (1984) and later readapted by Briffa and Jones (1990). Wigley et al. (1984) suggest an EPS threshold equal to or higher than 0.85.

5. Results and discussion

5.1. *Technical data recorded on oak boards*

All paintings were painted on oak boards (*Quercus* sp.). The catalogue of the museum refers to til (*Ocotea foetens* (William Aiton) Baill.) as the wood support of *Encontro de S. Joaquim e Sta Ana junto da porta dourada* painting (MASF26) (Baptista Pereira and Clode, 1997), a species endemic to Macaronesia (Madeira and Canary Islands). However, in this case the species used is also oak. All paintings present the boards arranged vertically, except the *São Jerónimo* painting attributed to Marinus van Reymerswaelle (MASF107).

The boards width in each of the Flemish paintings is variable, with about 72% of the analysed boards being between 20 cm and 30 cm wide. These measures are in accordance with observations of other panels of the same wood and epoch, which indicate a width varying between 25 and 29 cm (Wadum, 1998). The average thickness per panel is less variable in all the 13 paintings, ranging between 7 and 22 mm. These results are consistent with the 8 to 30 cm range observed in paintings from the 15th and 16th centuries as reported by Wadum (1998) (Table 1).

The orientation of the boards reveals that great care was taken during the wood preparation. A radial cut provides the best quality boards, because the risks of wood shrinkage, warping and distortion due

Table 3
Number of oak sapwood rings from the Baltic area (min = absolute minimum; max = maximum absolute; n.s. = not specified).

GEOGRAPHIC AREA	WOOD SPECIES / MATERIAL	NUMBER OF SAPWOOD RINGS		REFERENCE
		Median (med) / Average (av)	Range (confidence interval) / min–max	
Easter Baltic (Estonia, Finland, Latvia, Lithuania)	*Quercus pedunculate* L. / living oaks	12 (med)	*c.* 6 – 19 (95%)	Sohar et al. (2012)
Easter Baltic (Finland)	*Quercus robur* L. / living oaks > 120 yrs	*c.* 14 (av)	7 – 24	Baillie *et al.* (1985)
Poland (North)	*Quercus* spp. / living oaks	15 (med)	13 – 19 (50%)	Eckstein et al. (1986)
Poland	*Quercus* spp. / historical timbers	15 (med)	9 – 23 (90%)	Wazny (1990)
Poland	Oaks < 100 yrs	13 (av)	6 – 22	
Poland	Oaks 100–200 yrs	17 (av)	9 – 31	
Poland	Oaks > 200 yrs	18 (med)	9 – 30	
Poland (Western Pomerania)	Oaks > 100 yrs	17 (med)	10 – 26 (90%)	Wazny (2001)
Poland (South)		13 (med)	7 – 22 (90%)	
Poland (Greater)	n.s.	13 (med)	6 – 21 (90%)	Krąpiec *et al.* (2014)
Poland	Oaks > 300 yrs	n.s.	13 (minimum)	Bauch (2002)

to changing environmental conditions are minimised (Fletcher, 1976; Fraiture, 2011). Sixty-one of the sixty-two wood boards analysed were split in full-radial and radial direction. The analysis has not identified any panel with a tangential cut, which leads to the hypothesis that only the best boards were selected from the available raw materials (Table 2).

One of the general rules maintained in Flemish workshops from the 15th and 16th centuries was to fit the extreme side boards of the panel with the oldest rings, corresponding to the most stable and durable wood, placed on the outside (Wadum, 1998; Vandekerchove et al., 2009; Verougstraete, 2015). This rule was followed in almost all cases, except for *Anunciação* painting (MASF35) (Table 1). This means the most stable and durable part of extreme side boards is positioned outwards, with the part with the narrowest rings closest to the bark located nearer to the centre of the painting. The presence of a newer, non-original board in *Nossa Senhora do Amparo* painting (MASF39) precludes any conclusions about the panel assembly in this case.

5.2. *Dating of paintings and estimated tree felling dates*

Slow growing oaks produce wood more resistant to warping due to shrinkage or expansion. As a result, slower-growing oak is preferred for creating more stable supports for paintings. The homogeneity of the boards chosen for painting supports is revealed by the classification of oak tree rings according to their growth rates (Fraiture, 2011). Overall, the panels under investigation are made up of boards with growth rates ranging from "extremely low" to "medium." Approximately half of the 62 boards are characterized by 'medium' growth rates (49%), followed by 'very slow' and 'slow' growth rates (24% and 21%, respectively). Only four boards (6%) have a fast growth rate (Supplementary Table 1).

The tree ring dataset that originally represented 62 oak boards was reduced to 42 because several boards were derived from the same tree (Supplementary Table 1). Three paintings (MASF32, MASF55 and MASF39) from three different workshops (Joos van Cleeve, Pieter van Aelst and Jan Gossart, respectively) were composed exclusively of 2–3 boards belonging to the same tree, revealing a careful selection of the supporting material for a single artwork.

Table 4
Time span between felling an oak and the use of its wood as a painting support according to dendrochronological research.

MATERIAL (CENTURY)	TIME SPAN (YEARS)	REFERENCE
Panels (15th century)	10 – 15	Klein (1982)
Panels attributed to Petrus Christus (15th century)	18 (minimum)	Klein (1994a)
Panels (15th and 16th centuries)	10 (approximately)	Klein (1994b)
Dutch and Flemish panels (16th and 17th centuries)	2 – 8	Bauch *et al.* (1981); Klein (1981)
Panels (16th and 17th centuries)	3 – 10	Bauch et al. (1974)

Of the 42 final series, 33 were correctly dated, and the youngest measured ring in most paintings predates the respective historical date (Supplementary Table 1). The exception is the *São Jerónimo* painting attributed to Marinus van Reymerswaelle (MASF107), for which the youngest ring dates to 1553 while it is historically assigned to 1521–1540 (i.e., 1521 at the earliest). Of the nine undated boards, two belong to the *Sta. Maria Madalena* painting attributed to Jan Provost's workshop (MASF29), and three of them compose the central panel assigned to the Master of Holy Blood (MASF43). The remaining four are from four different paintings.

All the 62 oak boards were composed entirely of heartwood, indicating that the sapwood section of the stem had been removed. Due to the sapwood vulnerability to biological deterioration, it was common practice in the Flemish workshops during the 15th and 16th centuries to remove it from the boards (Baillie, 1982; Fraiture, 2002; Haneca et al., 2005; Bernabei et al., 2007; Wazny, 2011). The estimated number of sapwood rings to determine (or estimate) the earliest oak felling date varies with: (1) the tree age, with old trees tending to have more sapwood rings than younger trees (Haneca et al., 2009; Klein, 1994b); (2) position in relation to the tree height, with the lowest number in the lowest stem levels (Hughes et al., 1981); and (3) the geographical location where the trees have grown in Europe, since a downward trend in the number of oak sapwood rings has been observed from West to East (Eckstein et al., 1986; Wazny and Eckstein, 1991). Table 3 summarizes the number of oak sapwood rings from the Baltic region obtained in several dendrochronological studies. The current investigation counts with the median of 15 rings presented by Wazny (1990) and based on archaeological material and historical objects.

There are several procedures between cutting down a tree in the forest and using its wood as a painting support: logs are cut in the forest and floated as rafts downriver to the main harbors, or as planks on river-ships, shipped to Flanders, seasoned, and finished (Fraiture, 2002; Krąpiec and Krąpiec, 2014; Verougstraete, 2015). Wood supports should be well seasoned for stability reasons, as incomplete seasoning could lead to deformation and diagonal distortions of the panels (Wadum, 1998). Historical sources provide relevant information related to this time span: (1) at least six years (Viollet-le-Duc, 1863); (2) at least eight years (Roubo, 1769); and (3) 20 years, according to historical documents associated with the construction of Flemish altarpieces from the 15th century (Verougstraete, 2015). Dendrochronological studies that attempt to evaluate the elapsed period report different values, as summarised in Table 4. The current research considers a minimum of two years.

Except for the Marinus van Reymerswaelle's painting (MASF107), the earliest possible creation date established for each painting, which includes the estimated average number of sapwood rings and the seasoning and transport time, does not contest the assigned historical date (Supplementary Table 1). The findings are a good example of the potential of dendrochronology as a scientific approach based on tree-rings measurements and statistical analysis, for the historical-

Fig. 3. Hole and wood peg in the *Anunciação* painting, the central panel of the Triptych *Bom Jesus* attributed to Joos van Cleeve's workshop (MASF35).

iconological-iconographical studies of artworks in terms of authorship and date assignments. Notwithstanding, tree ring dating cannot always provide the desired and concrete response when applied to artefacts due to three types of constraints: biological (e.g., ring-growth anomalies and predictable missing sapwood-heartwood rings); methodological (e.g., structural condition of the wood and unavailable reference chronologies to the dating); and historical (e.g., old or reused woods and time span after tree felling). Nonetheless, the integration of dendrochronology with history, art and archaeology, in a truly interdisciplinarity approach, has been acknowledged and regarded as a future study field to be encouraged (Baillie, 2002; Sass-Klaassen, 2002).

The 33 dated series correlated optimally with oak chronologies derived from material of eastern Baltic origin (Supplementary Table 2). The strongest dendrochronological matches were obtained mainly with master chronologies BALTIC 1, NL Baltic Import, NL Baltic A, NL Baltic B and the site chronology BOWHILL-B. In other cases, the best matches were obtained against master chronology BALTIC 2.

Anunciação **painting (MASF35), attributed to Joos van Cleeve's workshop**

The *Anunciação* painting (Supplementary Fig. 1) is the central panel of the Triptych *Bom Jesus*, initially destined for a Chapel of the Convent of *São Francisco* in Funchal. The historical and iconographic attribution of Baptista Pereira and Clode (1997) places the artwork in the first period of the painter's activity (1500–1510). The present study places the earliest possible creation date in the year of 1505 (Supplementary Table 1), which is compatible with the historical and iconographic allocation. However, a caveat should be made. During the visual inspection of the painting after removing the frame, a hole with a partially broken wooden peg was discovered on the last board on the right side (Fig. 3). The panel maker made such holes on either side of the joint to reduce the possibility of boards slipping during tightening, after which small bolts were inserted in the holes for better fitting and to avoid reinforcing the bonding (Glatigny, 2010). This indicates a board is missing which is also reinforced by the incompleteness of the book in the lower corner and the window in the upper corner of the painting (Supplementary Fig. 1). Therefore, the dendrochronological dating proposed in this analysis is reliable given the current board composition of the artwork, but there is always the possibility of a renewed dating in case of the missing board is found.

S. Pedro **painting (MASF27), attributed to Joos van Cleeve's workshop**

The *S. Pedro* painting (Supplementary Fig. 2) is the central panel of the Triptych *São Pedro, São Paulo e Santo André*. Without any inscriptions, it shows the influence of Quentin Matsys and can be dated iconographically to the beginning of the sophisticated phase of Joos van Cleeve's work, *c.* 1520 (Baptista Pereira and Clode, 1997). Leeflang (2015) suggests a date of around 1515, due to the close affinity of the style and underdrawings to those of the Saint Reinhold Altarpiece, which was installed in 1516 in St. Mary's Church in Gdansk. Dendrochronologically, the earliest possible creation date is the year of 1495 (Supplementary Table 1), which is consistent with the historical date.

Fig. 4. Inscription *ANNO* on top of the jar of lilies in the central panel of the triptych *Encarnação, Anunciação e o Mistério da Encarnação* attributed to Joos van Cleeve's workshop (MASF32) (photo credits: Museum of Sacred Art of Funchal archive).

Anunciação e o Mistério da Encarnação **painting (MASF32), attributed to Joos van Cleeve's workshop**

The central panel of the Triptych *Encarnação, Anunciação e o Mistério da Encarnação* (Supplementary Fig. 3) contains three inscriptions: *veritas/manet/in. e/ternu(m)*; *sã(ctis)sima.rosa*; *ANNO* (Baptista Pereira and Clode, 1997). The word *ANNO* in the jar of lilies (Fig. 4) could be considered an unfinished inscription of the date of the execution. However, according to Baptista Pereira and Clode (1997), this date, in association with the small picture of the Child Jesus on the jar, refers to the "year zero," i.e., the beginning of the Christian era. The last-formed hardwood ring identified in the central panel dates to the year 1485, which places the earliest possible creation date the year of 1496 (Supplementary Table 1). This date is consistent with the iconographic attribution of this painting by Baptista Pereira and Clode (1997) at the end of the first period of the painter's activity.

***Santiago Menor e S. Filipe* painting (MASF40), attributed to Pieter Coecke van Aelst's workshop**

The central panel *Santiago Menor e S. Filipe* belongs to the triptych of the same name (Supplementary Fig. 4). Recognizing the donor's and his family's high social standing, van Aelst contextualised the male and female figures with the portrayal of the castle and the monastery, as well as a natural reference to the Flemish style of building and vegetation portrayed in the landscape (Baptista Pereira and Clode, 1997). The historic date of the triptych is based on chronological facts: the first date relates to the donor's resignation year, and the second to the begin of his succession (Baptista Pereira and Clode, 1997). The dendrochronological analysis reveals as the earliest possible creation date the year 1516, which is compatible with the stylistic and historical interpretations attributed by Baptista Pereira and Clode (1997) of 1528–1531 (Supplementary Table 1).

***Calvário* painting (MASF55), attributed to Pieter Coecke van Aelst's workshop**

Given its size, the painting *Calvário* (Supplementary Fig. 5) probably belonged to a triptych representing the cycle of the Passion and Resurrection of Jesus Christ of which the two wings were lost. Based in stylistic analyses, Baptista Pereira and Clode (1997) conclude that the master had taken a straightforward approach to Italian art, which is fully justified since van Aelst travelled to Italy in the 1530′s (Born, 2018). Oriental details can be identified in the architectural background of the *Calvário* painting, thus suggesting that the work was carried out immediately after the painter's trips to Constantinople in 1533 or to Tunis in 1535 (Baptista Pereira and Clode, 1997; Born, 2018). The dendrochronologically established earliest possible creation date is in or after 1508, which is in consonance with the stylistic attribution (Supplementary Table 1). The pattern of the growth ring is more analogous to the BALTIC2 master chronology ($t_{BP} = 9.7$, Glk = 74% and $P < 0.0001$) (Supplementary Table 2), as observed in the *Descida da Cruz* painting (MASF20) and the *São Jerónimo* painting (MASF107). The typology of this master chronology is not often observed in the woods of this time and, for this reason, a solid date replication for the *Calvário* painting is not achieved.

***Nossa Senhora do Amparo* painting (MASF39), attributed to Jan Gossart's workshop**

The *Nossa Senhora do Amparo* painting (Supplementary Fig. 6A) is notable for having an inscribed date (*ANNO. DO. 1543*) (Supplementary Figures 6B and 6C). Despite the presence of inscriptions and monograms on some paintings attributed to Jan Gossart (1478–1532), few provide a date: (a) *Neptunus en Amphitrite* (±*IOANNES* + *MALBODIVS* + *PINGEBAT* + *1516* +) (Gemäldegalerie Staatliche Museen, Berlin); (b) *Portrait of Hendrik III van Nassau* (*1524*) (Anhaltische Gemäldegalerie Schloss Georgium, Dessau); and (c) *Virgin and Child* (*1527*) (Alte Pinakothek, Munich) (https://dendro4art.org/). The date shown in the *Nossa Senhora do Amparo* painting is after Jan Gossart's death. Baptista Pereira and Clode (1997) raise the hypothesis that this painting was sketched out and started by the painter himself and completed by followers after his death. In that case, the inscription would correspond to the year of the final execution of the work. According to these authors, it is conceivable, however, that local masters added it as a reference to the founding year of the religious cult in the Madeira Island chapel for which the artwork was intended. The dendrochronological analysis shows 1536 as the earliest possible creation date, which is consistent with the current interpretation of the date engraved on the painting (Supplementary Table 1).

***Sta. Maria Madalena* painting (MASF29), attributed to Jan Provoost's workshop**

Sta. Maria Madalena is one of the paintings commissioned to Jan Provoost's (1465–1529) workshop in Portugal. It bears the inscription *Maria Madalena* in the canopy above the figure (Supplementary Fig. 7), but it is not dated. Beside none of the over hundred known works from Group Provoost are signed (Spronk, 1998), Baptista Pereira and Clode (1997) identified a few elements associated with the painter by means of a stylistic comparison: (a) the decorations and props appropriate to the monumental scale of Santa Maria Magdalena; (b) the landscape background; and (c) a rich variety of Christian symbols that the authors believe to reveal the deep and devout faith of the artist. In fact, Jan Provoost was a leading member of the Brotherhood of Jerusalem Pilgrims in Bruges and a confraternity regent in 1527 (Spronk, 2005). The historical dating of *Sta. Maria Madalena* (1524–1526) is based on the patron's will from 1524, which states that if the artwork was not on the Church *Madalena do Mar* (Madeira Island) at the time of his death, the church administration would have two years to secure its placement (Baptista Pereira and Clode, 1997). Considering the historical documentation and iconography, this painting should have been created in a later phase of Provoost's career in keeping with the last two artworks he created both of which are safely authenticated by historical records: *Last Judgment* (Groeningemuseum, Bruges) and *Virgin in the Clouds* (Hermitage, Saint Petersburg) (Baptista Pereira and Clode, 1997; Spronk, 1998). The dendrochronological analysis shows that the last preserved ring dates to 1508, indicating an earliest possible creation date the year 1519 (Supplementary Table 1). This result is in good agreement with the historical date.

***Descida da Cruz* painting (MASF20), attributed to Gerard David's workshop**

The central panel *Descida da Cruz* (Supplementary Fig. 8), attributed to Gerard David's (1460–1523) workshop, belongs to a triptych with the same name. The historical date of this artwork is based on the time span between the year of the founder's will (1518) and the conclusion of the monastery's construction (1527) (Baptista Pereira and Clode, 1997). The authors do not exclude the possibility of his collaborators may complete the work since Gerard David died in 1523. The current study reveals that the last-formed heartwood ring dates 1416, showing the year 1427 as the earliest possible creation date (Supplementary Table 1). The dendrochronological result does not question the historical date (1518–1527), but it also does not allow for its clarification or refinement. The following factors may explain why a dendrochronological date is so much earlier than the historical date: (a) the historical attribution is too late; (b) a longer period of wood stabilization; (c) the wood was taken more towards the inside of the tree; (d) the option to use older boards; or (e) a possible reuse of the board (Klein, 2008). As shown above, the dating of the *Descida da Cruz* painting is stylistically based on complementing historical documents. The estimated period of wood stabilization applied to Gerard David's workshop has so far been uncertain. However, with the dendrochronological analysis of the only two known paintings dated with precision (*Judgement of Cambyses* dated 1498 (Groeninge Museum, Brugge) and *Virgin among the Virgins* dated 1509 (Musée des Beaux-Arts, Rouen) (Klein, 1998)), fascinating and valuable studies could be initiated in order to learn more about the rules applied in his workshop. The use of boards taken from the innermost part is verified by a dendrochronological analysis of the paintings *The Annunciation* (Städel Museum, Frankfurt am Main) (https://rkd.nl/explore/technical/5004561) and the two wings from Cervara Altarpiece - *Angel of the Annunciation / Mary of the Annunciation* (The Metropolitan Museum of Art, New York) (https://rkd.nl/explore/technical/5009533). The youngest rings on the three boards from the same tree in these three paintings are 1475, 1375, and 1315, respectively. The dendrochronological study in *The Saint Anne* altarpiece provides an example of the use of older boards in artworks attributed to Gerard David's workshop (National Gallery of Art, Washington D. C.). This artwork is composed of two groups of five and four boards, from two distinct trees, with the youngest rings ranging 1353–1387 and 1477–1481, respectively (https://rkd.nl/explore/technical/5008453). In light of these observations, the reuse of boards in *The Saint Anne* altarpiece can be considered. To validate it, Kuniholm (2000) advised an

X-ray analysis to evaluate the possible existence of any underpainting. Unfortunately, the radiological examination carried out at the central panel *Descida da Cruz* by the Instituto José de Figueiredo (Direcção Geral do Património Cultural) was not conclusive.

***Natividade* painting (MASF30), attributed to Master of the Triptych of Morrison**

The *Natividade* painting (Supplementary Fig. 9) is the central panel of the Triptych from *Capela dos Reis Magos*, originally intended for the main Church from *Ribeira Brava*. This artwork is assigned to the Master of the Tryptich of Morrison, the name given to a Flemish painter who was active in Antwerp in *c.* 1500. It depicts a night scene that is extremely rare in Renaissance, Flemish and Italian paintings (Baptista Pereira and Clode, 1997). The historical dating of the *Natividade* painting (1510–1515) is based on comparative stylistic analysis with other works attributed to the painter, complementing the historical facts of the church for which the painting was destined (Baptista Pereira and Clode, 1997). The dendrochronological results show that the last-formed heartwood ring dates to 1485, which means an earliest possible creation date in the year of 1496 (Supplementary Table 1). This result does not compromise the existing historical dating. The side cuts of the painting which were made when the main Church from *Ribeira Brava* was restored (Baptista Pereira and Clode, 1997) do not question the dendrochronological dating, because the ends of the extreme side boards match to the tree's innermost section (Table 2).

Triptych from *Ribeira Brava* (MASF43), attributed to Master of the Holy Blood

The central panel of the Triptych from *Ribeira Brava* (Supplementary Fig. 10) is one of the 150 copies of the original *The Descent from the Cross* painting, now lost, attributed to Rogier van der Weyden (Baptista Pereira and Clode, 1997). The Triptych from *Ribeira Brava* resembles the one at the Metropolitan Museum of Art (MET, New York), which is attributed to the Master of the Holy Blood, a Bruges follower of Quentin Massys, with a workshop specializing in the art export (Baptista Pereira and Clode, 1997). As a result, its historic dating is based on the dating of the MET triptych (*c.* 1520) and on the date of the main Church from Ribeira Brava's renovation work (1510–1520). Dendrochronological dates were obtained for the two side panels, made of boards belonging to the same tree. The last-formed heartwood ring identified dates to 1478, which suggests as the earliest possible creation date the year of 1489 (Supplementary Table 1). The result does not question the stylistically assigned date of *c.* 1520.

Encontro de S. Joaquim e Sta Ana junto da porta dourada* (MASF26), attributed to Master of *Adoração de Machico

The small *Encontro de S. Joaquim e Sta Ana junto da porta dourada* painting (Supplementary Fig. 11) was originally destined for the Church *Madalena do Mar*, built at the beginning of the second half of the 15th century. According to Baptista Pereira and Clode (1997), the possible patron of the painting was Henrique Alemão, the Knight of Saint Catherine of Mount Sinai. The painting shows Henrique Alemão and his wife as figures of Sacred History, based on two attributes present on the male figure: a dagger (indicating his royal ancestry) and a pilgrim's bag (representing his pilgrimage to the Holy Land). According to the legend described by Gomes (1941), Henrique Alemão was Ladislaus III, King of Poland and Hungary who was defeated and disappeared during the Battle of Varna (currently in Bulgaria) in 1444. After a period of refuge in the Holy Land, in 1454 he took refuge on Madeira Island with the support of King Afonso V of Portugal. The present study shows that the last-formed identified heartwood ring dates to 1484, revealing as the earliest possible creation date the year of 1495 (Supplementary Table 1). The dendrochronological result is in line with the stylistic date (end of the 15th century).

São Nicolau* (MASF25), attributed to Master of *Adoração de Machico

It is certain that the *São Nicolau* painting (Supplementary Fig. 12) is the central panel of a triptych, also attributed to the Master of *Adoração de Machico*, probably from the Chapel *Nossa Senhora do Calhau* founded in the 15th century (Baptista Pereira and Clode, 1997). The dendrochronological results show that the last preserved ring identified on this panel dates 1438, suggesting as the earliest possible creation date the year of 1449 (Supplementary Table 1). The result does not question the assigned creation date at the beginning of the 16th century, but it does not allow further dating refinement.

***São Jerónimo* (MASF107), attributed to Marinus van Reymerswaelle (*ca.* 1490 – *ca.* 1567)**

The small *São Jerónimo* painting (Supplementary Fig. 13A) is based on an Albrecht Dürer painting from 1521 (National Museum of Ancient Art, Lisbon) and features the inscription *MEMORARE / NOVISSIMA / TVA.ET.IN / AETERUM / NON. PECCABIS* (Baptista Pereira and Clode, 1997). The dendrochronological results demonstrate that the last preserved ring identified on this artwork dates 1553, suggesting the year 1564 as the earliest possible creation date (Supplementary Table 1). However, the results are somewhat less robust than in other cases. The

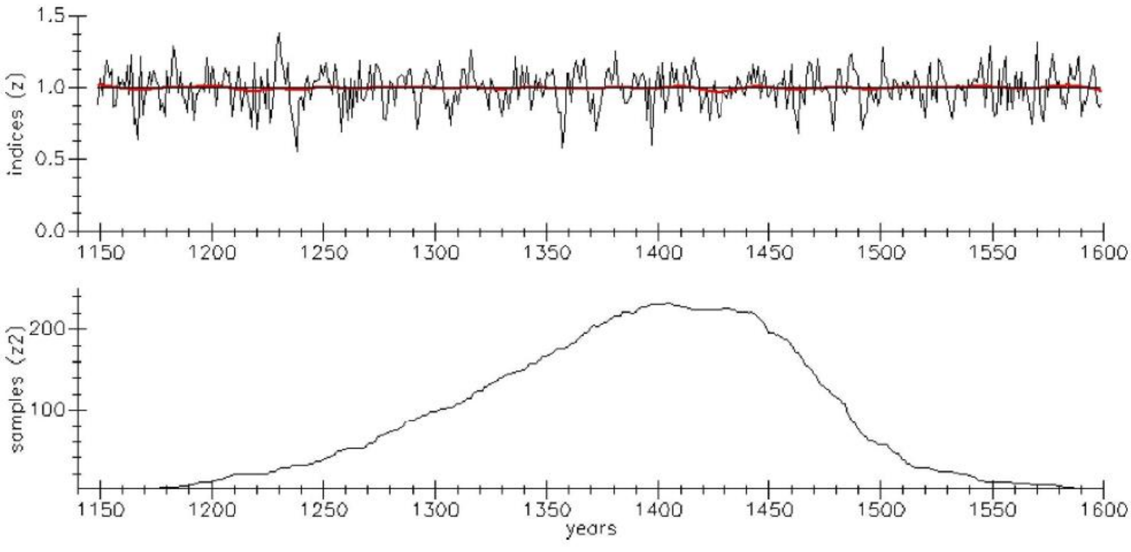

Fig. 5. *Top:* PORTHER01 oak chronology. *Down:* Sample depth.

Table 5
Best correlations between PORTHER01 and seven oak chronologies from Baltic area ((a) unpublished chronologies, kindly provided by Peter Klein, which were developed by Josef Bauch, Dieter Eckstein and Peter Klein of the Institute of Wood Science, University of Hamburg).

CHRONOLOGIES	REFERENCE	OVERLAP	Glk	t_{BP}	P < than
NL Baltic A	Jansma (unpublished)	451	80	25.3	0.0000001
BALTIC1	Hillam and Tyers (1995)	442	79	22.2	0.0000001
0520003 M	Eckstein et al. (1975)	451	80	21.9	0.0000001
BALTIC IMPORT	Jansma et al. (2004)	433	77	12.4	0.0000001
0520006 M	(a)	343	76	17.4	0.0000001
0520004 M	(a)	237	75	8.9	0.0000001
NL Baltic B	Jansma (unpublished)	378	74	15.0	0.0000001

reason is that the growth ring pattern is more similar to the BALTIC2 master chronology ($t_{BP} = 5.6$, Glk = 67% and $P < 0.0004$), as opposed to the other Flemish paintings addressed in the present study, which are primarily in agreement with BALTIC1 (Supplementary Table 2). There is also a very good crossmatch with a board sequence of the *Lady Elizabeth Audley* painting ($t_{BP} = 7.4$, Glk = 69% and $P < 0.0002$), attributed to the Flemish painter Adriaen Thomasz Key (1544–1589). This painting is part of the Audley End House artwork collection, for which Tyers (2014) established a predominant correspondence to BALTIC2. The typology of this specific master chronology is rarely found in the woods of this period. This fact may clarify the difficulties of dating the *São Jerónimo* painting, since the databases include only a few examples of this typology, as Fraiture (2009) reported for the *Saint John* painting belonging to the *Ghent* altarpiece. Baptista Pereira and Clode (1997) propose a historical date range of 1521 to 1540, although the dendrochronological finding suggests an artwork created later, in the painter's final years of his career.

5.3. Wood provenance

The presumption that the wood came from different forests and probably different countries should be the starting point for dendrochronological studies of a series of paintings from different workshops (Hillam and Tyers, 1995). The 15 Flemish paintings at the Sacred Art Museum of Funchal on which the research was based were all made of Baltic oak and showed excellent synchronizations with master chronologies that cover a vast area (Supplementary Table 2). However, master chronologies cannot provide accurate information about a particular wood provenance since their signal is too generic to represent regionally specific growth variations and instead site chronologies are more suitable for determining geographical wood sources (Fraiture 2009). The most useful site chronology for this study (BOWHILL-B) was based on samples collected from old buildings in the United Kingdom. According to Groves (2002), this material was imported from the eastern Baltic region, reinforcing the assumption that these timbers could be used for high-quality panelling throughout the country. This outcome, however, cannot be used to determine the wood's provenance in greater detail.

5.4. New oak chronology

The first version of PORTHER01 chronology included 366 tree-ring series, spanning the period from 1041 to 1599, but its quality was questionable since $\bar{r}$ was 0.45 (i.e., lower than the established threshold of 0.50) and 27% of all intervals represented values of $r_i^k \leq 0.32$. The final chronology was reduced to 256 series with $\bar{r}$ of 0.53, no>7% of 50-yr intervals with $r_i^k \leq 0.32$ and covers the period CE 1149–1599 (Fig. 5).

The Expressed Population Signal (EPS) of PORTHER01 varies between 0.87 and 0.99 over the chronology's full coverage span, which is above the 0.85 threshold.

PORTHER01 shows high similarities with several Baltic chronologies, with range values of t_{BP} between 8.9 and 25.3. The Netherlands-based chronology NL Baltic A and the UK-based chronology BALTIC1 provide the strongest matches (Table 5).

The PORTHER01 chronology's primary purpose is to use it to date a larger range of historical objects such as artworks, furniture, historic buildings, and archaeological artifacts. With future dendrochronological study, this new chronology can be strengthened and expanded in its temporal scale.

6. Conclusion

The dendrochronological analysis of 13 of the 15 examined Flemish paintings belonging to the Museum of Sacred Art of Funchal, consolidated the historical, iconological, and iconographic dates stated in the museum catalogue. The research provided a more precise date for the *Anunciação* panel attributed to Joos van Cleeve's workshop since the historic-iconological-iconographical attribution placed the artwork between 1500 and 1510, whereas the dendrochronological analyses set the earliest date in 1505. Using dendrochronology, we uncovered new information about the *S. Jerónimo* panel attributed to Marinus van Reymerswaelle, suggesting that it was painted after the historical dating, in the painter's later years of his career.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2022.103379.

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SUPPLEMENTARY MATERIAL

Supplementary Figures 1–13 represent thirteen artworks from the Museum of Sacred Art of Funchal (Madeira Island), assigned to different Flemish artists of the 15th and 16th centuries, and examined through a dendrochronological approach.

Supplementary Figure 1. *Anunciação*. Central panel of the Triptych *Bom Jesus* (inventory number MASF35), assigned to Joos van Cleeve & collaborators (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 2. *S. Pedro*. Central panel of the Triptych *Encarnação* (inventory number MASF27), assigned to Joos van Cleeve & collaborators (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 3. *Anunciação e o Mistério da Encarnação*. Central panel of the Triptych São Pedro, São Paulo e Santo André (inventory number MASF32), assigned to Joos van Cleeve & collaborators (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 4. *Santiago Menor e S. Filipe.* Central panel of the Triptych *Santiago Menor e São Filipe* (inventory number MASF40) assigned to Pieter Coecke van Aelst & collaborators. In the left wing the donor and his two sons are represented; in the right wing are represented the donor's wife and the wife of his male child (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 5. *Calvário* (inventory number MASF55), assigned to Pieter Coecke van Aelst & collaborators (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 6. [A] *Nossa Senhora do Amparo* (inventory number MASF39), assigned to workshop of Jan Gossart (Mabuse) (photo credits: Sacred Art Museum of Funchal archive) **[B and C]** Details of the inscriptions *ANNO. DO. 1543* in the columns (photo credits: IJF/DGPC, 2015).

Supplementary Figure 7. *Sta. Maria Madalena* (inventory number MASF29), assigned to Jan Provoost (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 8. *Descida da Cruz*. Central panel of the Triptych Descida da Cruz (inventory number MASF20), assigned to Gèrard David & collaborators (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 9. *Natividade*. Central panel of the Triptych from Capela dos Reis Magos (Inventory number MASF30), assigned to Master of the Morrison Triptych (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 10. *Descida da Cruz* [Central panel of the Triptych from *Ribeira Brava*] *Nicodemos* [Left wing] *Maria Madalena* [Right wing] (inventory number MASF43), assigned to Workshop of Master of the Holy Blood (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 11. *Encontro de S. Joaquim e Sta Ana junto da porta dourada* (inventory number MASF26), assigned to Master of *Adoração do Machico* (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 12. *São Nicolau* (inventory number MASF25), assigned to Master of *Adoração do Machico* (photo credits: Museum of Sacred Art of Funchal archive).

Supplementary Figure 13. [A] *São Jerónimo* (inventory number MASF107), assigned to Marinus van Reymerswaelle (photo credits: Museum of Sacred Art of Funchal archive) **[B]** back of the painting with two painted and illegible inscriptions (photo credits: Mercês Lorena, Instituto José de Figueiredo / Direcção Geral do Património Cultural).

Supplementary Table 1 provides the major published and unpublished oak reference chronologies used to date the Flemish paintings, as well as a reference to the tree-ring series derived from dendrochronological study on Portuguese heritage done over the previous decades.

Supplementary Table 1. Reference chronologies and tree-ring series of *Quercus* sp. used to date the Flemish paintings from the Museum of Sacred Art of Funchal (Madeira Island, Portugal) [(a) unpublished chronologies, kindly provided by Peter Klein, which were developed by Josef Bauch, Dieter Eckstein and Peter Klein of the Institute of Wood Science, University of Hamburg; [1] Paintings on Baltic wood made in Portugal].

REFERENCE CHRONOLOGIES (IDENTIFICATION CODE)	FIRST YEAR	LAST YEAR	REFERENCE
BALTIC 1	1156	1597	Hillam *et al.* (1995)
BALTIC 2	1257	1615	Hillam *et al.* (1995)
NL BALTIC IMPORT	1167	1637	Jansma *et al.* (2004)
NL Baltic A	1030	1602	Jansma (unpublished)
NL Baltic B	1167	1544	Jansma (unpublished)
0520001M	1173	1619	(a)
0520002M	1199	1635	(a)
0520003M	1115	1643	Eckstein *et al.* (1975)
0520004M	1363	1643	(a)
0520006M	1146	1491	(a)
BOWHILL-B	1161	1483	Groves (2004)
PAINTINGS BELONG TO THE PORTUGUESE CULTURAL HERITAGE [NR. SERIES]			
Portuguese[1] [89]	1157	1593	Instituto José de Figueiredo (Direcção Geral do Património Cultural) (unpublished)
Flemish [47]	1041	1536	
Portuguese[1] [98]	1144	1599	Forest Research Centre, School of Agriculture, University of Lisbon (unpublished)
Flemish [52]	1186	1553	

Supplementary Table 2 summarizes the major technical data collected on oak boards from 13 artworks attributed to several Flemish painters from the 15th and 16th centuries during dendrochronological investigation.

Supplementary Table 2. Wood support of the 15 oak paintings from 13 artworks attributed to several Flemish painters from the 15th and 16th centuries, belonging to the Museum of Sacred Art of Funchal (Madeira Island) [Type of cut: A=full radial or full quarter; B=radial (or quarter); C=semi-radial (or false quarter); D=tangential (Fraiture, 2011); **(a)** Plank not analyzed; n.a.=not applicable].

NAME [INVENTORY NUMBER]	NUMBER OF BOARDS	WIDTH (cm)	TYPE OF CUT	ORIENTATION OF THE EXTREME SIDE BOARDS ← →
Anunciação [MASF35]	9	15.5 / 28.2 / 17.5 / 23.4 / 22.3 / 18.0 / 26.8 / 25.0 / 27.2	B / A / B / B / C / B / A / B / B	Pith Bark
S. Pedro [MASF27]	4	27.5 / 27.8 / 31.5 / 29.5	A / B / B / A	Pith Pith
Anunciação e o Mistério da Encarnação [MASF32]	6	26.4 / 27.8 / 27.2 / 27.3 / 17.0 / 27.5	B / A / A / B / B / B	Pith Pith
Santiago Menor e S. Filipe [MASF40]	5	16.1 / 23.3 / 23.4 / 27.5 / 25.0	B / B / A / A / A	Pith Pith
Calvário [MASF55]	6	20.0 / 26.5 / 23.6 / 23.5 / 26.7 / 19.9	B / B / B / B / A / B	Pith Pith
Nossa Senhora do Amparo [MASF39]	9	30.3 / 21.4 / 21.6 / 21.2 / 28.3 / 20.8 / 23.0 / 23.0 / 31.4	(a) / B / B / A / B / B / A / B / B	(b) Pith
Sta. Maria Madalena [MASF29]	5	28.7 / 24.0 / 28.0 / 28.0 / 14.0	A / (a) / A / B / B	Pith Pith
Descida da Cruz [MASF20]	5	21.5 / 24.7 / 31.5 / 23.0 / 20.5	B / B / B / B / B	Pith Pith
Natividade [MASF30]	6	4.0 / 30.9 / 27.1 / 26.3 / 28.3 / 24.3	A / B / B / B / B / A	Pith Pith
Descida da Cruz & Nicodemos & Maria Madalena [MASF43]	3 1 1	30.0 / 20.5 / 28.2 33.9 33.5	B / A / B A B	Pith Pith n.a. n.a.
Encontro de S. Joaquim e Sta Ana junto da porta dourada [MASF26]	1	39	C	n.a.
São Nicolau [MASF25]	4	28.0 / 28.5 / 7.7 / 28.0	B / (a) / (a) / B	Pith Pith
São Jerónimo MASF107]	1	34.5	B	n.a.

Supplementary Table 3 summarizes the major dendrochronological data obtained on oak boards from 13 artworks attributed to different Flemish artists from the 15th and 16th centuries, along with a comparison to the respective historical date.

Supplementary Table 3. Dendrochronological and historical dates of 13 Flemish paintings from the Museum of Sacred Art of Funchal (Madeira Island, Portugal) [laboratory filename=internal identification of each board; total rings=number of growth rings measured; growth ring width (average ± dp) in mm; wood growth rate: VS (very slow)-less than 1.0 mm; S (slow)-between 1.0 and 1.2 mm; M (medium)-between 1.2 and 2.0 mm; F (fast)-greater than 2.0 mm (Fraiture, 2011); t_{BP}=t-value Baillie-Pilcher (Baillie and Pilcher, 1973); dendrochronological date: **(1)** earliest possible felling date=add 9 years **(2)** estimated felling date=add 15 years **(3)** earliest presumed date=earliest possible felling date plus 2 years of seasoning; **(a)** inconclusive date; **(b)** partial measurement; **(c)** few tree rings for a dendrochronological study; n.a. – not applicable].

PAINTER	INVENTORY NUMBER	BOARD	TOTAL NUMBER OF RINGS	RING WIDT [WOOD GROWTH RATE]	BOARDS FROM THE SAME TREE [t_{BP}]	DENDROCHRONOLOGICAL DATE (AD)					HISTORICAL DATE	TIME LIFE
						FIRST RING	LAST PRESERVED RING	EARLIEST POSSIBLE FELLING DATE	ESTIMATED FELLING DATE	EARLIEST PRESUMED DATE		
Joos Van Cleeve & collaborators	MASF35	0064	147	0.98±0.20 [VS]	-	1342	1488	1503	1509	1505	1500-1510	1485 – 1541
		0065	215	1.04±0.29 [S]	-	1272	1486					
		0066	98	1.62±0.52 [M]	-	-	-					
		0067	149	1.00±0.23 [S]	-	-	-					
		0068	188	1.04±0.28 [S]	-	-	-					
		0069	99	1.78±0.63 [M]	-	-	-					
		0070	215	1.24±0.45 [M]	-	1273	1487					
		0071	231	0.94±0.21 [VS]	-	-	-					
		0072	147	0.91±0.19 [VS]	-	-	-					
		0066-0069	103	-	19.7	1391	1493					
		0067-0068	193	-	11.0	1302	1494					
		0071-0072	237	-	11.6	1246	1482					
	MASF27	0073	164	1.68±0.63 [M]	-	1309	1472	1493	1499	1495	1520	
		0074	294	0.83±0.28 [VS]	-	1187	1480					
		0075	215	1.36±0.38 [M]	-	-	-					
		0076	210	1.40±0.42 [M]	-	-	-					
		0075-0076	215	-	12.3	1270	1484					
	MASF32	0077	254	0.96±0.32 [VS]	-	-	-	1494	1500	1496	1510-1515	
		0078	275	0.99±0.32 [VS]	-	-	-					
		0079	201	1.32±0.37 [M]	-	-	-					
		0080	226	1.17±0.38 [S]	-	-	-					
		0081	154	1.05±0.33 [S]	-	-	-					
		0082	270	0.98±0.31 [VS]	-	-	-					
		0077-0078-0082	280	-	9.4 / 11.2 / 11.8	1203	1482					
		0079-0080-0081	242	-	13.3 / 13.7 / 17.8	1244	1485					
Pieter Coecke van Aelst & collaborators	MASF40	0047	51	1.75±0.35 [M]	-	1455	1505	1514	1520	1516	1528-1531	1502 – 1550
		0048	112	1.57±0.76 [M]	-	-	-					
		0049	109	1.25±0.42 [M]	-	-	-					
		0050	51	1.87±0.73 [M]	-	(a)	(a)					
		0051	76	1.26±0.38 [M]	-	1430	1505					
		0048-0049	122	-	12.0	1379	1500					

PAINTER	INVENTORY NUMBER	BOARD	TOTAL NUMBER OF RINGS	RING WIDT [WOOD GROWTH RATE]	BOARDS FROM THE SAME TREE [illegible]	DENDROCHRONOLOGICAL DATE (AD)					HISTORICAL DATE	TIME LIFE
						FIRST RING	LAST PRESERVED RING	EARLIEST POSSIBLE FELLING DATE	ESTIMATED FELLING DATE	EARLIEST PRESUMED DATE		
Pieter Coecke van Aelst & collaborators	MASF55	0041	156	1.20±0.25 [M]	-	-	-	1506	1512	1508	1533-1534	1502 - 1550
		0042	150	1.71±0.56 [M]	-	-	-					
		0043	216	1.08±0.62 [S]	-	-	-					
		0044	212	1.04±0.61 [S]	-	-	-					
		0045	156	1.70±0.55 [M]	-	-	-					
		0046	142	1.17±0.23 [S]	-	-	-					
		0041-0046	156	-	18.3	1342	1497					
		0042-0045	157	-	15.8	(a)	(a)					
		0043-0044	216	-	12.6	1252	1467					
Workshop of Jan Gossart (Mabuse)	MASF39	0052	168	1.15±0.36 [S]	-	-	-	1534	1540	1536	*ANNO DO 1543*	-
		0053	171	1.22±0.38 [M]	-	-	-					
		0054	168	1.22±0.30 [M]	-	-	-					
		0055	237	1.16±0.36 [S]	-	-	-					
		0056	163	1.24±0.34 [M]	-	-	-					
		0057	167	1.33±0.52 [M]	-	-	-					
		0058	150	1.50±0.60 [M]	-	-	-					
		0059	122	1.19±0.36 [S]	-	-	-					
		0052-0053	174	-	17.5	1333	1506					
		0054-0056	170	-	21.2	1342	1511					
		0055-0059	237	-	10.8	1289	1525					
		0057-0058	168	-	20.6	1288	1455					
Jan Provoost	MASF 29	0060	51(b)	0.98±0.13 [VS]	-	(a)	(a)	1517	1523	1519	1524-1526	1465 - 1529
		0061	241	0.93±0.29 [VS]	-	1250	1490					
		0062	227	0.86±0.24 [VS]	-	1282	1508					
		0063	94	1.53±0.50 [M]	-	(a)	(a)					
Gérard David & collaborators	MASF20	0083	142	1.42±0.34 [M]	-	-	-	1425	1431	1427	1518-1527	1460 - 1523
		0084	197	1.38±0.32 [M]	-	-	-					
		0085	229	1.18±0.30 [S]	-	1188	1416					
		0086	131	1.44±0.32 [M]	-	1270	1400					
		0087	95	1.72±0.48 [M]	-	(a)	(a)					
		0083-0084	208	-	15.8	1205	1412					
Master of the Morrison Triptych	MASF30	0087	26	1.31±0.35 [M]	-	(c)	(c)	1494	1500	1496	1510-1515	-
		0088	133	2.19±0.72 [F]	-	1353	1485					
		0089	240	0.96±0.40 [VS]	-	-	-					
		0090	221	1.09±0.23 [S]	-	1251	1471					
		0091	283	0.95±0.40 [VS]	-	-	-					
		0092	149	1.59±0.43 [M]	-	1310	1458					
		0089-0091	283	-	16.2	1186	1468					
Workshop of Master Holy Blood	MASF43	0103	57(b)	0.89±0.17 [VS]	-	(a)	(a)	1487	1493	1489	1515-1520	-
		0104	152	0.65±0.15 [VS]	-	(a)	(a)					
		0105	103	0.94±0.31 [VS]	-	(a)	(a)					
		0101	197	1.70±0.80 [M]	-	-	-					
		0102	208	1.65±0.78 [M]	-	-	-					
		0101-0102	208	-	24.2	1271	1478					

PAINTER	INVENTORY NUMBER	BOARD	TOTAL NUMBER OF RINGS	RING WIDT [WOOD GROWTH RATE]	BOARDS FROM THE SAME TREE [tbp]	DENDROCHRONOLOGICAL DATE (AD)					HISTORICAL DATE	TIME LIFE
						FIRST RING	LAST PRESERVED RING	EARLIEST POSSIBLE FELLING DATE	ESTIMATED FELLING DATE	EARLIEST PRESUMED DATE		
Master of *Adoração do Machico*	MASF 26	0106	108	2.42±0.76 [F]	-	1377	1484	1493	1499	1495	Final XV c.	-
	MASF 25	0107	161	1.35±0.45 [M]	-	-	-	1447	1453	1449	Early XVI c.	
		0108	152	1.33±0.43 [M]	-	-	-					
		0107-0108	165	-	9.9	1274	1438					
M. van Reymerswaele	MASF 107	0040	99	2.69±0.67 [F]	-	1455	1553	1562	1577	1564	1521-1540	*ca.* 1490 – *ca.* 1567

Supplementary Table 4 summarizes the number of oak sapwood rings from the Baltic region based on geographic area and dendrochronological investigations.

Supplementary Table 4. Number of oak sapwood rings from the Baltic area [min=absolute minimum; max=maximum absolute; n.s.=not specified].

GEOGRAPHIC AREA	WOOD SPECIES / MATERIAL	NUMBER OF SAPWOOD RINGS		REFERENCE
		Median (med) / Average (av)	Range (confidence interval) / min-max	
Easter Baltic (Estonia, Finland, Latvia, Lithuania)	*Quercus pedunculate* L. / living oaks	12 (med)	*c.* 6 – 19 (95%)	Sohar *et al.* (2012)
Easter Baltic (Finland)	*Quercus robur* L. / living oaks > 120 yrs	*c.* 14 (av)	7 – 24	Baillie *et al.* (1985)
Poland (North)	*Quercus* spp. / living oaks	15 (med)	13 – 19 (50%)	Eckstein *et al.* (1986)
Poland	*Quercus* spp. / historical timbers	15 (med)	9 – 23 (90%)	Wazny (1990)
Poland	Oaks < 100 yrs	13 (av)	6 – 22	
Poland	Oaks 100-200 yrs	17 (av)	9 – 31	
Poland	Oaks > 200 yrs	18 (med)	9 – 30	
Poland (Western Pomerania)	Oaks > 100 yrs	17 (med)	10 – 26 (90%)	Wazny (2001)
Poland (South)		13 (med)	7 – 22 (90%)	
Poland (Greater)	n.s.	13 (med)	6 – 21 (90%)	Krapiec *et al.* (2014)
Poland	Oaks > 300 yrs	n.s.	13 (minimum)	Bauch (2002)

Supplementary Table 5 provides several criteria for the time delay between felling an oak and using its wood as a painting support based on different dendrochronological research.

Supplementary Table 5. Time span between felling an oak and the use of its wood as a painting support according to dendrochronological research.

MATERIAL (CENTURY)	TIME SPAN (YEARS)	REFERENCE
Panels (15th century)	10 – 15	Klein (1982)
Panels attributed to Petrus Christus (15th century)	18 (minimum)	Klein (1994a)
Panels (15th and 16th centuries)	10 (approximately)	Klein (1994b)
Dutch and Flemish panels (16th and 17th centuries)	2 – 8	Bauch *et al.* (1981); Klein (1981)
Panels (16th and 17th centuries)	3 – 10	Bauch *et al.* (1974)

Supplementary Table 6 lists the best matches between index series obtained from Flemish paintings and available oak reference chronologies, according to three dendrochronological statistic parameters.

Supplementary Table 6. Statistical matches obtained when cross-matching the index series of the Flemish paintings and the oak reference chronologies listed in Supplementary Table 1 [t_{BP}=t-value Baillie-Pilcher (Baillie and Pilcher, 1973); Glk=percentage of parallel variation, also termed *Gleichläufigkeit* (Eckstein and Bauch, 1969); P=probability of exceedance, based on the percentage of parallel variation (Jansma, 1995); empty cells correspond to t_{BP} lower than 5.0].

PAINTER	BOARD	BALTIC 1			BALTIC 2			NL Baltic Import			NL Baltic A			NL Baltic B			0520003M			0520006M			BOWHILL-B		
		t_{BP}	Glk	P < than	t_{BP}	Glk	P < than	t_{BP}	Glk	P < than	t_{BP}	Glk	P < than	t_{BP}	Glk	P < than	t_{BP}	Glk	P < than	t_{BP}	Glk	P < than	t_{BP}	Glk	P < than
Joos van Cleeve & collaborators	0064							5.2	69	0.0001	5.6	71	0.0001				5.9	68	0.0001	5.6	68	0.0001			
	0065	5.8	64	0.0001				5.4	63	0.0007				6.7	65	0.0001	5.6	64	0.0001				5.7	61	0.0007
	0070	8.5	65	0.0001				10.0	66	0.0001	7.8	65	0.0001	8.9	64	0.0001	7.5	62	0.0005	7.6	63	0.0001	7.6	65	0.0001
	0066-0069	8.1	69	0.0001				6.7	68	0.0002	8.5	68	0.0002				7.5	68	0.0002	6.2	63	0.005	5.2	63	0.01
	0067-0068	8.8	65	0.0001				8.2	63	0.0002	7.2	60	0.005	9.7	62	0.0005	5.4	58	0.02	5.3	56	0.05	7.6	64	0.0001
	0071-0072	5.9	58	0.01				7.2	62	0.0002	8.1	69	0.0001	5.9	57	0.02	7.2	65	0.0001	6.1	63	0.0001	6.1	60	0.002
	0073	10.9	74	0.0001	5.1	60	0.006	10.4	76	0.0001	10.1	76	0.0001	8.5	75	0.0001	9.6	71	0.0001	8.8	68	0.0001	7.9	72	0.0001
	0074	5.2	58	0.004				6.2	62	0.0001	5.5	61	0.0001	6.4	60	0.0004	5.1	61	0.0001	5,0	61	0.0001	5.9	59	0.002
	0075-0076	7.9	68	0.0001				5.9	65	0.0001	5.4	65	0.0001	6.8	64	0.0001	5.0	64	0.0001						
	0077-0078-0082	8.7	67	0.0001				8.6	66	0.0001	8.3	66	0.0001	7.0	66	0.0001	7.9	64	0.0001	6.8	61	0.0002	7.9	66	0.0001
	0079-0080-0081	7.7	69	0.0001				7.9	69	0.0001	6.1	66	0.0001	8.9	74	0.0001	7.3	67	0.0001	6.4	63	0.0001	8.0	67	0.0001
P. van Aelst & collaborato	0047	5.4	73	0.0006				5.0	66	0.02	5.0	70	0.003	5.8	67	0.008									
	0051	5.4	69	0.0005				5.0	71	0.0002	5.3	71	0.0002												
	0048-0049	7.3	69	0.0001				6.2	60	0.02	5.7	64	0.001	7.9	68	0.0001				5.2	65	0.001	5.8	67	0.0003
	0041-0046				9.7	74	0.0001																		
	0043-0044	7.8	63	0.0001				9.8	63	0.0001	7.5	64	0.0001	6.5	58	0.01	7.1	60	0.002	7.4	63	0.0001	8.0	66	0.0001
Work. Jan Gossaert	0052-0053	8.7	73	0.0001				6.7	67	0.0001	6.2	64	0.0002	7.6	67	0.0001	6.0	69	0.0001	5.5	63	0.0006			
	0054-0056	9.4	60	0.005				8.4	59	0.01	8.3	63	0.0005	10.4	62	0.001	6.7	62	0.001	7.3	64	0.0004	7.5	63	0.001
	0055-0059	6.9	59	0.003				6.9	64	0.0001	5.6	63	0.0001	7.7	65	0.0001							5.8	65	0.0001
	0057-0058	6.4	67	0.0001				5.4	63	0.0004				7.3	69	0.0001							5.1	63	0.0004
J. Provoost	0061	7.1	66	0.0001				7.4	66	0.0001	7.3	65	0.0001	6.4	61	0.0005	7.3	63	0.0001	6.7	60	0.001	8.2	65	0.0001
	0062							5.0	63	0.0001	5.4	64	0.0001										5.0	61	0.001

PAINTER	BOARD	BALTIC 1			BALTIC 2			NL Baltic Import			NL Baltic A			NL Baltic B			0520003M			0520006M			BOWHILL-B		
		tBP	Glk	P < than	tBP	Glk	P < than	tBP	Glk	P < than	tBP	Glk	P < than	tBP	Glk	P < than	tBP	Glk	P < than	tBP	Glk	P < than	tBP	Glk	P < than
Gerard David & collaborators	0085				5.0	66	0.0001										5.0	66	0.0001						
	0086				5.5	62	0.007																		
	0083-0084				6.5	59	0.02				5.1	59	0.005				6.0	61	0.001	5.8	61	0.001			
Master of the Morrison Triptych	0088	11.7	76	0.0001				8.7	72	0.0001	8.7	71	0.0001	10.3	73	0.0001	7.6	69	0.0001	7.9	69	0.0001	8.1	68	0.0001
	0090	7.5	62	0.0002				7.2	59	0.004	10.5	66	0.0001				8.0	60	0.002	6.6	61	0.0006	8.7	66	0.0001
	0092	8.7	67	0.0001				7.5	61	0.005	7.4	62	0.002	8.8	70	0.0001	8.2	60	0.008	8.3	61	0.005	6.5	61	0.005
	0089-0091	6.6	62	0.0001				6.5	63	0.0004	8.0	63	0.0001	5.6	62	0.0001	6.8	63	0.0001	6.3	63	0.0004	6.0	62	0.0001
Workshop of Master of the Holy Blood	0101-0102	9.0	67	0.0001				8.6	66	0.0001	7.1	61	0.0008	9.2	67	0.0001	7.6	63	0.0001	6.1	63	0.05	8.1	64	0.0001
Master of *Adoração do Machico*	0106	6.5	65	0.001				6.3	60	0.02	7.8	68	0.001												
	0107-0108	5.6	61	0.0003				5.2	64	0.0002	6.7	64	0.0002				5.3	65	0.0001				6.5	65	0.0001
M. Reymerswaele	0040				5.6	67	0.0004																		

2.3. Dendrochronological research of musical instruments

2.3.1. Development of a new database to coniferous wood artworks

Since access to dendrochronological data is highly restricted, the development of a new database for the dating of coniferous wood artworks is essential. Despite public access to the ITRDB, the geographical and temporal range of dendrochronological sequences is so wide that a database must be created and continually improved. Figure 75 illustrates the CEF-ISA database in three stages of development in this thesis.

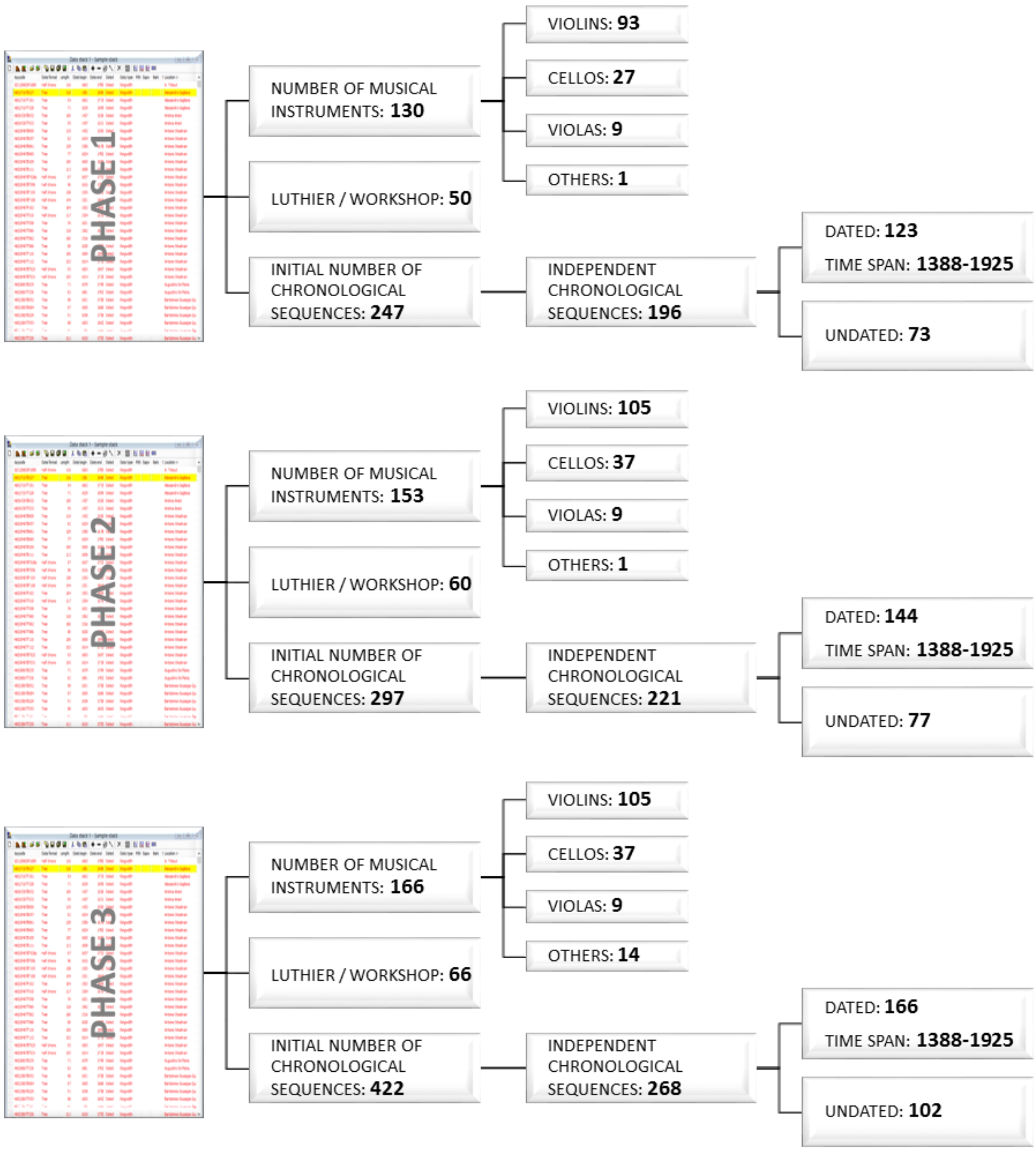

Figure 75. Development phases of the CEF-ISA database for dating musical instruments.

In the first phase, the bellies of 130 musical instruments from 50 different luthier/workshops in three major countries - Italy, Germany, and France - were measured. A total of 29% of the instruments had no established attribution (Figure 76). Approximately 98% of the instruments were kindly provided, mainly through photographs, by two luthiers who requested anonymity. The instruments' measurements were coded based on the type of instrument, assignment, and piece, with the universal designation of some of them never being mentioned.

Figure 76. Distribution of musical instruments analysed by country and luthier/workshop in phases 1 and 3 of the CEF-ISA database.

The observations from the 130 instruments resulted in 247 dendrochronological sequences. Visual and statistical research confirmed the existence of pieces from the same tree in many cases, yielding a total of 196 distinct sequences of more than 50 tree rings for dating. At this phase, 68% of the sequences have been successfully dated. The time span ranged from the late XIV to the early XX centuries, with a special focus on the XVII century (Figure 77). This database stage was used in the dendrochronological analysis presented in the article "*Violins and cellos from Portuguese collections. A tree ring study as a historical source of the Portuguese heritage*".

The results of the 12 violins and 10 cellos listed in the published article V*iolins and cellos from Portuguese collections. A tree ring study as a historical source of the portuguese heritage* (see subchapter 2.3.2) were incorporated into phase 2 of the CEF-ISA database, bringing the total number of luthiers/workshops to 60. The number of independent dated sequences increased to 144 while retaining the same temporal amplitude. This database stage was used for the dendrochronological analysis of harpsichords and fortepianos.

Phase 3 of the database includes 166 musical instruments, resulting in 166 independent dated sequences for further dendrochronological research. From phase 1 to phase 3, the number of manufacturers and countries represented has increased, with a focus on Italian instruments and Antonio Stradivari's workshop (Figure 76). On the other hand, the time span of the chronologies has remained unchanged, with a reinforcement for the period between the late XVI and early XVIII centuries (Figure 77).

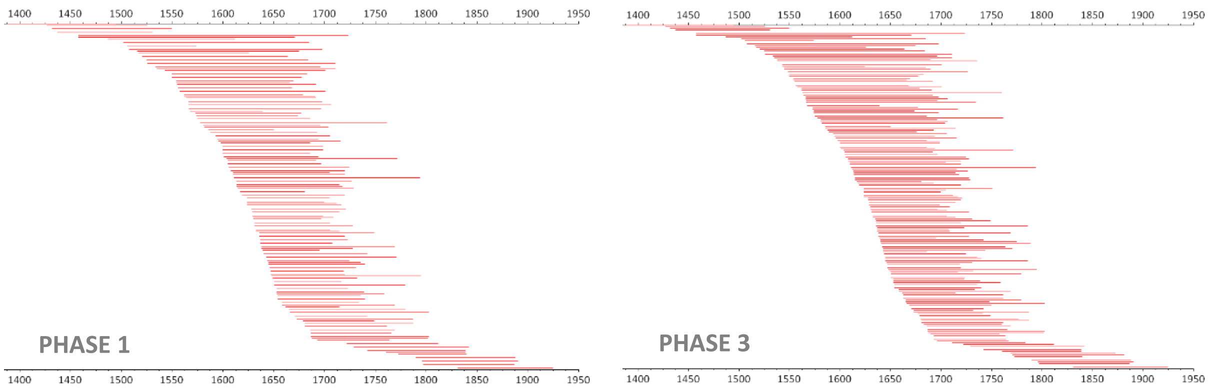

Figure 77. Chronological position of all dated dendrochronological sequences/combination of sequences in phases 1 and 3 of the CEF-ISA database [Graph by TSAP Win Scientific 4.64].

2.3.2. Violins and cellos (ARTICLE)

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Original article

Violins and cellos from Portuguese collections. A tree ring study as a historical source of the Portuguese heritage

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ABSTRACT

This first dendrochronological study of 13 violins and cellos from Portuguese workshops of the XVIII and XIX centuries aims at a deeper knowledge of dates and origin of the top woods used to build the instruments, as well as adding to the understanding of specific assembly techniques. A similar study was also made on 10 violins and cellos of foreign manufacture from the XVII and XVIII centuries, which are currently in Portugal, showing the scientific potential as well as limitations of the dendrochronological approach. The best chronological references which were applied to date the musical instruments manufactured in Portugal came from the Alpine regions of Switzerland, Germany, Austria and Italy, but the identification of specific wood sources was not possible. The only known musical instrument in Portugal attributed to Antonio Stradivari (cello Chevillard) belongs to the collection of the National Museum of Music (Lisbon). The growth patterns on two pieces which compose the belly were compared with those of five other instruments made by the same luthier and was allowed to conclude that the wood came from the same region and, in one specific case, from the same tree. The *terminum post quem* obtained by the dendrochronological dating allowed the confirmation of attribution to a maker for most of the instruments but for two violins the attributions proved erroneous making the case for a reassignment of the two instruments. Dendrochronology led us to the conclusion that the Portuguese musical instruments can be seen as a physical proof of the historical records which document Portuguese maritime wood trade with Europe, mainly with Italy.

Introduction

Wood is a remarkable and unique material when used in the making of musical instruments, which is particularly true for the craftsmanship of violins and cellos. The fascination that we have for these instruments is due to their exceptional sonority, as well as their elegant forms. Wood species with an impressive regular anatomical structure and great acoustic properties are known as 'resonance woods', as their main purpose is to amplify emitted tones [1].

Violins and cellos have wooden bodies made up of several parts, and the luthier carefully selected different wood species for each component, according to its specific function in the instrument. He checked the characteristics of the boards themselves, which need to be free of defects and homogeneous in structure and density. The selection of different wood species and of their geographical origin is therefore a principal element in the construction of musical instruments [2]. Historical manuals of luthiers identified the main tree species used in violins and cellos (e.g. spruce, acer and ebony), the choice of their provenance, as well as the selection criteria which had to be followed [3].

The information provided by luthiers' manuals is now an excellent starting point when studying musical instruments. The history of a musical instrument is important to establish its musical and economic values, and it is also a key information when the authenticity of instrument labels need to be confirmed, since misattributions and frauds have been detected in the past.

In addition to historical records, the methods of dendrochronology can be used when dating instruments, using tree-ring analysis and available chronologies for the respective species and geographical regions [4]. The dendrochronological results are likely to provide the most accurate date for the construction of the musical instrument. Additionally, they provide other information related to the construction procedures, e.g. wood storage duration, use of boards from the same tree and manufacturing details. If there is no

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organological assignment, information on the instruments origin can also be obtained through the regional wood origin. In certain cases, these studies can also be useful to identify wood relationships between different musical instruments [5,6]. Considering the depth of analysis allowed by these studies, a specific subdiscipline was added to dendrochronology: dendro-organology [7].

In the last four decades, several dendrochronological studies were applied to musical instruments, particularly to violins and cellos, and the results were presented to the scientific community [8–10]. For historical and cultural reasons, these studies focused on the research of violins and cellos of Italian, German, English and French origin. Ratcliff [11] mentions the development of five clusters of instruments according to time and provenance, attributing local growth patterns to each one. Particular attention was paid to Antonio Stradivari instruments, due to their renowned musical quality and high market value, and since there was a controversy around dating one of the instruments attributed to him [5,12,13]. Violins, cellos, violas and guitars from several museums and private collections were analyzed focusing on their wood bellies. Beyond dating and analysis of the wood provenance, interesting hypotheses were made regarding the working practices at Cremona workshops - for instance, there was no systematic attempt to remove sapwood, and the seasoning period for the wood had been shortened. Interestingly, several studies found that 16 violins were constructed with the wood of a single log [11].

There is a lack of research on violins and cellos of Portuguese construction from the country's active workshops during the XVIII and XIX centuries. Only three musical instruments attributed to Portuguese luthiers have been previously dated: (1) a guitar attributed to António dos Santos Vieira, from the XIX century, at the Ashmolean Museum, Oxford [14], (2) a violin dated 1929 (handwriting in ink on the bottom), attributed to Augusto Ernesto Pinheiro, belonging to the Theatre Museum Carlo Schmidl, Trieste [15] and (3) a small five-course Renaissance guitar dated 1581 (in label), attributed to Belchior Dias, in the collection of the Royal College of Music, London [16]. Trade and cultural exchanges with Europe in the XVIII century, through the acquisition of instruments of foreign construction, allowed thereby dissemination of knowledge and construction practices [17].

The purpose of the present research is to study the violins and cellos of Portuguese workshops from the XVIII and XIX century and the foreign instruments from the XVII and XVIII century belonging to the National Music Museum (Lisbon) and private collections, using a dendrochronological approach. The results will allow estimating dates and confirmation or rejection of labels and attributions. For the first time, it will give an insight into the construction rules of Portuguese workshops by examining the wood components in violins and cellos.

This study also intends to evaluate to what extent the musical instruments can be considered 'witnesses' of the commercial routes established between Portugal and Europe, with regard to timber trade and cultural exchanges thereby adding information to already existing historical manuscripts of the XVIII and XIX centuries.

Wood resonance for violins' bellies

The historical descriptions of the wood used for violins' bellies refer to different types, e.g. '*sapin*' [3,18]; Swiss pine [19]; '*azarole*' [18], an Italian word referring to '*Epicea*' [20]; 'white pine' [20]; 'pine and fir' [21]. The term 'pine' is used to describe the wood of various species; Norway spruce (*Picea abies* (L.) H. Karst.) is the first to be considered for violins' bellies [1,22].

Picea abies (L.) Karst. subsp. *abies* is the scientific name for Norway spruce, although, for a long-time various terms were used, e.g. *Pinus abies* L. (1753), *Abies picea* Mill. (1768), *Pinus picea* Duroi (1771), *Pinus excelsa* Lam. (1778), *Picea rubra* A. Dietr. (1824), *Picea excelsa* Link (1841), *Picea alpestris* Bruegg ex Stein (1887). *Picea abies* occurs in the mountain ranges of central and southeastern Europe, in the eastern European lowlands and in the Scandinavian peninsula, while Norway spruce forests are found in many countries, namely Switzerland, Austria, Italy, Germany, Russia, Romania, Ukraine and the Scandinavian countries.

The wood is nearly white in color, sometimes with a light-yellow tint. The annual rings are visible very clearly in the cross section and radial surface, with very distinct boundaries caused by cellular differences between earlywood and latewood. Resin canals are few and indistinct [23]. According to the European Standard EN 350 [24], the durability of spruce wood is classified as slightly durable (index DC 4). The physical and mechanical properties of Norway spruce make it a valued source of resonant wood for manufacturers of musical instruments [23].

The wood quality selection for the violin's belly has been related to the tree-growing conditions with the traditional wood selection being performed on trees cut during winter [18,25,26]. Norway spruce harvested and debarked in summer tends to crack quickly [23].

Wood obtained from older trees is considered best for the manufacture of musical instruments [18,26]. In Norway spruce, the border between sapwood and heartwood is not distinct, since both types of wood have a similar structure and colour [19,23,27]. Therefore, a trunk with a regular and uniform texture will produce larger and more homogeneous planks.

Depending on geographic region and climatic conditions, Norway spruce wood shows variations in the annual growth ring width, and therefore the physical and mechanical properties of the wood also vary. Over time, manufacturers developed a preference for woods with rings which were not too wide or too narrow, in order to obtain a texture which was neither too hard nor too soft [28–30]. Achieving desirable tree ring patterns is the underlying reason for the preference of cutting sites on southern slopes and, on the tree itself, choosing the section facing the sun [18,19,25]. Regular and straight grain from the top to bottom of the violins belly is considered standard [18,25,28]. However, Bucur [1] notes that indented spruce seems to produce a brilliant sound in violins.

Drying wood in the open air whilst protecting it from rain and sun, has long been the preferred method over any less natural process [31]. Norway spruce wood dries relatively quickly with minimal shrinkage, although it is susceptible to cracking [23]. However, the duration of the wood seasoning process in violin construction varies according to the literature: a minimum of 5 years [18,20,32]; a maximum of 3 years, based on 34 violins from the Italian Guarneri family [6]; 5–25 years, for Italian and German masters from 1563 to 1892 [33]; a minimum of 45 years for German masters from XVIII century [33]; 10–50 years [34].

Material and methods

Musical instruments

This study is based on a set of 13 violins and ten cellos of Portuguese and foreign workshops belonging to the National Music Museum (Lisbon, Portugal) and private Portuguese collections. Table 1 lists the inventory codes for the instruments (Museum: MNM; private collections CP), their attributions, the maker's lifetime or activity period and the label date. The label dates cover the period between the early 1600s to 1892. All the instruments were playable and fitted with strings, except for the MNM0300 cello.

Table 1
Violins and cellos from the National Music Museum (Lisbon, Portugal) with MNM inventory code and from private collections with CP inventory code, with their attribution, the maker's lifetime/activity period, and the label date.

Musical instrument (inventory number)	Atributtion	Lifetime/ activity period[a]	Label date
Portuguese workshop			
Violin (MNM0067)	António Joaquim Sanhudo, Porto	1846–1869	1860
Violin (MNM0069)	António Joaquim Sanhudo, Porto	1846–1869	1849
Violin (MNM0078)	António Joaquim Sanhudo, Porto	1846–1869	1865
Violin (MNM0185)	António Joaquim Sanhudo, Porto	1846–1869	1867
Violin (MNM0070)	Henrique Monteiro & Son, Lisbon	1840–1910	1892
Violin (MNM0073)	Henrique Monteiro & Son, Lisbon	1840–1910	1891
Violin (MNM0074)	Joaquim José Galrão, Lisbon	1760–1787	1794
Violin (MNM0075)	Joaquim José Galrão, Lisbon	1760–1787	1780
Cello (MNM0041)	António Joaquim Sanhudo, Porto	1846–1869	1862
Cello (MNM0043)	Felix António Diniz, Lisbon	1807–1858	1797
Cello (MNM0044)	Joannes Petrus Hausz, Lisbon	Unknown	1750
Cello (MNM0040)	Joaquim José Galrão, Lisbon	1760–1787	1769
Cello (MNM0046)	Joaquim José Galrão, Lisbon	1760–1787	1781
Foreign workshop			
Violin (CP10)	Anonymous Mirecourt, France François Richard, France (significant finalisation[b])	Mid-XIX century in Paris	××
Violin (CP01)	Giovanni Battista Gabrielli, Italy	1716–1771	1753
Violin (CP11)	Giovanni Paolo Maggini, Italy	1580–1651	16?0
Violin (CP16)	Johann Gottlob Ficker, Germany	1744–1832	××
Violin (CP19)	Nicola Amati, Italy	1596 – 1684	1670
Cello (MNM0047)	Antonio Stradivari, Italy	1644–1737	1725
Cello (MNM1300)	Christian Friedrich Mann, Germany	1754-????	1791
Cello (MNM0039)	Attrib. Henry Lockey Hill, England	1774–1835	×
Cello (MNM0799)	Anonymous, Germany	n.a.	×
Cello (CP06)	Anonymous, France	n.a.	××

× no label; ×× label without date; n.a. not applicable.
[a] Source: Vannes [78];
[b] Luthier's personal comment.

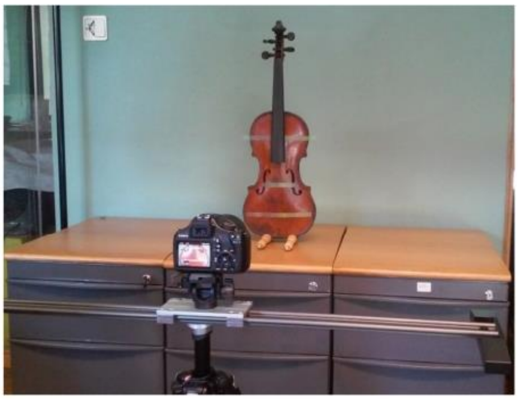

Fig. 1. Measuring stage with digital photographic camera attached to a slider on a tripod.

Methodology

Growth rings were measured on the top plate of the instrument. The instrument was securely placed on a wooden base to ensure a vertical position for taking photographs. A digital photographic camera (CANON EOS 1100d) with a macro lens EF S 60 mm was attached to a 60 cm long slider on a tripod, so that the camera lens was positioned parallel to the surface of the instrument (Fig. 1). The brightness was adjusted individually for each image, taking in account the type and colour of the instrument's varnish. A laptop was attached to the digital camera to view the growth rings on a larger screen, and to enable better border discrimination, if necessary.

The images of the growth rings from the bass and treble sides of the belly were taken along a line crossing the widest part of the instrument, to ensure the capture of the largest number of rings. If the rings were not completely distinct, two higher levels of the instrument were considered. Scale labels were attached on the instrument's surface.

Ring measurements were performed on photographs using Image Analisys software (version 3.2, AnalySIS Soft Imaging System GmbH, Münster, Germany), with image calibration based on the scale reference. The tree-ring sequences were visualized and analysed with TSAP Win Scientific 4.64 (Rinntech) software. The dendrochronological dating was based on statistical parameters such as (a) *Gleichläufigkeit* indicator (Glk) which is a statistical tool in dendrochronology assessing the similarity between two growth curves, by analysing upward and downward trends between two consecutive points in time; (b) Glk statistical significance, that can be 90.0%, 95.0% or 99.9%; and (c) t-value based on Hollstein (1980), t_H.

The ring series obtained from the instrument were compared by visually and statistically matching them with master chronologies. The present study used several chronologies from the Laboratory for Dendrochronological Investigations on Musical Instruments and Art Objects of Micha Beuting (Germany) and from the International Tree-Ring Data Bank (ITRDB). European chronologies of Norway spruce (*Picea abies* (L.) H. Karst.), silver fir (*Abies alba* Mill.), European larch (*Larix decidua* Mill.) and Swiss stone pine (*Pinus cembra* L.) were selected, over a total interval time from 1456 to 2004. Cross-dating was also performed through comparison with several tree-ring patterns obtained from other musical instruments, for instance violins, cellos, clavichords and harpsichords, available online (https://www.cybis.se/wiki/index.php?title=List_of_references_useful_for_violins) and in scientific reports [35,36].

The following criteria were used to establish statistically valid dating: (a) t_H equal or greater than 4 [37,38]; (b) Glk equal or greater than 60% [37–39]; and (c) replication of each series with local and regional chronologies and master-chronologies, thereby allowing a continual and a desired cross-check [4,40].

To determine if two wood pieces of an instrument belong to the same tree, the criteria defined by Beuting [7] was applied: (a) t_H greater than 8; (b) Glk greater than 70%; (c) 99.9% statistical significance; (d) a minimum of 70 years of tree rings overlap; (e) graphical similarity between the two growth curves; (f) similar tree-ring widths of compared sequences; (g) agreement of pointer years; and (h) nearly the same year of the beginning or end of the sequences.

Dendrochronology can be used in the research of the original timber source. The reference chronologies used for the successful dating of an artefact are associated with geographical areas. If these areas are sparsely dispersed, the material source may be precise; however, the study may be inconclusive if there is a great spatial dispersion in the chronologies [41].

Results

The study of the 23 musical instruments (Table 2) provides information on their construction, namely on the number of wood pieces that compound the instrument's belly: in the large majority of cases the belly was made up of two wood pieces, with the exception of violin MNM0067 with only one piece, and of the cellos MNM0046 and MNM0041 with four and five pieces respectively.

A total of 50 sequences of growth rings with different dimensions were measured, from 46 years (violin CP01, treble side) up to 198 years (cello MNM0039, bass side). The average width of the annual growth rings in the chronological series ranged between 0.54 mm (violin MNM0073, treble side) and 3.09 mm (cello MMM0041, treble side) with one of the lowest standard deviations and the highest (0.14 and 0.92, respectively). This means that the violin shows a more uniform ring pattern, in contrast to an irregular ring pattern in the cello.

The statistical analysis for the sequences belonging to the same instrument, as detailed in Table 2, provides information on the wood selection for the instruments. In 19 of the 23 instruments analyzed, the wood pieces used for the instrument's belly came from the same tree since they met the requirements set by Beuting [7]. However, three of them did not comply with at least one of the conditions: (a) Portuguese violin MNM0069 and German cello MNM1300 with an overlap lower than 70; and (b) the Italian cello MNM0047 with a Glk lower than 70%. Nevertheless, in these three cases, the graphical similarity between the two growth curves of each instrument is very high, suggesting that they are pieces belonging to the same tree (Figs. 2 and 4). The Italian violin CP01 is a particular case: overlap lower than 70, a great difference between the number and the average width of the rings of the two planks (92 and 46 rings; 0.99 mm and 2.04 mm). The graphic analysis of the sequences (Fig. 3) and the high values of Glk, statistical significance and t_H (84%, 99% and 8.8, respectively) suggest that the plank with the lowest number of rings was cut in the innermost part of the trunk, with wider rings. The pattern is very similar in the area of overlap of the two sequences. In three instruments it is clear that the pieces did not belong to the same tree: (a) Portuguese violin MNM0075 and the English cello MNM0039 with t_H less than eight and Glk below 70% and (b) Portuguese cello MNM0041 consisting of five short sequences with a short overlap and weak similarity between the growth curves.

The dating (*terminus post quem*) of the musical instruments was possible for 20 musical instruments (eleven violins and nine cellos). The most significant correlations were obtained with the chronologies of Norway spruce from the Alpine region (codes ITRDB: AUST, GERM, IT and SWIT) (Table 3).

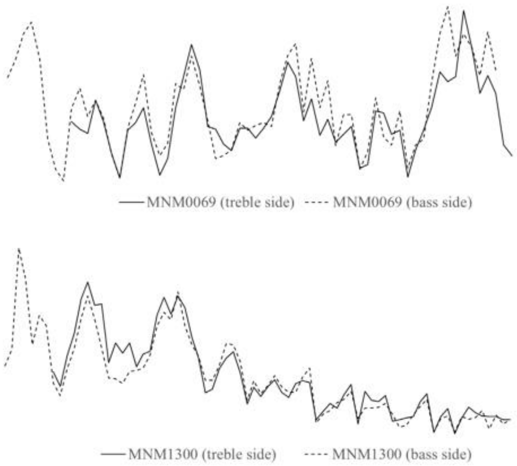

Fig. 2. Comparison of ring sequences from the treble and bass sides of the Portuguese violin MNM0069 and the German cello MNM1300.

Fig. 3. Comparison of ring sequences from the treble (46 rings) and bass (92 rings) sides of an Italian violin (CP01) made by Giovanni Battista Gabrielli (1716-1771).

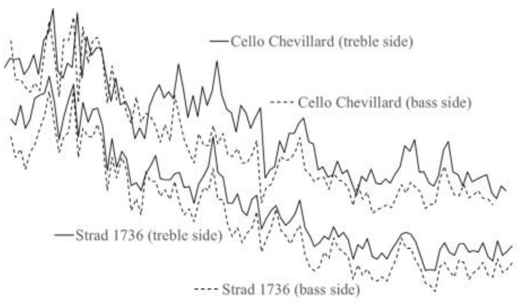

Fig. 4. Comparison of ring sequences from the treble and bass sides of the cello Chevillard and a cello from a private owner made by Antonio Stradivari.

The period between the date mentioned on the label (historical date) and the *terminus post quem*, calculated through dendrochronology, displayed approximate values (<30 years) in seven instruments and a considerable difference in six instruments, ranging from 34 to 201 years (Table 3). High and low negative values were obtained in four violins (−6 in MNM0185 and −9 in CP01; −98 (at least) in CP11 and −116 in CP19), making it likely that the information on the labels inside the instruments is correct.

A comparative analysis of the dendrochronological sequences was made among the Portuguese instruments (Table 4) and between these and the foreign instruments (Table 5), in order to obtain some insight into the wood supply. One of the most impor-

Table 2
Characterization of violins' and cellos' bellies of Portuguese and foreign workshops [Glk: *Gleichläufigkeit*; Statistical significance *90.0% **95.0% *** 99.9%; t_H: t-value, after Hollstein [77]; n.a.: not applicable] [1] best results between the three longest sequences.

Musical instrument (inventory number)	Number of belly pieces	Pieces same tree	Statistical parameters for comparative analysis between series of the same instrument			Tree rings			
						Number		Width (mean ± stdv) mm	
			Overlap	Glk	t_H	Bass/ treble	Serie	Bass	Treble
Portuguese workshop									
Violin (MNM0067)	1	n.a.	n.a.	n.a.	n.a.	n.a.	157	1.03 ± 0.28	
Violin (MNM0069)	2	Yes	54	82^{***}	11.3	56 / 62	64	1.21 ± 0.36	1.35 ± 0.45
Violin (MNM0078)	2	Yes	79	76^{***}	8.5	84 / 83	88	1.13 ± 0.31	1.15 ± 0.29
Violin (MMM0185)	2	Yes	80	77^{***}	10.9	105 / 80	105	1.00 ± 0.42	1.02 ± 0.32
Violin (MMM0070)	2	Yes	88	83^{***}	12.5	90 / 139	141	0.83 ± 0.19	0.68 ± 0.24
Violin (MNM0073)	2	Yes	110	71^{***}	7.5	153 / 110	153	0.58 ± 0.17	0.54 ± 0.14
Violin (MMM0074)	2	Yes	94	74^{***}	14.4	96 / 100	102	1.01 ± 0.44	0.98 ± 0.50
Violin (MNM0075)	2	No	69	65^{**}	4.2	69 / 100	n.a.	1.30 ± 0.15	0.95 ± 0.30
Cello (MNM0041)	5	No	44[1]	86^{***}[1]	8.3[1]	12; 21; 67 / 48; 41	n.a.	1.66 ± 0.56 1.88 ± 0.53 1.86 ± 0.67	3.09 ± 0.92 2.03 ± 0.63
Celllo (MNM0043)	2	Yes	133	70^{***}	13.0	133 / 136	136	1.62 ± 0.50	1.58 ± 0.42
Cello (MNM0044)	2	Yes	144	79^{***}	14.4	169 / 144	169	1.29 ± 0.34	1.61 ± 0.48
Cello (MNM0040)	2	Yes	112	84^{***}	12.9	113 / 124	125	1.85 ± 0.59	1.84 ± 0.53
Cello (MNM0046)	4	Yes	123	70^{***}	12.1	58; 127 / 123; 61	127	1.06 ± 0.27 1.25 ± 0.32	1.22 ± 0.33 1.14 ± 0.28
Foreign workshop									
Violin (CP10)	2	Yes	140	83^{***}	10.1	140 / 151	151	0.67 ± 0.19	0.62 ± 0.18
Violin (CP01)	2	Yes	38	84^{****}	9.9	92 / 46	100	0.99 ± 0.79	2.04 ± 0.99
Violin (CP11)	2	Yes	96	78^{***}	10.0	98 / 96	98	0.96 ± 0.34	0.95 ± 0.31
Violin (CP16)	2	Yes	147	75^{***}	11.0	147 / 149	149	0.76 ± 0.15	0.75 ± 0.17
Violin (CP19)	2	Yes	127	72^{***}	12.8	127 / 142	142	0.75 ± 0.16	0.67 ± 0.11
Cello (MNM 047)	2	Yes	101	67^{***}	9.0	101 / 105	105	1.95 ± 1.01	1.89 ± 0.90
Cello (MNM1300)	2	Yes	67	80^{***}	11.5	67 / 74	74	2.73 ± 1.28	2.77 ± 1.33
Cello (MMM0039)	2	No	146	46	2.9	198 / 146	n.a.	1.09 ± 0.45	1.50 ± 0.45
Cello (MNM0799)	2	Yes	108	80^{***}	13.8	112 / 108	112	1.99 ± 0.87	2.05 ± 0.85
Violin (CP06)	2	Yes	172	80^{***}	21.6	179 / 172	179	1.16 ± 0.30	1.22 ± 0.29

tant conclusions that emerged was the fact that the provenance of the wood used in the Portuguese cello MNM0046 differs from the wood of all the other Portuguese instruments. Similarly, the wood's origins of the CP11 and CP16 violins and the MNM1300 and MNM0039B cellos differed from the remaining instruments studied.

Discussion

Portuguese musical instruments

The starting point for the present, first extensive dendrochronological research is a set of violins and cellos attributed to manufacturers with a working life in Portugal. Topham [14] published the first article with a dendrochronological result of a Portuguese instrument, in which he assumed a priori that any instrument made in an Iberian Peninsula's workshop would have been built with local wood. However, when dating a guitar attributed to António dos Santos Vieyra (XVII century), Topham [14] demonstrated that the timber source was the alpine region. Thus, this single result put his initial hypothesis into question. Our study confirms Topham's result, as it was possible to establish dates for the wood of the stringed instruments manufactured in Portuguese workshops of the XVIII and XIX centuries by using reference chronologies of the alpine area (Table 3).

To evaluate the flow of the Portuguese wood trade in the XVIII and XIX centuries, it was necessary to look into the customs systems of the time. However, the presence of successive custom structures and reforms made this analysis extremely complex. The *Paço da Casa da Madeira* was a Portuguese government agency, tasked to deal with the wood trade and other types of commerce between Portugal and the rest of the world. In 1644, the first Rules of Procedures were signed, determining that timber and other commodities should only be unloaded at certain locations. There was a review by order of King João IV, by which the entire movement of incoming and outgoing goods was specified, and which also regulated the sale and chartering of vessels, e.g. ¨*all wood planks that come from outside the Kingdom, and from the Islands, or from any part that comes to this City by sea or by land, . . . shall pay the rights of the tithe and siza*" [42]. In addition to these two taxes, a third one was introduced after the 1755 earthquake in Lisbon, and the reconstruction of Lisbon was partly carried out by a tax of 4% on imported products, as confirmed by a Royal Decree of 2 January 1756. The *siza* and tax were collected in cash and the tithe in kind.

During the successive customs reforms, a new institution was created in 1774 by order of King José I - *Contadoria da Superintendência Geral dos Contrabandos, e Descaminhos dos Reaes Direitos.* This was an agency which was meant to prevent smuggling and the embezzlement of royal rights with the main objectives of developing a new annual system of registration for Portuguese commerce and controlling the resources of the Empire. Due to the Portuguese civil war between 1828 and 1834, known as the Liberal Wars, customs records were interrupted, and the new records starting in the 1840s show a different data structure [43].

The available handwritten records from these two institutions, as well as the periodicals [44–50], indicate Sweden, England, Russia, Denmark, Norway, Finland and the Baltic region as the main wood suppliers. In addition to this, wood supply from Italy is also mentioned in Gazeta de Lisboa [51] *"Venice, 30th June . . . Our arsenal and our Rills are filled with wood, iron and hemp (. . .)".* However, wood components for musical instruments were registered under a different category. In *Resumos de Importação e Exportação de Por-*

Table 3
Cross-dating of sequences using ITRDB and personal databases. Comparison between *terminus post quem* (TPQ) and respective label date [× no label; × × label without date].

Musical instrument (inventory number)	Dendrochronological output (best results)				Historical dating (label)	Δ Historical - dendro dating (TPQ)
	Glk	t_H	*TPQ*	References		
Portuguese workshop						
Violin [MNM0067]	66***	6.3	1834	GERM011, SWIT173, ITAL006 (ITRDB); Houbrechts [35]; 9999983 m (Micha Beuting personal database)	1860	26
Violin [MNM0069]	–	–	–	–	1849	–
Violin [MNM0078]	–	–	–	–	1865	–
Violin [MNM0185]	73***	4.9	1873	SWIT120, SWIT173, ITAL007 (ITRDB)	1867	−6
Violin [MNM0070]	68****	5.6	1685	6525701_vgl (Micha Beuting personal database)	1829	144
Violin [MNM0073]	63***	6.8	1690	6525702_vgl (Micha Beuting personal database)	1891	201
Violin [MNM0074]	73***	9.2	1744	AUST003, SWIT169, SWIT173 (ITRDB); [35]; origHK023507B038	1794	50
Violin [MNM0075]	75*** 78***	9.7 11.9	17581762	AUST003, SWIT169, SWIT173 (ITRDB); Houbrechts [35]; origHK023507B038; 03_002 (Micha Beuting personal database)	1780	18
Cello [MNM0041]	–	–	–	–	1862	–
Celllo [MNM0043]	72***	6.8	1775	SWIT173 (ITRDB); [35]; origHK023507B038;	1797	22
Cello [MNM0044]	65***	6.5	1735	SWIT169, SWIT173 (ITRDB); [35]; origHK030407BT031; origHK020102T041	1769	34
Cello [MNM0040]	81***	10.9	1698	GERM063, SWIT169, SWIT173 (ITRDB); Houbrechts, [35]; origHK020102T041; origHK030407BT031; 9999919 m (Micha Beuting personal database)	1769	71
Cello [MNM0046]	71***	4.8	1707	Houbrechts [36]	1781	74
Foreign workshop						
Violin [CP10]	77***	9.2	1780	AUST003, GERM062, SWIT169, SWIT293 (ITRDB); 9999919 m (Micha Beuting personal database)	× ×	–
Violin [CP01]	73***	8.8	1762	AUST003, ITAL025, SWIT347 (ITRDB); Houbrechts [35]; 03_002 (Micha Beuting personal database)	1753	−9
Violin [CP11]	74***	6.3	1777	AUST003, SWIT170 (ITRDB); Houbrechts [35]; 9999903 m (Micha Beuting personal database)	16?0	−98 (at least)
Violin [CP16]	75***	10.1	1789	GERM4, GERM5 (ITRDB); Houbrechts [35]; 9999981 m (Micha Beuting personal database)	× ×	–
Violin [CP19]	71***	5.6	1786	9999908 m, 9999909 m (Micha Beuting personal database)	1670	−116
Cello [MNM0047]	77***	10.9	1716	SWIT169 (ITRDB); HK030407BT031; 330mk_01, 02_005 (Micha Beuting personal database)	1725	9
Cello [MNM1300]	73***	5.7	1784	BayPC, BayPC1, GERM12 (ITRDB)	1791	7
Cello [MNM0039]	76***63***	6.9 11.6	17601690	GERM062, GuA2, SWIT170, SWIT169 (ITRDB); [35]; 02_001 (Micha Beuting personal database)	×	–
Cello [MNM0799]	74***	7.1	1882	GERM014, GERM020, GERM039, GERM040 (ITRDB); 04_002, 05_002 (Micha Beuting personal database)	×	–
Cello [CP06]	780***	16.1	1727	AUST003, GERM062, SWIT169, SWIT293 (ITRDB); 9999919 m (Micha Beuting personal database)	× ×	–

Table 4
T-values (t_H) obtained for the cross-matching of the mean ring width sequences from Portuguese instruments from the XVIII century ("–" value less than 4).

	MNM0074	MNM0075B	MNM0075T	MNM0043	MNM0044	MNM0040	MNM0046
MNM0074		5.0	6.6	4.8	–	4.1	–
MNM0075B			4.2	4.4	–	4.5	–
MNM0075T				5.8	–	–	–
MNM0043					5.7	–	–
MNM0044						4.5	–
MNM0040							–
MNM0046							

Table 5
T-values (t_H) obtained for the cross-matching of the mean ring width sequences between Portuguese and foreign instruments from the XVIII century ("–" value less than 4).

	CP06	CP10	CP01	CP11	CP16	MNM0047	MNM1300	MNM0039B	MNM0039T
MNM0074	4.1	5.2	7.2	–	–	6.7	–	–	–
MNM0075B	–	4.9	4.4	–	–	–	–	–	–
MMM0075T	7.2	8.2	6.3	–	–	4.1	–	–	–
MNM0043	4.7	4.6	6.2	–	–	–	–	–	4.0
MNM0044	6.7	4.7	–	–	–	–	–	–	7.1
MNM0040	7.0	7.0	–	–	–	5.2	–	–	6.5
MMM0046	–	–	–	4.3	–	–	–	–	–

tugal para o Brasil, Ilhas, América, África, Ásia e Nações Estrangeiras [52,53] and *Mappas Geraes do Commercio de Portugal* [54–58], which intermittently cover the period between 1796 and 1870, items are mentioned for repair or construction of stringed musical instruments, e.g. the import of instrument components. This includes bellies and bottom planks for violas and strings for four instruments: sitar, guitar, clavichord, and viola. The main country of origin of bellies and wood for violas was Italy, with a single registration from England to Porto in 1827. This information is confirmed by Gazeta de Lisboa [59,60] and by the correspondence of the Portuguese consulates in Trieste [61–66], which indicate the import of wood for violas from Trieste and Venice to Lisbon. The records for the 4% tax also mentioned payments from Venice relating to "*800 tops violla to deliver whom belong*" and "*200 packs of tops violla to deliver whom belong*" and "*3000 tops violla to deliver whom belong*" [67].

This historical information can now be backed by the dendrochronological results performed on the musical instruments, showing that the best reference chronologies for the ring series that allowed the dating of instruments were from the Alpine regions of Switzerland, Germany, Austria and Italy (Table 3). However, the precise wood growing location used to make the belly of the Portuguese violins and cellos is unclear since the geographical dispersion of the reference chronologies is wide. Nevertheless, the continuous improvement of the databases of reference chronologies used in the dating of musical instruments may allow, in the future, a deeper analysis of the wood provenance.

It was not possible to date three instruments: two violins and a cello attributed to António Joaquim Sanhudo (MNM0069, MNM0078 and MNM0041, respectively) (Table 3). The inability to cross-match the sequences of these instruments with several chronologies can be partially explained by the singularity of the wood growth conditions since numerous factors influence tree-ring characteristics, especially climatic factors, and site location (altitude, forest structure, the tree's age, etc), which will determine distinct growth patterns even in relatively localised areas [26]. However, it should also be taken into consideration that the available reference databases and master chronologies do not yet cover all areas.

This dendrochronological study also unveiled some working practices followed by Portuguese workshops. Most of the studied violins and cellos were composed by two or more frontal pieces belonging to the same tree (Table 2), except for a violin attributed to Joaquim José Galrão (MNM0075). In all instruments with two belly pieces, the board was positioned with the oldest and thinnest growth rings located on the innermost area of the top plate, corresponding to the standard procedure [26].

According to Buksnowitz et al. [68], the sound quality of an instrument depends on the construction techniques, the quality of the raw materials and the luthier's experience and intuition when selecting the wood. The width of the annual rings and their regularity were the most important structural-anatomical parameters, followed by the wood colour [68,69]. In all the Portuguese instruments that were studied, the comparative analysis of the number and average width of the rings in the same instrument did not reveal large differences (Table 2), showing a homogeneous visual appearance. The fact that the selected woods displayed rings which were not too wide (average width under 2 mm) and had no defects, confirms that aesthetics were also considered by Portuguese workshops. Wide rings were considered as *"aesthetically disadvantageous"* [69].

The time span between the date mentioned in the label (historical date) and the *terminus post quem* ranged between 7 and 74 years, with the exception of two violins attributed to Henrique Monteiro & Son with a time difference of 144 and 201 years (Table 3). In this specific case, it may be assumed that the luthier chose very old wood and selected the innermost section of the wood stem with the removal of sapwood rings. The data which were determined for the Portuguese instruments do not diverge from those obtained in other studies for Italian [15] and British [70] stringed instruments from the XIX century.

The criteria for selecting and assembling the frontal pieces which were followed by Portuguese workshops for violins and cellos construction are identical to those used in the largest European centers at the time. This indicates a knowledge transfer between countries [22,31,70], either through the travels of Portuguese musicians abroad, or through the arrival of foreigners to Lisbon [71]. An example of a foreigner violinmaker in Lisbon is Joannes Petrus Hausz, whose presence in the city has been proved by a violoncello (MNM0044) which has a label reading "*Joannes Petrus HAUSZ fecit Original Lisbon An. 1750*".

Foreign musical instruments

According to Hill et al. [72], the cello Chevillard (MNM0047) does not differ from the other Stradivari violoncellos, in shape and size, but it shows work and style details from other hands, thus proving a collaboration with Stradivari' sons. Presumably, this violoncello was one of the last to be created by A. Stradivari, because the few years before 1730 correspond with a period of absence from cello construction, probably due to his old age [72]. The two pieces of the cello Chevillard (MNM0047) have a high degree of correlation in the wood ring series, thus suggesting the same tree origin (Fig. 4; Table 2), as also found in several instruments manufactured by A. Stradivari [5,12,16]. Unsurprisingly, both sides of the cello Chevillard also closely match another cello (Strad 1736 from a private owner) from the same maker (Fig. 4), suggesting the provenance of the four pieces from the same tree stem (t_H between 10.3 and 10.6). The belly showed a symmetrical distribution of rings, which narrowed in the middle and widened towards the edges. This procedure is more common in the instruments constructed by A. Stradivari after 1700, because before this time the choice of wood seemed to be more random [12,14]. *Terminus post quem* (1716) was significantly earlier than the label date (1725), therefore not questioning the attribution to A. Stradivari, who died in 1737. A short seasoning period of less than ten years (including the sapwood rings that were removed) is in line with the results by Topham [14] and Gassmann [73], who demonstrated a range of seven to eleven years in eight instruments. Nevertheless, in several other instruments a longer storage period, spanning from 16 to 36 years was also reported [14,73,74].

The Italian violin (CP01), labeled '*Gio. Battista de Gabbrielli Fece in Firenze* 1753', was considered by an expert as *"(. . .) a beautiful example of this important Florentine master"*. *Terminus post quem* (1762) was significantly later than the label date (1753), although a seasoning period from two to ten years was established in other instruments of the same maker [9]. However, our result does not question the attribution since Giovanni Battista Gabrielli died in 1771. Indeed, the question of a violin's authenticity is rarely substantiated by the information contained in the label, which is considered unreliable [22,72].

The German cello (MNM1300) bears the label '*Christian Friedrich Mann Instrumentmacher in Zittau* 1791'. Biographical notes are practically non-existent. No references were found in connection with Christian Friedrich Mann, except for the date and place of birth of 25 February 1754, Cunersdorf, Sachsen, Germany. The determined *terminus post quem* (1784) is earlier than the label date (1791), and therefore not questioning the attribution. This is an example where a label is an important source of information, in this case on an obscure maker of minor importance [72].

In cases where authorship is unknown, dendrochronological analysis allows for the object to be put into a historical context. This was the case for: (a) a German cello (MNM0799), stylistically dated by the National Museum of Music as belonging to the second half of the XIX century, for which *terminus post quem* was the year 1882; and (b) a French violoncello (CP06), dated stylistically as belonging to the XVIII century, which was dated here to the first quarter of the century (1727).

The French violin (CP10) with an undated label and assigned to François Richard, was built in Mirecourt, an important and famous violin manufacturing center [21]. However, it was only finished by François Richards, who worked between 1850 and 1870 in Paris. This hypothesis is confirmed by the dendrochronological study since *terminus post quem* is the year 1727.

The cello attributed to Henry Lockey Hill (MNM0039) has no date label and it is questionable whether this cello was built by Lockey Hill (1756–1810) or by his son Henry Lockey Hill (1774–1835). The dendrochronological results show that the last datable ring corresponds to the year 1760, a *terminus post quem* which therefore cannot contribute to the clarification of the issue, as it makes both two makers possible. A similar case is verified with the German violin (CP16), stamped inside the back with the initials 'J.G.F.' and flanked by small flowers or crosses as symbols. It can be questionable whether the violin was built by Johann Gottlob Ficker I (1744–1832) or by his son Johann Gottlob Ficker II (1778–1827), both admitted into the violinmakers' guild of Markneukirchen [75]. The dendrochronological results reveal that the last datable ring corresponds to the year 1789, a *terminus post quem* which therefore cannot clarify this matter, as it makes both two violinmakers viable.

Dendrochronology is in certain cases applied in forensic investigations [76], and several false attributions and dates for works of historical and artistic interest were exposed through dendrochronological studies [12,30]. This was also the case in the present study for two Italian violins, belonging to a private collection. The violins had been initially attributed to Giovanni Paolo Maggini (CP11) and Nicola Amati (CP19), dated as 16?0 and 1670, respectively. Giovanni Paolo Maggini and Nicola Amati died in 1651 and 1684, respectively. However, the *terminus post quem* were found to be later dates (1777 and 1786, respectively), making the case for a reassignment of the two instruments.

Cross-matching of the tree ring sequences from the Portuguese instruments from the XVIII century did not reveal strong correlations (Table 4), thereby not allowing to draw conclusions about the existence of a common source of timber supply for musical instruments in Portugal. However, in certain cases, there was a strong correlation between Portuguese and foreign instruments (Table 5), thereby suggesting similar sources of wood for instruments built in Italy, France, England and Portugal in the XVIII century. This hypothesis is confirmed by the Portuguese historical records presented above.

Conclusions

This study proves that it is possible to use a dendrochronological approach when dating violins and cellos built in Portuguese workshops in the XVIII and XIX centuries. The theories regarding the provenance of the woods selected for the construction of these instruments are confirmed by historical records of Portuguese maritime trade with Europe, especially Italy. Several cases presented in this study prove the significant contribution made by the close examination of growth rings when researching the scientific and historical context of these instruments. This proved particularly useful for the confirmation of attribution to a particular maker and for the identification of forgeries. However, in some instances, the limitations of dendrochronology as a means for the accurate dating of instruments were also revealed. In some cases, the results were inconclusive regarding the accuracy of the initial historical hypothesis.

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2.3.3. Harpsichords and fortepianos

The soundboard of a keyboard instrument is recognised as the most important component of its acoustic quality (BUCUR, 2006). The present research applied to clavichords, harpsichords and fortepianos enabled, in addition to its primary purpose of dating the instrument, a more thorough study of their construction. However, it is important to point out that this dendrochronological analysis has no intention of assessing the musical quality of the instruments.

2.3.3.1. Composition of the soundboard

The wood boards of all the soundboards of the analysed harpsichords and pianofortes are arranged perpendicularly to the keyboard (see ANNEX 4 - Figures 3B, 4D, 5C, 6C, 7B, 9B, 11D and 12C). The exception is the Portuguese harpsichord of unknown attribution (MNM0681) with oblique boards (see ANNEX 4 - Figure 8B). The boards are parallel to the keyboard on the right side of the three clavichords (see ANNEX 4 - Figures 1B, 2B and 10B). The boards on the Ruckers virginal (MNM0395) are parallel across the instrument's entire width (see ANNEX 4 - Figure 13C).

The soundboards of the examined harpsichords and pianofortes present a variable number of wood boards, ranging from five (CRMM) to nineteen (MNM0681) (Table 28), as it was also verified in several Belgian and French pianos studied by HOUBRECHTS (2004, 2006).

The width of the board in Portuguese clavichords, harpsichords, and pianofortes differs inside and between instruments (Table 28), as seen in several Belgian pianos (HOUBRECHTS, 2014; 2016). There is no evidence that a standard requirement for board placement based on width exists (see ANNEX 4 - Figures 1B-3B, 4D, 5C-6C, 7B-10B, 11D, 12C and 13C). The instruments assigned to foreign manufactures with a workshop in Portugal, such as Henry van Casteel and Mathias Bostem, have a larger number of large boards varying from 10 cm to 22 cm (see ANNEX 4 - Figures 3B, 4D, 5C and 6C) (Table 28). Soundboards with a greater number of boards and all of them very narrow, varying from 1 cm and 11 cm, are used on instruments belonging to Portuguese manufacturers (MNM0373, MNM0372, and MNM0681) (see ANNEX 4 - Figures 7B-9B) (Table 28).

A supposed requirement for the boards used in Joseph-Pascal Taskin's (MNM1096) French harpsichord soundboard cannot be considered. This instrument is one of eight harpsichords from this manufacturer that have survived to the present day, according to ESTROMPA (2012), and is catalogued as a grand *ravalement*[74] of an earlier instrument attributed to the Ruckers family. This enlargement is noticeable over the entire soundboard by inserting around 5 cm (ESTROMPA, 2012) which, according to our study, can lead to the first board with a width of 4.5 cm (see ANNEX 4 - Figure 11D). The remaining six boards range from 7.7 cm to 13.8 cm (Table 28).

In the soundboards of Portuguese harpsichords and fortepianos, the location of the boards in relation to the orientation of the growth ring differs in the same instrument and between the instruments (see ANNEX 4 - Figures 3B, 4D, 5C-6C, 7B-9B), as has also been shown in some Belgian pianos (HOUBRECHTS, 2014, 2016). There is no typical assembly pattern in the three instruments assigned to Mathias Bostem (CRMM, MNM0648 and MNM0833) and the other Portuguese instruments. The French harpsichord assigned to Pascal Taskin (MNM1096) is composed of two consecutive pairs of counter-directional boards (see ANNEX 4 - Figure 11D), but without any other assembly rule in the other foreign instruments.

The boards parallel to the keyboard in the MNM0406 and MNM0407 Portuguese clavichords have the same growth ring orientation (see ANNEX 4 - Figures 1B and 2B). This may be interpreted as a rule in Portuguese workshops or merely a coincidence. More in-depth studies on Portuguese keyboard instruments from the XVIII and XIX centuries are needed to clarify this question.

Table 28. Characterization of the wood boards that compose the clavichords, harpsichords and fortepianos soundboards and wrestplanks of Portuguese and foreigner workshops.

MUSICAL INSTRUMENT [INVENTORY NUMBER]	NUMBER [number of levels analysed]	LARGEST WIDTH (cm)	ORIENTATION RELATED TO THE KEYBOARD
PORTUGUESE INSTRUMENTS			
Clavichord [MNM0406]	S2 [2 levels]	23.0 / 11.5	Perpendicular
Clavichord [MNM0407]	S3 [1-2 levels]	11.5 / 13.5 / 6.8	Perpendicular
Fortepiano [MNM0425]	S7 [1-4 levels]	6.5 / 9.7 / 9.4 / 13.0 / 10.2 / 18.2 / 9.9	Perpendicular
Fortepiano [CRMM]	S5 [2-3 levels]	21.4 / 19.4 / 10.2 / 13.5 / 8.6	Perpendicular
Fortepiano [MNM0648]	S7 [1-4 levels]	18.3 / 13.8 / 10.0 / 7.4 / 10.5 / 1.9 / 8.6	Perpendicular
Fortepiano [MNM0833]	S9 [1-4 levels]	11.5 / 13.4 / 10.2 / 15.1 / 9.8 / 6.7 / 7.8 / 7.3 / 5.6	Perpendicular
Harpsichord [MNM0373]	S15 [1-4 levels]	1.0 / 1.5 / 5.7 / 5.4 / 4.0 / 8. 5/ 7.2 / 8.4 / 6.8 / 8.1 / 8.3 / 6.3 / 7.4 / 8.3 / 4.1	Perpendicular
	W12 [1 level]	4.0 / 5.8 / 9.1 / 8.4 / 7.0 / 5.3 / 6.8 / 1.4 / 7.0 / 7.0 / 4.4 / 8.5	Perpendicular
Harpsichord [MNM0372]	S9 [1-4 levels]	5.0 / 10.0 / 10.0 / 6.9 / 10.3 / 10.3 / 9.0 / 8.9 / 6.6	Perpendicular
	W9 [1 level]	7.3 / 6.0 / 8.3 / 8.9 / 9.1 / 7.6 / 8.6 / 7.0 / 5.4	Perpendicular

[74] Ravalement – "Rebuilding or enlarging, especially the extension of keyboard compasses of an old harpsichord. (…) This usage almost certainly originated with the process, extensively practised in the XVIII century Paris of rebuilding to renew their musical usefulness. These highly prized harpsichords had been made in Antwerp about a century earlier by members of the Ruckers family." (KOSTER, 2007)

MUSICAL INSTRUMENT [INVENTORY NUMBER]	NUMBER [number of levels analysed]	LARGEST WIDTH (cm)	ORIENTATION RELATED TO THE KEYBOARD
Harpsichord [MNM0681]	S19 [2 levels]	3.5 / 8.7 / 5.1 / 8.9 / 9.2 / 9.1 / 9.1 / 5.0 / 10.6 / 8.1 / 7.7 / 10.0 / 5.5 / 9.3 / 7.6 / 7.2 / 8.2 / 7.8 / 6.5	Obliquo
FOREIGNERS INSTRUMENTS			
Clavichord [MNM0419]	S3 [2 levels]	12.7 / 13.8 / 9.2	Perpendicular
Harpsichord [MNM1096]	S7 [2-4 levels]	4.5 / 7.7 / 9.6 / 10.0 / 13.8 / 13.4 / 13.3	Perpendicular
	W11 [1-3 level]	1.0 / 26.2 / 9.3 / 9.8 / 15.4 / 9.8 / 6.6 / 4.3 / 9.0 / 5.1 / 3.6	Perpendicular
Harpsichord [MNM0374]	S6 [2-4 levels]	10.3 / 8.0 / 8.5 / 8.4 / 11.8 / 9.8	Perpendicular
Virginal [MNM0395]	S3 [3 levels]	12.5 / 17.6 / 9.4	Perpendicular

All instruments presented the entire boards with a quarter or full-quarter cut. A tangentially cut board in a Portuguese pianoforte credited to Mathias Bostem (MNM0833) (Figure 78) and two boards in a Portuguese harpsichord of uncertain assignment are the only exceptions (MNM0681). KOSTER (2008) listed this single discrepancy in the boards cut in the Portuguese instruments, observing that the soundboard wood in the surviving Iberian instruments was not always well sawn on quarter cut.

All the instruments' soundboards had been carefully prepared, including the elimination of the pith and first rings. A Portuguese harpsichord (MNM0681) was the exception, with four boards also having rings next to the pith (Figure 79). Knots on boards were observed on two musical instruments (MNM0681 and MNM0374), suggesting a rougher preparation and a sloppy choice of wood material (Figure 80), because a complete lack of any defect is considered one of the macrostructural features of resonance wood (ROCABOY and BUCUR, 1990).

Figure 78. Board I with tangential cut and board II with radial cut in the Portuguese pianoforte attributed to Mathias Bostem (MNM0833) [Dashed white line represents the border between the two boards].

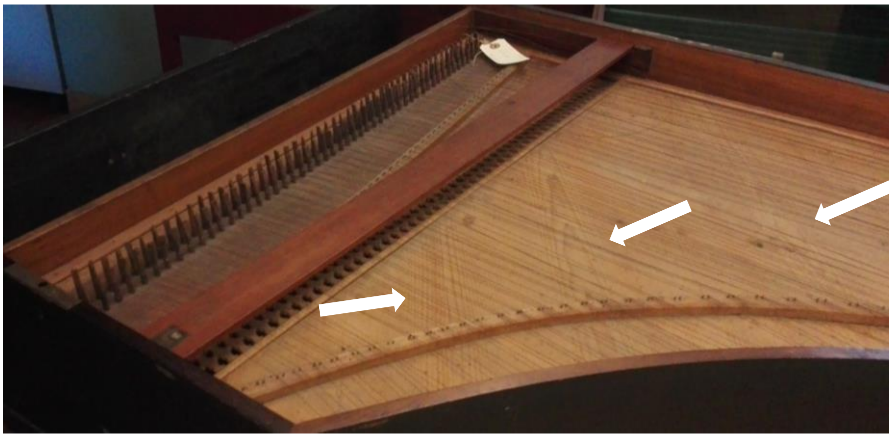


Figure 79. Soundboard of the Portuguese pianoforte of unknown assignment (MNM0681) [White arrows indicate the boards with some wider rings close to the pith].

Figure 80. Knots in: **[A-B]** board V and VII in the Portuguese harpsichord (MNM0681) of unknown attribution; and **[C]** board IV in the Dutch harpsichord (MNM0374) of unknown attribution.

2.3.3.2. Dendrochronological dating

A total of 13 musical instruments were dendrochronologically examined, with 125 tree ring measurement series developed and approximately 13800 rings measured. It was possible to examine the selection of boards from the same tree in Portuguese and foreign instruments based on a previous comparative study of the tree rings patterns of each of the boards that form the soundboard. However, it should be noted that meeting all of BEUTING (2009)'s criteria for deciding if two boards belong to the same tree was not easy. The conformity with the required overlap of 70 rings between series and the almost equivalent year of the series' beginning or end became the main challenges.

Table 29 provides a description of the dendrochronological and historical dates with the effective date of the six instruments – four Portuguese musical instruments (MNM0425, MNM0648, MNM0833, MNM0373 and CRMM), one German clavichord (MNM0419) and one French harpsichord (MNM1096).

The date of replication sought in the dendrochronological research, obtained through several individual and reference chronologies, is provided in ANNEX 7. The best crossmatch results were obtained against sequences concerning: **(1)** measurements made in musical instruments (violin, cello and piano) and historical woods in the sense of dendrochronological studies carried out by various research teams (HOUBRECHTS, 2004, 2006; GRISSINO-MAYER *et al.*, 2005; CEF-ISA database; ITRDB; http://www.cybis.se); and **(2)** individual trees and reference chronologies available in ITRDB. Below is a thorough analysis of the data collected for each dated keyboard's instrument.

Table 29. Dendrochronological and historical dates of the clavichords, harpsichords and fortepianos of Portuguese and foreigner workshops [* - hypothetical date].

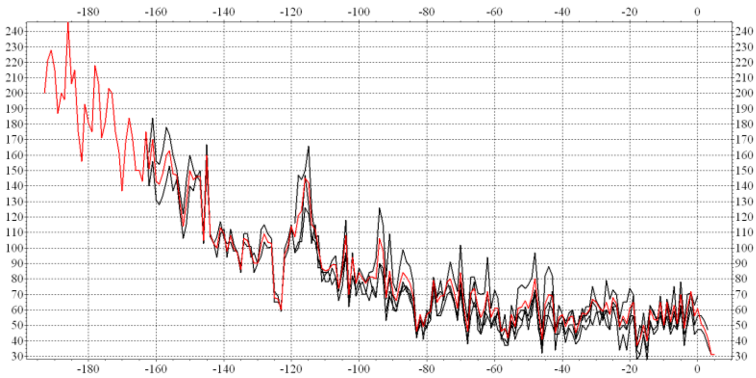
MUSICAL INSTRUMENT [INVENTORY NUMBER]	ATRIBUTTION	DENDROCHRONOLOGICAL DATE	HISTORICAL DATE
PORTUGUESE INSTRUMENTS			
Clavichord [MNM0406]	Unknown	undated	XVIII century (2nd quarter)
Clavichord [MNM0407]		undated	1750-1790
Fortepiano [MNM0425]	Henry van Casteel	1750	1763
Fortepiano [CRMM]	Mathias Bostem	1751	1777
Fortepiano [MNM0648]		1724	1786
Fortepiano [MNM0833]		1741	1789
Harpsichord [MNM0373]	João Baptista Antunes	undated	1789
Harpsichord [MNM0372]	Joaquim José Antunes	undated	1758
Harpsichord [MNM0681]	Unknown	undated	After 1725
FOREIGNERS INSTRUMENTS			
Clavichord [MNM0419]	Unknown, Germany	1760*	XVIII century
Harpsichord [MNM1096]	Pascal Taskin, France	1764	1782
		1625*	1636
Harpsichord [MNM0374]	Unknown, Italy or Portugal	undated	1724
Virginal [MNM0395]	Hans Ruckers family, Southern Netherlands	undated	1620

(1) Portuguese fortepiano attributed to Henry van Casteel (MNM0425)

From a total of seven boards, the soundboard showed a set of four boards belonging to the same tree (MNM00425002, MNM0425004, MNM0425006, and MNM0425007). This scenario is an outstanding example of following all of the pre-determined criteria: **(1)** t_H between 8.6 and 15.3 (Figure 81); **(2)** Glk between 74% and 81% with a statistical significance of 0.999 (Figure 81); **(3)** overlap higher than 70, ranging between 113 and 166 rings (Figure 81); **(4)** visual similarity between the four sequences (Figure 81); **(5)** similar tree-ring widths of compared sequences (0.86 mm, 0.78 mm, 0.91 mm and 0.73 mm, respectively) (Table 30); and **(6)** an agreement of pointer years and nearly the same year of final sequences (Figure 81). Of the seven boards that make up the soundboard of the fortepiano, it can be mentioned that four trees (corresponding to the final four different dendrochronological sequences) were involved in its structure. The MNM0425001 sequence could not be dated with certainty (Table 30).

Table 30. Cross-dating of sequences from the pianoforte's soundboard assigned to Henry van Casteel (MNM0425) using ITRDB and personal databases. Dendrochronological output refers to the best results with the best reference chronology/best individual sequence [MS - Mean sensitivity; "-" information integrated in the respective sequence combination].

SEQUENCE / COMBINATION OF SEQUENCES	TOTAL RINGS	RING WIDTH (mm) AVG±STDV	MS (%)	PRESERVED RING		DENDROCHRONOLOGICAL OUTPUT				HISTORICAL DATE
				FIRST	LAST	Overlap	Glk (%)	t_H	REFERENCE	
MNM0425001	67	0.97±0.33	17	undated						1763
MNM0425002	120	0.87±0.24	17	1612	1731	-	-	-	-	
MNM0425003	84	1.12±0.29	11	1665	1748	84/84	69/72	5.3/6.9	SWIT169/I02090801T042	
MNM0425004	166	0.78±0.34	16	1569	1734	-	-	-	-	
MNM0425005	82	1.28±0.35	12	1669	**1750**	82/82	71/77	4.6/6.1	SWIT169/IM005I	
MNM0425006	199	0.91±0.51	16	1538	1736	-	-	-	-	
MNM0425007	86	0.56±0.11	17	1639	1724	-	-	-	-	
MNM0425002-004-006-007	199	0.98±0.49	14	1538	1736	199/120	69/83	8.1/16.2	ITA024/IM009I	



	001	002	003	004	005	006	007
001							
002	-						
003	-	69/67/4.4					
004	-	122/81/**12.9**	70/75/6.0				
005	-	65/67/5.1	80/73/6.9	66/70/4.7			
006	-	122/74/**10.8**	-	166/78/**15.3**	-		
007	-	86/74/**9.6**	-	86/78/8.2	-	86/77/**8.6**	

Figure 81. *Top:* synchronization between four tree-ring patterns (MNM0425002, MNM0425004, MNM0425006 and MNM0425007) that belong to the same tree. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64]. *Down:* overlap rings, Glk (%) and t_H obtained for the cross-matching of all sequences from the pianoforte's soundboard assigned to Henry van Casteel (MNM0425) ["-" t_H less than 4.0].

The dating quality for the three final sequences is seen in Figure 82. In all cases, outstanding quality dates are reported with several replications for t_H equal to or greater than 4.0 and *P* value equal to or greater than 0.999, varying from 15 (MNM0425005) to 25 (MNM0425002-004-006-007) (see ANNEX 7-Table 1). The MNM0425002-004-006-007 sequence was exceptionally well matched against the seven sequences obtained in different instruments (see ANNEX 7-Table 1): **(1)** Belgian pianos (IM009I and IM027I); **(2)** French cello (I03010602BT078); **(3)** German violins (MITT1[68] and I02130602BT092); **(4)** English piano (IM0023II); and **(5)** Portuguese cello (I03090801B022). The results suggest the use of wood from the same tree for the manufacture of eight instruments since several criteria were fulfilled: **(1)** high t_H values, ranging from 9.0 to 16.2; **(2)** high Glk values, ranging from 65% to 83%; and **(3)** overlap higher than 70, ranging between 107 and 199 rings (see ANNEX 7-Table 1). However, the remaining preconditions have not been reached: **(1)** not graphical similarity between tree-ring patterns (Figure 83); **(2)** tree-ring widths not similar (0.82 mm, 0.96 mm, 0.80 mm, 0.64 mm, 0.65 mm, 1.19 mm, and 1.85 mm, respectively); **(3)** disagreement of pointer years; and **(4)** disagreement of the beginning or end years (Figure 83). In these cases, it can only be supposed that the boards probably came from different trees that grew under identical circumstances.

The youngest tree ring identified in the soundboard of the pianoforte dates from 1750 in the MNM0425005 sequence, with 82 rings. Therefore, the *terminus post quem* applies to 1750, which is compatible with the date stamped twice within the musical instrument (1763). The comparison of the dendrochronological and the historical dates indicates a time gap of 13 years, which HOUBRECHTS (2004) also found in Belgian instruments.

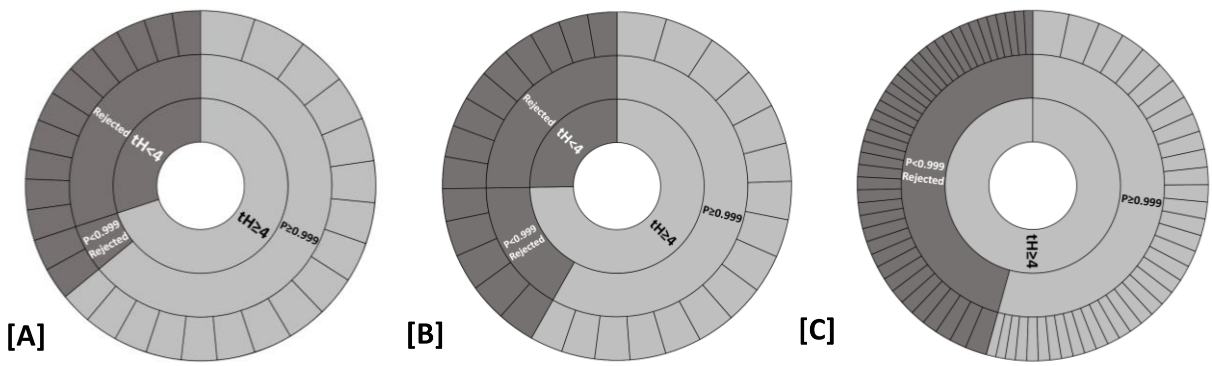


Figure 82. Quality dating of the sequences from the pianoforte's soundboard assigned to Henry van Casteel (MNM0425): **[A]** MNM0425003; **[B]** MNM0425005; and **[C]** MNM0425002-004-006-007 [Dark area corresponds to rejected replications for t_H<4, and t_{BP}≥4 and *P*<0.999; light area corresponds to accepted replications for t_H≥4 and *P*≥0.999].

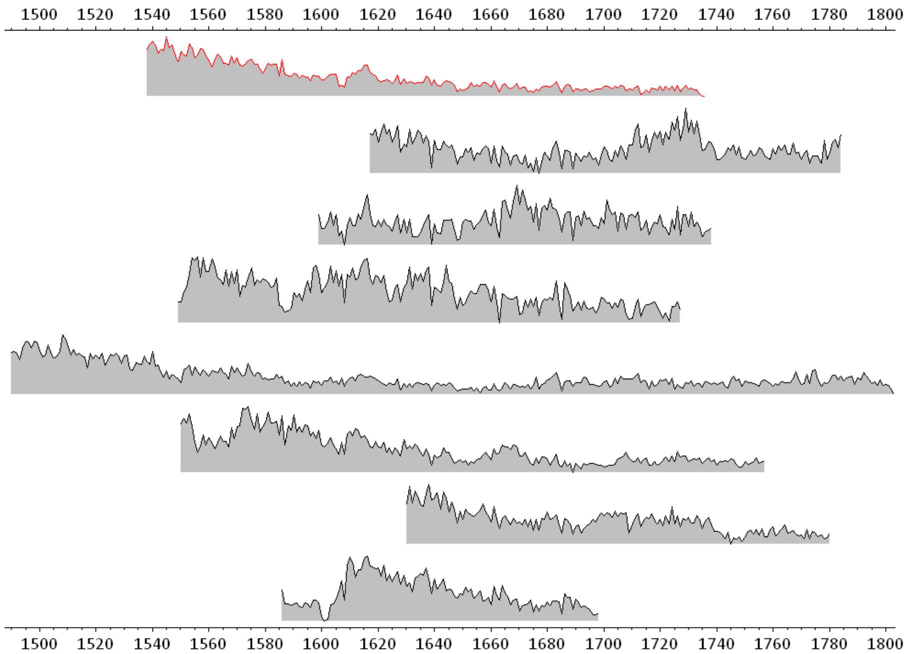


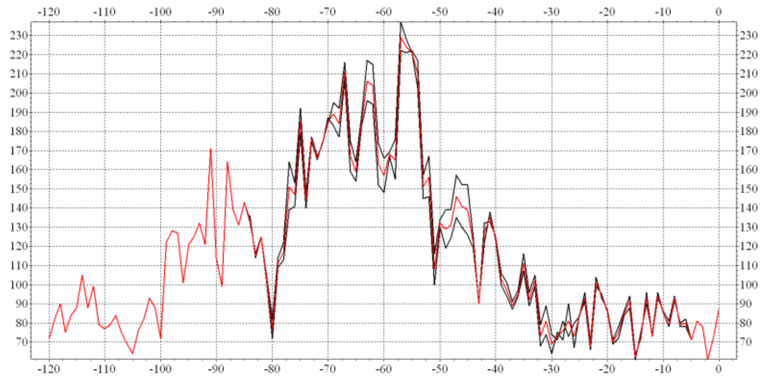
Figure 83. Visual comparison between MNM0425002-004-006-007 tree-ring pattern (red line) from the pianoforte's soundboard assigned to Henry van Casteel (MNM0425) and seven tree ring patterns from musical instruments (black lines): IM009I (HOUBRECHTS, 2004); IM027I (HOUBRECHTS, 2006); I03010602BT078 (CEF-ISA database); MITT1 (GERM062 from ITRDB); IM0023II (HOUBRECHTS, 2004); I02130602BT092 (CEF-ISA database); I03090801B022 (CEF-ISA database). X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64].

(2) Portuguese fortepianos attributed to Mathias Bostem (CRMM, MNM0648, MNM0833)

There is no correlation between the boards of the three instruments from Mathias Bostem's workshop, according to statistical analysis. Only the soundboard of the CRMM fortepiano has a pair of panels from the same tree (CRMM003 and CRMM004) that satisfy nearly all the specifications (Figure 84): **(1)** t_H value of 15.1; **(2)** Glk of 87%; **(3)** high overlap of 80 rings; **(4)** graphical similarity between the sequences; **(5)** agreement of pointer years; and **(6)** nearly the same year of final sequences. The average thickness of the rings of the two series does not present such a high similarity (0.78 mm and 1.28 mm, respectively) given the difference of 31 rings between each one (Table 31).

Table 31. Cross-dating of sequences from the musical instrument's soundboards assigned to Mathias Bostem using ITRDB and personal databases. Dendrochronological output refers to the best results with the best reference chronology/best index series [MS - Mean sensitivity; "-" information integrated in the respective sequence combination; "*" hypothetical date not considerate in the final decision; (a) tangential cut].

SEQUENCE	RINGS		MS (%)	PRESERVED RING		DENDROCHRONOLOGICAL OUTPUT				HISTORICAL DATE
	#	WIDTH (mm) avg±stdv		FIRST	LAST	Overlap	Glk (%)	t_H	REFERENCE	
CRMM										
CRMM001	128	0.87±0.24	14	1624	**1751**	128/106	66/65	4.9/6.1	SWIT173/ IM020I	
CRMM002	114	1.12±0.29	15	1615	1728	114/102	65/73	7.7/8.9	SWIT169/IM004I	
CRMM003	85	0.78±0.34	18	1644	1728	-	-	-	-	
CRMM004	116	1.28±0.35	15	1608	1723	-	-	-	-	1777
CRMM005	60	0.91±0.51	14	1673	1732	60/60	73/74	6.6/6.2	SWIT169/ I02090801T042	
CRMM003-004	121	0.98±0.49	14	1608	1728	121/112	66/74	7.5/8.1	SWIT169/IM009I	
MMN0648										
MNM0648001	130	1.35±0.79	13	1586	1715*	113/105	69/61	6.0/5.8	I03090801BT024/ I03010602BT078	
MNM0648002	97	1.53±0.30	15	1635	1731*	97/93	67/63	7.4/4.8	I03080801BT003/ I03010602BT078	
MNM0648003	88	1.39±0.46	14	1589	1676*	88/88	70/60	6.0/5.8	I03010602BT078/ I03111001T066	
MNM0648004	43	1.54±0.41	16	undated						1786
MNM0648005	76	1.25±0.38	11	1618	1693*	76/76	62/67	4.2/5.2	SWIT169/IM007I	
MNM0648006	26	0.73±0.15	17	undated						
MNM0648007	74	1.17±0.38	14	1651	**1724**	74/74	60/61	4.4/5.9	SWIT173/ I03010602BT078	
MNM0833										
MNM0833001	(a)									
MNM0833002	93	1.79±0.47	21	1628	1720	93/93	71/73	8.5/11.1	SWIT169/ IM009I	
MNM0833003	68	1.45±0.30	14	undated						
MNM0833004	142	1.04±0.23	14	undated						
MNM0833005	65	1.53±0.29	15	1677	**1741**	65/65	68/75	4.9/7.3	SWIT173/ I02090801T042	1789
MNM0833006	60	1.09±0.29	15	undated						
MNM0833007	73	1.07±0.26	16	1693	1765*	73/73	66/72	4.0/5.5	SWIT169/ I03101001BT064	
MNM0833008	72	1.01±0.24	17	1696	1767*	72/72	73/72	6.1/5.6	HK020107BT003/ I03101001BT064	
MNM0833009	35	1.60±0.31	18	undated						



	001	002	003	004	005
001					
002	-				
003	-	-			
004	-	109/63/4.7	80/87/**15.1**		
005	-	-	-	-	

Figure 84. *Top:* synchronization between two tree-ring patterns (CRMM003 and CRMM004) that belong to the same tree. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64]. *Down:* overlap rings, Glk (%) and t_H obtained for the cross-matching of all sequences from the pianoforte's soundboard assigned to Mathias Bostem (CRMM) ["-" t_H less than 4.0].

Out of the five boards that make up the CRMM fortepiano's soundboard, four different trees (corresponding to the final four distinct sequences) were used in the structure and were successfully dated (Table 31). Figure 85 illustrates the dating quality, confirming the particularly good crossmatch in three of them (CRMM001, CRMM002, and CRMM003-004), with a high degree of replications for t_H equal or greater than 4.0 and a *P* value equal or greater than 0.999 (20, 15 and 18, respectively) (see ANNEX 7-Table 2). The amplitudes of t_H values are identical in all replications (4.0-6.1, 4.3-8.9 and 4.0-8.1, respectively). The CRMM005 series provides medium/low quality data as, considering the low number of replications (5), the highest correlation (t_H=6.1) is obtained with the SWIT169 reference chronology. In conclusion, the youngest tree ring located in the soundboard of the CRMM fortepiano is 1751 in the CRMM001 sequence with 128 rings. In this way, the *terminus post quem* corresponds to the year 1751, which is consistent with the date in the inscription "*MATHIAS BOSTEM FECIT LISBOA 1777*" on the upper surface of the front block of the hammer rack (see ANNEX 4-Figure 4B). The relation between the dendrochronological and the historical dates indicates a time lag of 25 years, which is likely to correlate to the drying or long-term preservation of the wood or both.

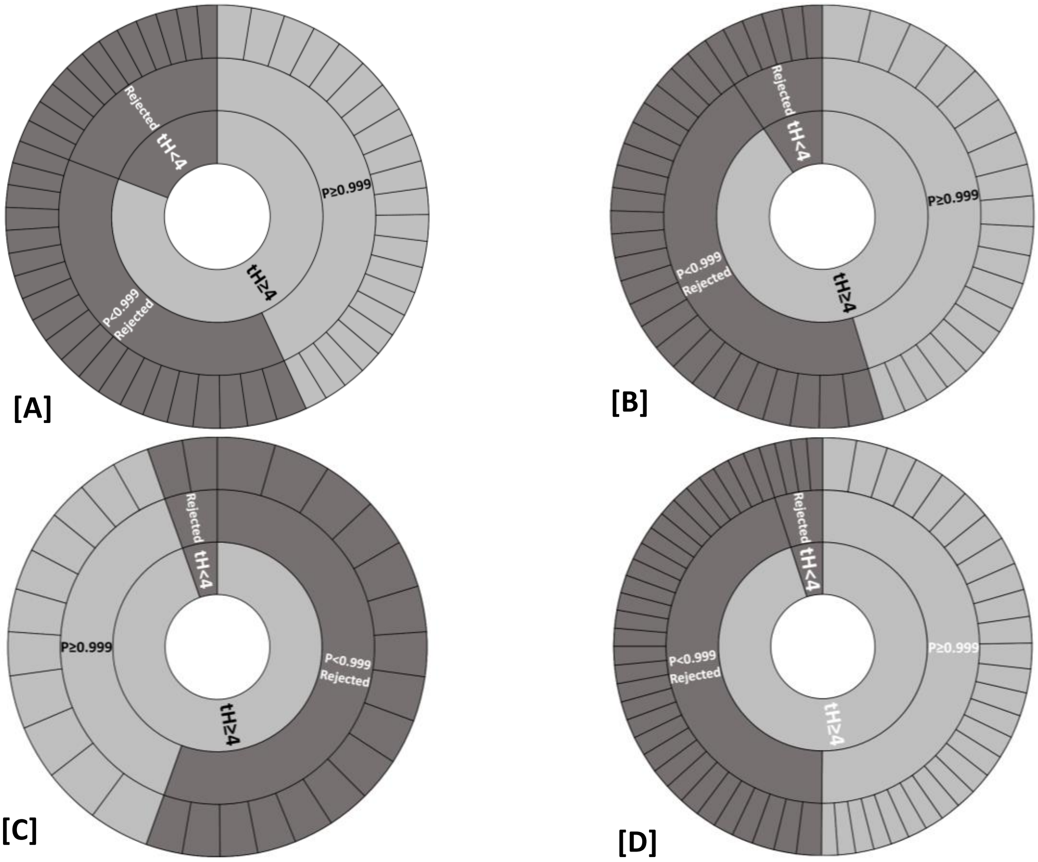


Figure 85. Quality dating of the sequences from the pianoforte's soundboard assigned to Mathias Bostem (CRMM): **[A]** CRMM001; **[B]** CRMM002; **[C]** CRMM005; and **[D]** CRMM003-004 [Dark area corresponds to rejected replications for t_H<4, and t_H≥4 and *P*<0.999; light area corresponds to accepted replications for t_{BP}≥4 and *P*≥0.999].

The soundboard of the MNM0648 fortepiano consists of seven panels of seven distinct trees. Two tree ring measurement series (MNM0648004 and MNM0648006) may not have been dated due to a limited number of rings (Table 31). The remaining five dendrochronological sequences were successful dated (Figure 86), but four of them are considered weak dating (MNM0648001, MNM0648002, MNM0648003 and MNM0648005). The MNM0648007 sequence was well matched to seven other index series acquired in various musical instruments, with t_H values ranging from 4.1 to 5.5 (see ANNEX 7-Table 3). Even though the MNM0648002 sequence (1731) contains the youngest tree ring, it should not be considered *terminus post quem* since it is based on a hypothetical date. Consequently, the *terminus post quem* in MNM0648007 series applies to 1724, which aligns to the date on the wrestplank inscription "*MATHIAS BOSTEM FECIT LISBOA 1786*" (see ANNEX 4-Figure 5B). Future dendrochronological research based on a more developed database, on the other hand, could allow for a more reliable replication of the sequence that provides the more recent tree ring.

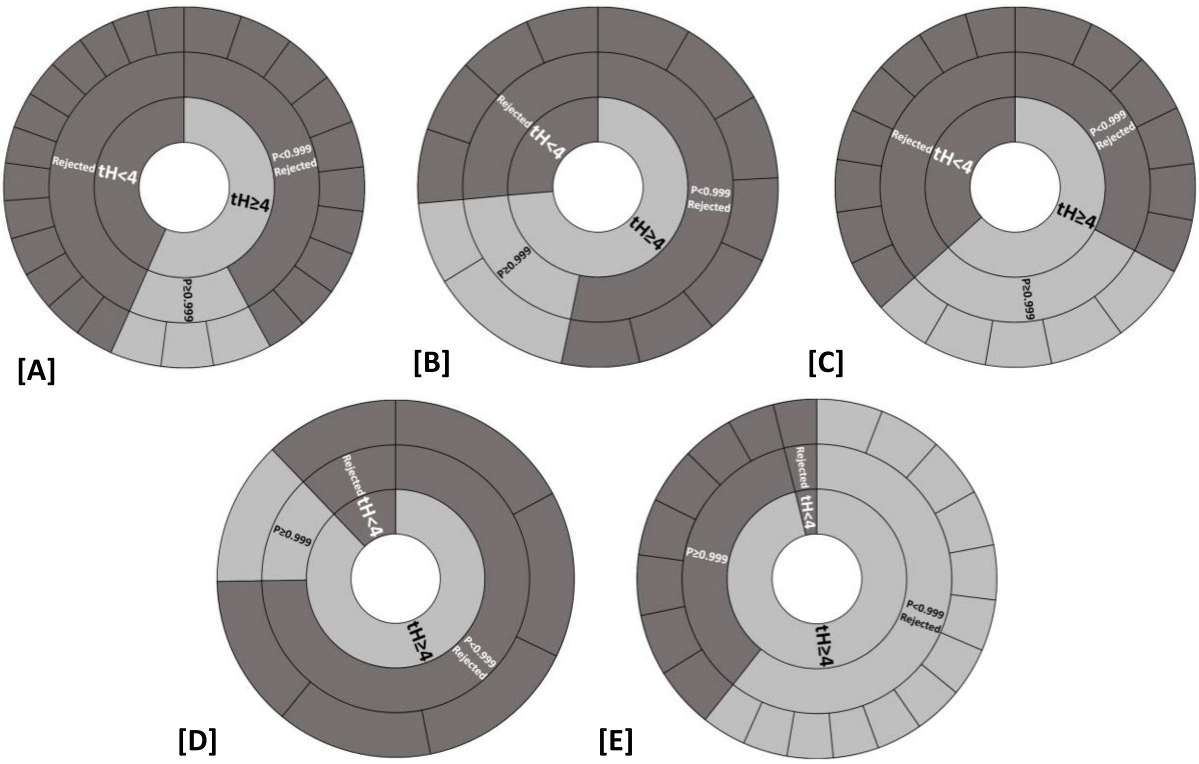


Figure 86. Quality dating of the sequences from the pianoforte's soundboard assigned to Mathias Bostem (MNM0648), according to t_H value for a *P*≥0.999: **[A]** MNM0648001; **[B]** MNM0648002; **[C]** MNM0648003; **[D]** MNM0648005; and **[E]** MNM0648007 [Dark area corresponds to rejected replications for t_H<4, and t_H≥4 and *P*<0.999; light area corresponds to accepted replications for t_{BP}≥4 and *P*≥0.999].

The soundboard of the MNM0833 fortepiano has nine panels, but the study is based on eight panels since the MNM0833001 has a tangential cut. One short sequence (MNM0833009) was unable to be successfully dated, leaving three sequences of expected size to be dated (MNM0833003, MNM0833004 and MNM0833006) (Table 31). Figure 87 indicates the dating quality of the remaining four sequences, suggesting that two of them have low dating (MNM0833007 and MNM0833008).

The MNM0833002 sequence was remarkably well-matched against several sequences obtained in various instruments and reference chronologies, with t_H values ranging from 4.0 to 11.1 (see ANNEX 7-Table 4). The results endorse the use of wood from the same tree for the soundboard of the MNM0833 fortepiano and three other instruments (IM009I, I03090801B022, and IM027I) if certain conditions are met: **(1)** high t_H values, ranging from 9.5 to 11.1; **(2)** high Glk values, ranging from 69% to 77%; and **(3)** overlap higher than 70 (see ANNEX 7-Table 4). The remaining prerequisites, however, were not fulfilled: **(1)** tree-ring patterns do not have a graphical similarity (Figure 88); **(2)** tree-ring widths not similar (0.82 mm, 0.96 mm, and 1.85 mm, respectively); **(3)** disagreement of some pointer years; and **(4)** disagreement of the beginning or end years (Figure 88). Thus, it can only be concluded that the panels could have originated from distinct trees that have grown under identical conditions.

Terminus post quem corresponds to the year 1741, identified in the MNM0833005 sequence. The dendrochronological result is consistent with the date in the inscription "*MATHIAS BOSTEM FECI LISBOA 1789"* on the wrestplank (see ANNEX 4-Figure 6B). As stated in the MNM0648 fortepiano soundboard, an upcoming study based on a more robust database may allow for a more substantial replication of the MNM0833008 series that defines the more recent tree ring.

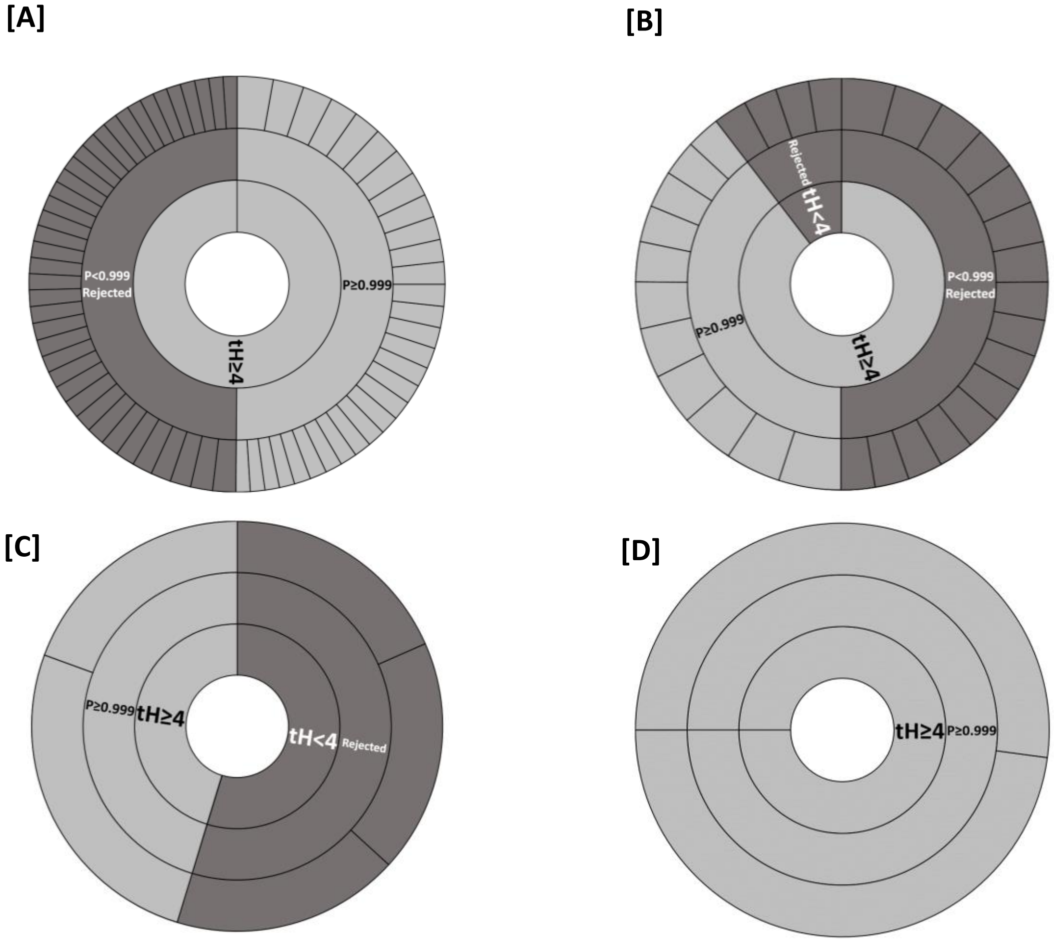


Figure 87. Quality dating of the sequences from the pianoforte's soundboard assigned to Mathias Bostem (MNM0833): **[A]** MNM0833002; **[B]** MNM0833005; **[C]** MNM0833007; and **[D]** MNM0833008 [Dark area corresponds to rejected replications for t_H<4, and t_H≥4 and *P*<0.999; light area corresponds to accepted replications for t_{BP}≥4 and *P*≥0.999].

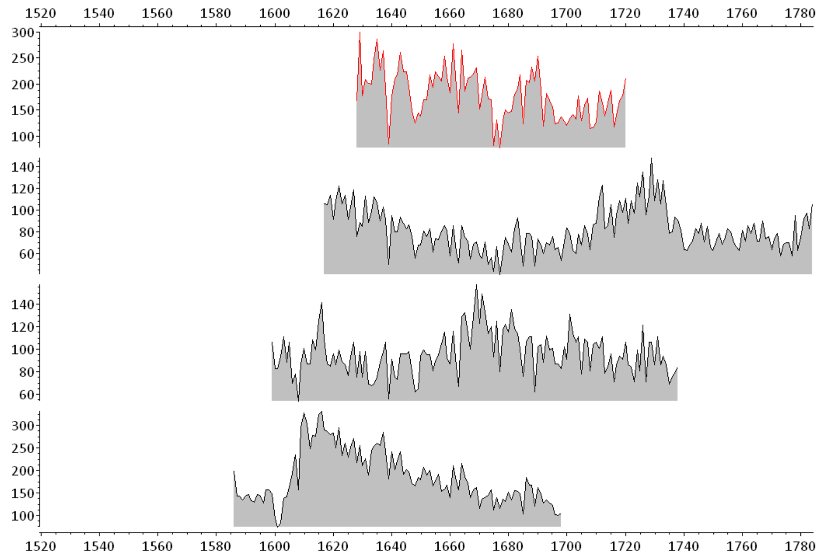


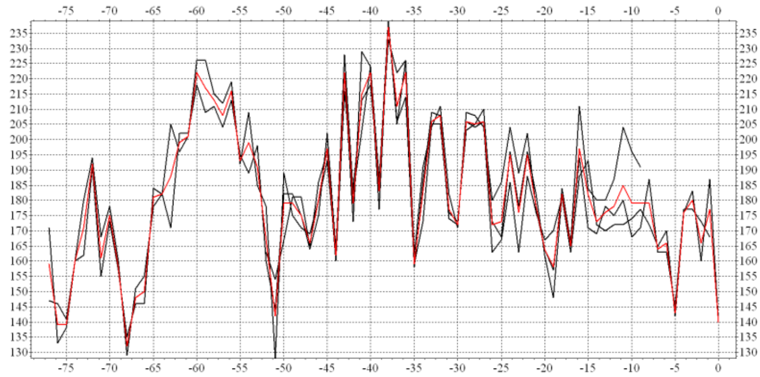
Figure 88. Visual comparison between MNM0833002 tree-ring pattern (red line) from the pianoforte's soundboard assigned to Mathias Bostem (MNM0833) and three tree ring patterns from musical instruments (black lines): IM009I (HOUBRECHTS, 2004); IM0023II (HOUBRECHTS, 2004); and I03090801B022 (CEF-ISA database). X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64].

(3) German clavichord of unknown attribution (MNM0419)

The soundboard is composed of three boards from the same tree. The comparative analysis shows the fulfilment of the parameters established by BEUTING (2009): **(1)** high t_H values, ranging between 9.0 and 12.0 (Figure 89); **(2)** Glk greater than 70% with statistical significance of 0.999 (Figure 89); **(3)** visual similarity between compared sequences; **(4)** similar tree-ring widths of compared sequences (1.85 mm, 1.82 mm and 1.81 mm, respectively) (Table 32); **(5)** agreement of pointer years (Figure 89); and **(6)** The same year of the beginning of the series between board I and II (1683) and nearly the same year of final series between board II and III (1759 and 1760) (Figure 89).

Table 32. Cross-dating of sequences from the German clavichord's soundboard of unknown attribution (MNM0419) using ITRDB and personal databases. Dendrochronological output refers to the best results with the best reference chronology/best index series [MS - Mean sensitivity; "-" information integrated in the respective sequence combination].

SEQUENCE	TOTAL RINGS	RING WIDTH (mm) AVG±STDV	MS (%)	PRESERVED RING		DENDROCHRONOLOGICAL OUTPUT			
				FIRST	LAST	Overlap	Glk (%)	t_H	REFERENCE
MNM0419001	63	1.81±0.25	10	1683	1745	-	-	-	-
MNM0419002	77	1.87±0.24	11	1683	1759	-	-	-	-
MNM0419003	53	1.82±0.29	10	1708	1760	-	-	-	-
MNM0419001-002-003	78	1.81±0.20	10	1683	**1760**	78/78	66/73	4.1/5.5	SWIT169/ HK026607T236



	001	002	003
001			
002	63/84/**11.4**		
003	38/84/**9.9**	52/75/**9.0**	

Figure 89. *Top:* synchronization between three tree-ring patterns (MNM0419001, MNM0419002 and MNM0419003) that belong to the same tree. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64]. *Down:* overlap rings, Glk (%) and t_H obtained for the cross-matching of all sequences from the German clavichord's soundboard of unknown attribution (MNM0419).

Figure 90 represents the final sequence's low-quality dating. The statistical study points to 1683-1760 as a potential chronological position: **(1)** from the four replications only one was based on a reference chronology; **(2)** t_H ranging from 4.1 to 5.0; and **(3)** Glk varying from 65% and 75% with overlap of 78 rings (see ANNEX 7-Table 5). While it is in line with the historical date listed in MatrizNet (XVIII century), the *terminus post quem* referred to 1760 should be considered a hypothetical proposal date (Table 32).

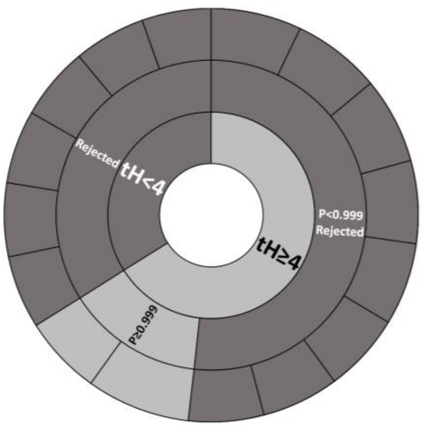


Figure 90. Quality dating of the sequences from the German clavichord's soundboard of unknown attribution (MNM0419). Dark area corresponds to rejected replications for t_H<4, and t_H≥4 and *P*<0.999; light area corresponds to accepted replications for t_{BP}≥4 and *P*≥0.999.

(4) French harpsichord attributed to Pascal Taskin (MNM1096)

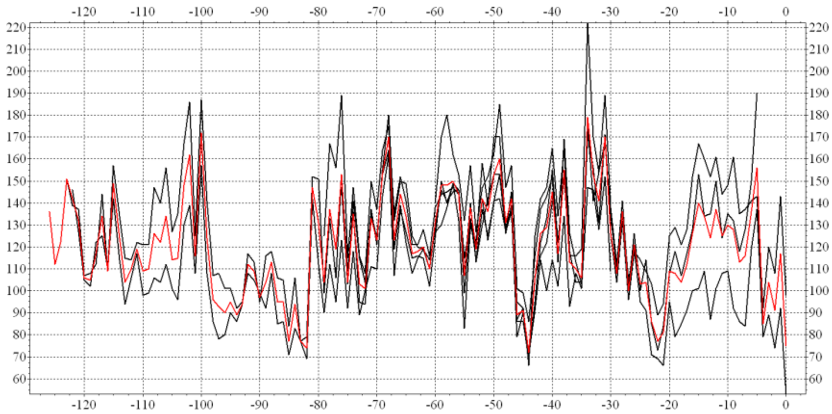
Considering this instrument as a *ravalement* of an earlier instrument attributed to the Ruckers family (ESTROMPA, 2012), an independent dendrochronological analysis should be carried out in relation to the wrestplank and soundboard historical dates.

The dendrochronological analysis of the wrestplank was carried out on 10 of 11 boards since the left sideboard (originally referred to as MNM1096w001) was only 1 cm wide. Statistical and visual analysis reveal that there is a set of five boards (MNM1096w003, MNM1096w004, MNM1096w005, MNM1096w007 and MNM1096w009) belonging to the same tree, as seen by the following parameters (Figure 91): **(1)** high t_H values, ranging from 9.7 to 13.5; **(2)** hight Glk values, ranging between 79% and 92% with a statistical significance of 0.999; **(3)** overlap extending between 37 and 83 rings; **(4)** visual similarity between the five sequences; **(5)** similar tree-ring widths of compared sequences (1.35 mm, 1.17 mm, 1.22 mm, 1.29 mm and 1.17 mm, respectively) (Table 34); and **(6)** an agreement of pointer years and nearly the same year of final sequences. Of the eleven boards that make up the wrestplank of the harpsichord, five individual trees (corresponding to the final five distinct sequences) were involved in its conception. The MNM1096w008 series could not be dated at all due to its short size (38 rings) (Table 33).

Table 33. Cross-dating of sequences from the wrestplank and soundboard of the harpsichord assigned to Pascal Taskin using ITRDB and personal databases. Dendrochronological output refers to the best results with the best reference chronology/best individual sequence [MS - Mean sensitivity; "-" information integrated in the respective sequence combination; "*" hypothetical date].

SEQUENCE	RINGS		MS (%)	PRESERVED RING		DENDROCHRONOLOGICAL OUTPUT				HISTORICAL DATE
	#	WIDTH (mm) avg±stdv		FIRST	LAST	Overlap	Glk (%)	t_H	REFERENCE	
WRESTPLANK										
MNM1096w002	145	1.71±0.41	16	1573	1717*	40/81	81/77	5.4/7.2	FRAN038/IM010II	1782
MNM1096w003	61	1.35±0.25	16	1704	1764	-	-	-	-	
MNM1096w004	83	1.17±0.23	16	1642	1724	-	-	-	-	
MNM1096w005	122	1.22±0.27	16	1638	1759	-	-	-	-	
MNM1096w006	73	1.30±0.28	16	1637	1709*	32/73	81/72	4.2/6.3	FRAN038/ I02010102BT061	
MNM1096w007	50	1.29±025	17	1685	1734	-	-	-	-	
MNM1096w008	38	1.15±0.22	15	undated						
MNM1096w009	77	1.17±0.29	17	1688	1764	-	-	-	-	
MNM1096w010	44	1.15±0.22	16	1643	1686*	44/44	78/74	6.6/5.6	I02010102BT061/ IM037I	
MNM1096w003-004-005-007-009	123	1.19±0.23	15	1642	**1764**	87/121	63/76	5.1/9.5	FRAN038/IM010II	
SOUNDBOARD										
MNM1096s001	14	3.05±0.65	9	undated						1636

SEQUENCE	RINGS		MS (%)	PRESERVED RING		DENDROCHRONOLOGICAL OUTPUT				HISTORICAL DATE
	#	WIDTH (mm) avg±stdv		FIRST	LAST	Overlap	Glk (%)	t_H	REFERENCE	
MNM1096s002	29	2.64±0.55	11	undated						
MNM1096s003	33	2.58±0.55	16	undated						
MNM1096s004	55	1.82±0.38	14	undated						
MNM1096s005	69	2.00±0.60	21	1554	1612	-	-	-	-	
MNM1096s006	83	1.62±0.42	19	1543	1625	-	-	-	-	
MNM1096s007	63	2.12±0.51	17	1543	1605	-	-	-	-	
MNM1096s002-003	37	2.61±0.55	15	undated						
MNM1096s005-006-007	83	1.85±0.48	18	1543	**1625***	81/83	64/68	6.4/6.3	I03111001T066/ IM017III	



	002	003	004	005	006	007	008	009	010
002									
003	-								
004	76/74/7.0	-							
005	80/70/7.1	56/85/8.5	83/84/**13.5**						
006	73/70/6.4	-	68/83/**11.1**	72/88/**10.2**					
007	-	31/85/**9.7**	40/92/**11.1**	50/85/**11.8**	-				
008	-	-	-	-	-	-			
009	-	61/79/**11.1**	37/86/**10.1**	72/80/**10.0**	-	47/79/**11.0**	-		
010	44/83/9.0	-	44/80/8.3	44/80/8.7	44/74/7.5	-	-	-	

Figure 91. *Top:* synchronization between five tree-ring patterns (MNM1096w003, MNM1096w004, MNM1096w005, MNM1096w007 and MNM1096w009) from the harpsichord's wrestplank that belong to the same tree. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm)" [Graph by TSAP Win Scientific 4.64]. *Down:* overlap rings, Glk (%) and t_H obtained for the cross-matching of all sequences from the harpsichord's wrestplank assigned to Pascal Taskin (MNM1096) ["-" t_H less than 4.0].

The dating quality for the four final sequences is illustrated in Figures 91 A-D. The MNM1096w003-004-005-007-009 sequence crossmatched very well against three sequences obtained in distinct instruments (see ANNEX 7-Table 6): **(1)** high t_H values, ranging from 6.6 to 9.5; **(2)** high Glk values, ranging from 68% to 76%; and **(3)** overlap higher than 70, ranging between 96 and 121 rings. Based on six further replications obtained from six different musical instruments with t_H values between 4.0 and 4.8, a medium quality dating to chronological position 1642-1764 can be considered (see ANNEX 7-Table 6; Table 33). The MNM1096w002 sequence crossmatches against five series obtained in five instruments (see ANNEX 7-Table 6) and FRAN038 reference chronology, with t_H ranging from 4.1 to 7.2, good Glk values, varying from 66% to 81% and most of overlaps greater than 70 rings. However, chronological position 1573-1717 should be viewed as hypothetical date, because the crossmatch with the FRAN038 is based on just 40 rings. The MNM1096w006 and MNM1096w010 sequences provide a strong match against the series obtained in different instruments, with t_H ranging from 4.1 to 6.6 and high Glk values, varying from 72% to 80% (see ANNEX 7-Table 6). However, chronological positions 1637-1709 and 1643-1686 should be viewed as hypothetical dates since overlaps are scarce (most of which vary from 32 to 44 rings) and replications are weaker in both cases (see ANNEX 7-Table 6; Table 33). In conclusion, the youngest tree ring identified of the French harpsichord's wrestplank corresponds to 1764 in the MNM1096w003-004-005-007-009 sequence with 123 rings. Thereby, the *terminus post quem* refers to the year 1764, which is consistent with the inscription "*FAIT PAR PASCAL TASKIN À PARIS, 1782*", on the wrestplank in front of the tuning pins (see ANNEX 4-Figure 11C).

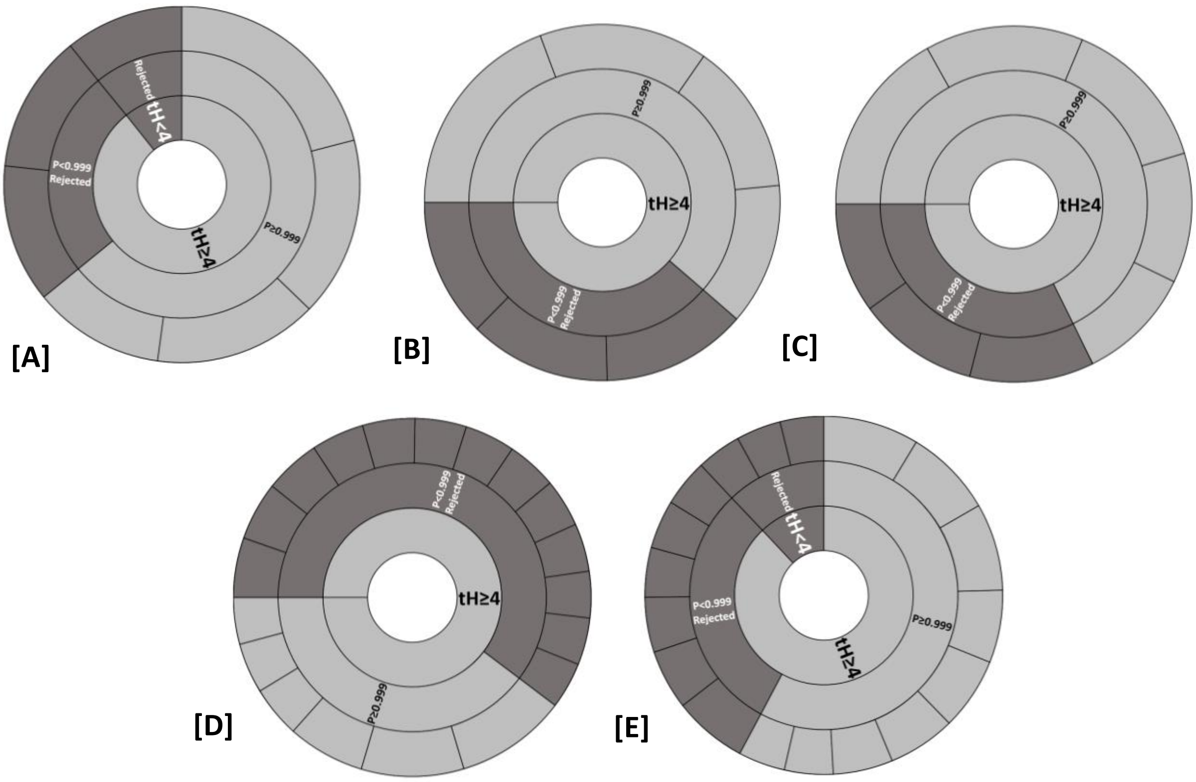
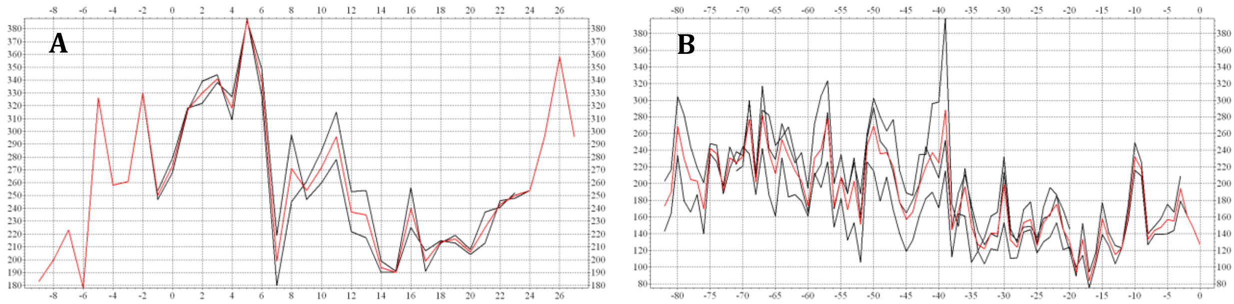


Figure 92. Quality dating of the sequences from the harpsichord assigned to Pascal Taskin (MNM1096): **[A]** MNM1096w002; **[B]** MNM1096w006; **[C]** MNM1096w010; **[D]** MNM1096w003-004-005-007-009; and **[E]** MNM1096s005-006-007 [Dark area corresponds to rejected replications for t_H<4, and t_H≥4 and *P*<0.999; light area corresponds to accepted replications for t_{BP}≥4 and *P*≥0.999].

The dendrochronological analysis of the soundboard was done on seven boards. Statistical and visual examination reveal a group of two boards (MNM1096th002 and MNM1096th003) and another one of three boards (MNM1096th005, MNM1096th006 and MNM1096th007) that belong to the same tree. Although MNM1096th002 and MNM1096th003 sequences show a reduced number of rings (29 and 33, respectively), synchronisation and high t_H value (9.3) substantiate the inference, resulting in a final sequence of 37 rings (Figure 93A). The statistical evidence for the second group is straightforward and results in a final sequence with 83 rings: **(1)** high t_H values, ranging from 8.8 to 11.6 (Figure 93); **(2)** hight Glk values, ranging between 71% and 77% (Figure 93); **(3)** overlap extending between 52 and 69 rings (Figure 93); **(4)** visual similarity between the three sequences (Figure 93B); **(5)** similar tree-ring widths of compared sequences (2.00mm, 1.62 mm and 2.12 mm, respectively) (Table 34); and **(6)** an agreement of pointer years and nearly the same year of final sequences (Figure 93B).



	001	002	003	004	005	006	007
001							
002	-						
003	-	25/85/**9.3**					
004	-	-	-				
005	-	-	-	-			
006	-	-	-	-	69/71/8.8		
007	-	-	-	-	52/77/**9.4**	63/77/**11.6**	

Figure 93. *Top:* two synchronizations tree-ring patterns from the harpsichord's soundboard that belong to the same tree: **[A]** MNM1096th002 and MNM1096th003; and **[B]** MNM1096th005, MNM1096th006 and MNM1096th007. The red line corresponds to the mean representative sequence. X-axis corresponds to "year" and Y-axis to "tree ring width (mm) [Graph by TSAP Win Scientific 4.64]. *Down:* overlap rings, Glk (%) and t_H obtained for the cross-matching of all sequences from the harpsichord's soundboard assigned to Pascal Taskin (MNM1096) ["-" t_H less than 4.0].

Of the seven boards that make up the soundboard of the harpsichord, the dendrochronological data are based on four final sequences. Only one is successful (MNM1096s005-006-007) because the remaining (MNM1096s001, MNM1096s002-003 and MNM1096s004) are short sequences (Table 33). The dating quality for the MNM1096s005-006-007 sequence is illustrated in Figure 92E, where a low replication of the data is evident. It can be inferred that the chronological position 1543-1625 is a hypothetical proposal date. Future statistical analysis based on a more robust database could validate the chronological results proposed here, because the result is consistent with "*1636*" historical date painted in golden letters on the soundboard) (see ANNEX 4-Figure 11B).

Five Portuguese musical instruments (MNM0406, MNM0407, MNM0372, MNM0373 and MNM681), one Dutch harpsichord (MNM0374) and one Dutch virginal (MNM0395) were not dated according to the actual database. Three reasons can explain the undatable sequences:

(1) There are not sufficiently preserved rings. Several tree ring measurement series of less than 50 rings were found on eight musical instruments (MNM0407, MNM0648, MNM0833, MNM0372, MNM0373, MNM0681, MNM1096 and MNM0395) (Table 34).
(2) All regions, sites, and different altitudinal gradients are not covered by the available reference and individual chronologies. This may explain the undated six final series found in five instruments, each with more than 50 rings (MNM0425, MNM0833, MNM0372, MNM1096 and MNM0395).
(3) The use of local woods in Portuguese musical instruments for which no reference chronologies exist. For the five undated Portuguese instruments, this theory should not be ignored (MNM0406, MNM0407, MNM0373, MNM0372, and MNM0681).

Table 34. Tree ring measurements from undated clavichords, harpsichords and fortepianos of Portuguese and foreigner workshops [(a) - tangential cut].

MUSICAL INSTRUMENT [INVENTORY NUMBER]	TOTAL RINGS	RING WIDTH (mm) AVG±STDV	MINIMUM (mm)	MAXIMUM (mm)	MEAN SENSITIVITY (%)
PORTUGUESE INSTRUMENTS					
Clavichord [MNM0406]					
MNM0406001	77	3.73±1.14	1.21	7.17	22
MNM0406002	35	3.29±1.20	2.17	5.27	25
MNM0406001-002	92	3.64±0.88	1.21	7.17	21
Clavichord [MNM0407]					
MNM0407001	48	2.48±0.57	1.33	3.51	11
MNM0407002	55	2.54±0.75	1.50	5.33	11
MNM0407003	26	2.63±1.17	1.41	5.27	14
Harpsichord [MNM0372]					
MNM0372s001	6	8.20±1.27	7.11	10.30	15
MNM0372s002	19	4.78±1.94	2.35	8.82	24
MNM0372s003	22	4.99±2.22	2.20	11.17	32
MNM0372s004	13	5.33±2.00	2.64	8.30	17
MNM0372s005	20	5.15±3.07	1.75	11.00	22
MNM0372s006	21	4.89±2.60	2.17	11.22	21
MNM0372s007	15	6.44±1.19	4.27	8.98	17
MNM0372s008	15	5.95±1.09	3.89	8.15	16
MNM0372s009	12	5.49±0.94	3.94	7.02	17
MNM0372s002-003-004-005-006	25	5.33±2.36	2.55	11.17	23
MNM0372s007-008-009	15	6.10±1.17	4.03	8.56	16

MUSICAL INSTRUMENT [INVENTORY NUMBER]	**TOTAL RINGS**	**RING WIDTH (mm) AVG±STDV**	**MINIMUM (mm)**	**MAXIMUM (mm)**	**MEAN SENSITIVITY (%)**
MNM0372w001	41	1.88±0.48	1.30	3.35	15
MNM0372w002	31	1.92±0.38	1.29	2.98	13
MNM0372w003	48	1.74±0.44	0.95	2.69	13
MNM0372w004	14	6.33±1.15	4.17	8.17	16
MNM0372w005	56	1.66±0.62	0.89	3.76	16
MNM0372w006	48	1.61±0.40	0.99	2.47	13
MNM0372w007	14	6.11±1.23	4.27	9.15	16
MNM0372w008	12	5.83±1.02	4.01	7.54	22
MNM0372w009	8	6.77±1.29	4.18	8.21	20
MNM0372w001-002-003-005-006	56	1.76±0.56	0.94	3.28	13
MNM0372w004-007-008-009	15	6.35±1.21	4.15	9.15	17
Harpsichord [MNM0373]					
MNM0373s001	11	0.79±0.16	0.55	1.00	15
MNM0373s002	6	1.02±0.26	0.64	1.32	29
MNM0373s003	24	2.87±1.24	1.18	5.60	15
MNM0373s004	19	3.08±0.98	1.55	5.19	18
MNM0373s005	27	1.30±0.30	0.85	1.90	17
MNM0373s006	38	2.24±1.07	0.71	5.24	22
MNM0373s007	46	1.58±0.72	0.77	3.75	18
MNM0373s008	43	2.02±1.06	0.74	5.75	22
MNM0373s009	40	1.84±0.82	0.80	4.75	19
MNM0373s010	41	2.02±0.79	0.81	4.03	23
MNM0373s011	38	2.18±0.98	0.82	4.61	27
MNM0373s012	23	3.11±0.83	1.40	4.60	21
MNM0373s013	20	3.70±1.22	1.86	6.53	19
MNM0373s014	41	2.02±0.92	0.70	4.27	27
MNM0373s015	42	1.00±0.22	0.55	1.47	15
MNM0373w001	5	7.90±1.24	6.66	9.75	11
MNM0373w002	24	2.43±0.74	1.33	4.80	17
MNM0373w003	56	1.62±1.10	0.40	4.12	22
MNM0373w004	34	2.47±1.18	0.54	5.02	17
MNM0373w005	25	2.76±1.79	1.01	6.78	22
MNM0373w006	37	1.44±0.75	0.57	2.84	20
MNM0373w007	26	2.62±0.99	1.62	6.17	16
MNM0373w008	13	1.08±0.28	0.64	1.46	21
MNM0373w009	24	2.87±0.54	2.11	4.01	13
MNM0373w010	27	2.57±0.91	0.97	4.41	13
MNM0373w011	16	2.77±0.81	1.70	4.54	10
MNM0373w012	25	3.41±0.97	1.86	5.30	16
Harpsichord [MNM0681]					
MNM0681001	24	1.55±0.27	0.99	2.12	19
MNM0681002	52	1.66±0.66	0.96	4.08	16
MNM0681003	31	1.73±0.34	1.08	2.60	15
MNM0681004	58	1.56±0.65	0.71	3.98	14
MNM0681005	56	1.66±0.74	0.81	4.63	15
MNM0681006	55	1.69±0.68	0.84	4.48	16
MNM0681007	43	2.09±1.08	1.21	7.46	16
MNM0681008	(a)	(a)	(a)	(a)	(a)
MNM0681009	47	2.37±1.09	1.20	6.41	13
MNM0681010	(a)	(a)	(a)	(a)	(a)
MNM0681011	38	2.00±1.12	1.20	7.35	15
MNM0681012	47	2.07±0.81	1.02	5.21	12
MNM0681013	40	1.39±0.44	0.75	2.59	13
MNM0681014	(a)	(a)	(a)	(a)	(a)
MNM0681015	52	1.47±0.51	0.74	2.90	18

MUSICAL INSTRUMENT [INVENTORY NUMBER]	TOTAL RINGS	RING WIDTH (mm) AVG±STDV	MINIMUM (mm)	MAXIMUM (mm)	MEAN SENSITIVITY (%)
MNM0681016	40	1.89±0.59	1.20	4.02	16
MNM0681017	46	1.75±0.99	0.77	6.35	14
MNM0681018	41	1.91±0.79	1.05	4.01	14
MNM0681019	43	1.47±0.36	0.82	2.32	17
MNM0681001-002-003-004-005-006-007-009-010-011-012-013-014-015-016-019	62	1.94±0.99	1.18	7.35	13
FOREIGNERS INSTRUMENTS					
Harpsichord [MNM0374]					
MNM0374001	59	1.82±0.43	0.90	3.01	18
MNM0374002	43	1.90±0.41	1.11	2.71	13
MNM0374003	52	1.59±0.31	0.96	2.41	14
MNM0374004	44	1.93±0.45	1.06	2.75	13
MNM0374005	64	1.83±0.42	0.91	3.01	18
MNM0374006	58	1.70±0.38	0.85	2.96	15
MNM0374003-005	72	1.72±0.41	0.91	3.01	16
MNM0374001-002-004-006	62	1.76±0.41	0.87	2.76	15
Virginal [MNM0395]					
MNM0395001	88	1.45±0.68	0.59	3.40	19
MNM0395002	109	1.74±0.80	0.48	3.78	23
MNM0395003	48	1.87±0.51	0.95	3.07	21

2.3.3.3. Dendroprovenance

From the dendrochronological analysis of the six dated instruments, nine reference chronologies from three countries (France, Italy, and Switzerland) obtained in ITRDB were successfully applied, covering an area from 42.05° to 46.73° N latitude and from 7.43° to 12.06° E longitude (Figure 94). Three other chronologies concerning musical instruments' measurements (GERM062[68] and GERM063[69]) and architectural timbers (GERM021[67]) were also helpful in expanding the geographical field to the German region. According to the spatial distribution presented in Figure 94, it is unreasonable to state the woods' exact provenance for the dated musical instruments soundboards studied in the present thesis, considering the broad coverage of the reference chronologies. However, several dendrochronological sequences obtained from European keyboard instruments, well dated and the respective probable wood provenance identified (HOUBRECHTS, 2004; 2006) allow for a deeper understanding of the instruments examined in this study.

Figure 94. Spatial distribution of the European reference chronologies available in ITRDB used to date the clavichords, harpsichords and pianofortes of Portuguese and foreigners' workshops [SOURCE: Images by GoogleMaps].

Excellent statistical results were obtained between the MNM0425002-004-006-007 sequence (obtained in the Portuguese pianoforte assigned to Henry van Casteel (MNM0425)) and IM009I, IM027I, and IM023II series from Belgian keyboard instruments (t_H=16.2, t_H=14.0 and t_H=10.1, respectively, respectively) (see ANNEX 7-Table 1). Hence, it allows an assumption on the most plausible wood's source. The woods' possible origin, according to HOUBRECHTS (2004, 2006), is the Bavarian Pre-Alps, raising the Tyrol hypothesis. A strong match was also observed with the MITT1[68] series (t_H=10.9), which was recorded as "wood most likely local, central southern German border with Austria"[68]. Other Belgian instruments of the same woods' possible sources (IM005I, IM015I, and IM020I) produced weaker statistical results for the remaining two sequences (MNM0425003 and MNM0425005), still of reasonable quality (t_H between 5.5 and 6.9). In comparison, the significant correlations between these two boards and the remainder confirm the idea of a similar origin of all soundboard boards (t_H between 4.4 and 6.9) (Figure 81).

The Portuguese pianoforte assigned to Mathias Bostem (CRMM) also showed especially good statistical results with the replication of data across comparison chronologies. Apart from the high-level similarities between the CRMM003-004 sequence and the SWIT169 and ITA024 reference chronologies, two well-defined wood origins (t_H=7.5 and t_H=7.0, respectively), the most possible wood origin is not obvious (see ANNEX 7-Table 2). Notwithstanding SWIT169 and ITA024 reference chronologies, which cover remote regions (Simmental, Switzerland, and Fodara Vedla, Italy, respectively), they are correlated with high and similar altitudes (1900m and 1970m, respectively), illustrating the similarity of growth patterns and strong statistical correlations. The other board of the instrument's soundboard could be from the same region. Still, the reduced number of replications with known provenance sequences does not further discuss this hypothesis.

The Portuguese pianoforte attributed to Mathias Bostem (MNM0833) brings unique cases for the four dated series. The MNM0833002 sequence shows a strong match with IM009I and IM027I series (t_H=10.1 and t_H=9.5, respectively) identified with the Bavarian Pre-Alps as a possible origin (HOUBRECHTS, 2004; 2006). Nevertheless, the excellent correlations with the reference chronologies SWIT169 and ITA024 (t_H=8.5 and t_H=6.8, respectively) expand the spectrum, decreasing the likelihood of identifying the source of the timber (see ANNEX 7-Table 4). The MNM0833005 sequence shows lower correlations (t_H=4.9, t_H=4.3 and t_H=4.3, respectively) with lower overlaps (65 rings) with known and larger origin reference chronologies (SWIT173, ITA042 and ITA024), not allowing any assumption about the wood provenance. The same conclusion is drawn with the two remaining sequences, as their lower date replications were obtained from series of musical instruments of unknown origin.

The dated sequence of the German clavichord (MNM0419) presents lower date replications, a similar condition to the two previously sequences. Despite the good correlation obtained with SWIT169 reference chronology (t_H=4.1), it is inconclusive with respect to the timber source (see ANNEX 7-Table 5). A more substantial number of replicates of known origin chronologies will be required to draw conclusions regarding the origin of the wood used in the German clavichord.

The Portuguese pianoforte attributed to Mathias Bostem (MNM0648) presents four dated sequences with a lower data replication of uncertain wood possible origin sequences. This reality does not permit any inference as to the origins of the material. The MNM0648007 sequence exhibits poor correlations with five known wood origin sequences (IM017III, MITT2[69], GuA23B1, IM009I and IM023II) (see ANNEX 7-Table 5). As they are all associated with the Bavarian Alps, this assumption concerning the MNM0648 pianoforte board remains open.

Besides the reference chronologies of Norway spruce (*Picea abies* Karst), other wood species have been successfully used, e.g., larch (*Larix decidua* Mill.), silver fir (*Abies alba* Mill.) and Arolla pine (*Pinus cembra* L.) (see ANNEX 7). Silver fir chronologies are a special case, as they may provide equal results in reference chronologies defined for remote regions. In these cases, it was not feasible to select the most plausible source of timber. The French harpsichord assigned to Pascal Taskin (MNM1096) is an outstanding example. The MNM1096w003-004-005-007-009 sequence shows high correlations with the IM010II and IM006I silver fir sequences (t_H=9.5 and t_H=6.6, respectively), for which possible origins have been identified as the Lorraine region (north-eastern France) and Bavaria (Germany), respectively (HOUBRECHTS, 2004; 2006). In turn, the MNM1096w002 sequence shows high correlations with the IM010II and IM037I silver fir series (t_H=7.2 and t_H=5.6, respectively) with the Lorraine region as potential wood source, as well as the FRAN038 silver fir reference chronology (t_H=5.4) from the remote island of Corsica (France) (see ANNEX 7-Table 6; Figure 94).

2.3.3.4. Regularity of growth rings

Apart from dating, dendrochronological analyses of European musical instruments constructed since the XVII century have uncovered valuable data regarding building rules and material selection (HOUBRECHTS, 2004; 2006; VANDERVELLEN *et al.*, 2017). The main purpose of the piano manufacturer was to obtain a soundboard made of a very homogeneous material (VANDERVELLEN *et al.*, 2017).

Several macrostructural features of resonance wood were described, including the width and regularity of the annual growth rings, as well as the absence of wood defects (GHELMEZIU and BELDIE, 1972; ROCABOY and BUCUR, 1990; BUCUR, 2006; BUKSNOWITZ *et al.*, 2007; SPYCHER *et al.*, 2008). Throughout history, board selection based on tree ring width has been based on the type of musical instrument and its vibration spectrum (BUCUR, 2016), for example: **(a)** 1.2 mm for violins, 1.9 mm for cellos and 2.2 mm for double bass (BUCUR, 2016); and **(b)** 0.5-2.0 mm for violins and guitars, 2.0-4.0 mm for cellos and contrabass (KRZYSIK, 1968). In older keyboard instruments, other ranges have been observed, e.g.: **(a)** 0.7-3.0 mm (HOLZ (1967) cited by BUCUR (2006)); and **(b)** 0.8-2.3 mm (HOUBRECHTS, 2004; 2006) although in contemporary pianos, Richardson (1998) alluded to wider rings and a broader range of values of 6-10 mm.

Interestingly, values similar to the older ones were collected in the Portuguese keyboard instruments allocated to foreign manufacturers (Henry van Casteel (MNM0425) and Mathias Bostem (CRMM, MNM0648 and MNM0833)) (Tables 30 and 31), ranging from 0.73 mm (MNM0648) to 1.79 mm (MNM0406). However, the instruments from Portuguese manufacturers have a high number of boards with a higher average annual growth rate, ranging from 0.79 mm (MNM0373) to 8.20 mm (MNM0372). The Portuguese harpsichord attributed to José Joaquim Antunes (MNM0372) has several boards with quite a few wider rings, presumably referring to the innermost portion of the stem (Table

35). These results are consistent with the observations of KOSTER (2008) on Iberian instruments, for which the fine and normal grain was not always reported. The foreigner's instruments examined have thin rings with an average annual growth of less than 2.00 mm (Tables 31 to 33), as found by HOUBRECHTS (2004, 2006) for many Belgian instruments. The exception is found in the French harpsichord (MNM1096), with some boards having an average annual growth of more than 2.20 mm (Table 33), as has also been noted by HOUBRECHTS (2004, 2006) on two French instruments.

According to BUCUR (2006), the incremental transition of the ring diameter between the bordering boards of a soundboard is also a consideration to be addressed in an acoustic instrument. In most instruments, smooth variations are found between the wooden boards, as the average ring thickness between them is not quite divergent (Tables 30 to 34). A particular emphasis should be given to the Portuguese instruments assigned to Henry van Casteel (MNM0425) (Table 30) and Mathias Bostem (CRMM, MNM0648 and MNM0833) (Table 31), as well as to a German clavichord (MNM0419) (Table 32) and a Dutch harpsichord (MNM0374) (Table 33), of which all boards have a similar average ring thickness and a low standard deviation. The exceptions are two Portuguese harpsichords attributed to José Joaquim Antunes (MM372) and João Batista Antunes (MM373) (Table 35) and in the French harpsichord (MNM1096) (Table 33).

The overall perception is that a regular ring arrangement on soundboard boards is a priority prerequisite (ROCABOY and BUCUR, 1990). Although the visual and qualitative study of the different boards that make up the soundboard is often subjective and not readily accepted between researchers/specialists (see ANNEX 4 – Figures 1C-3C, 4E, 5D, 6D, 7C-10C, 11E, 12D and 13D), the regularity of the board rings has been quantified in the present thesis. The chosen metrics cannot be correlated individually with each other, but rather with an interconnected approach, because the definition underlying each measurement is different (Table 35). KRZYSIK (1968) and HOLZ (1972) developed indices based on the thickness difference between consecutive rings (δ and ε_J, respectively). HOLZ (1972) suggested a second index based on the number of rings within two consecutive 2 cm (ε_k). ROCABOY and BUCUR (1990) considered the amplitude between the widest and narrowest rings identified in each board.

In the 13 instruments, it was confirmed that 91 out of the 94 boards examined were within the limits of rings regularity index, ε_J, given by HOLZ (1972) to wood with acoustic qualities (Table 35). The exceptions are three boards in three Portuguese instruments – the clavichord of the unknown assignment (MNM0406) (ε_J = 32), the harpsichord attributed to José Joaquim Antunes (MNM0372) (ε_J=36) and the harpsichord of the unknown assignment (MNM0681) (ε_J=32). The index ε_k was calculated for 91 boards since three of them were no larger than 2 cm. The index was higher than the

HOLZ (1972) value for acoustic wood only in five boards. The exceptions are the two harpsichords listed above. Since the value 30 for both indices is known to be the limit between a good and a lousy wood resonance (HOLZ, 1972), it can be claimed that the thirteen instruments examined are made up of boards suitable for their intended function. the more uniform the composition of the growth ring is (HOLZ, 1972). Thus, two Portuguese pianofortes attributed to Matias Bostem (CRMM and MNM0648) and the German clavichord (MNM0419) stand out with soundboards composed of all boards with lower ε_J (Table 35).

KRZYSIK (1968) stated that boards with good acoustic qualities should satisfy two requirements: **(1)** the difference in the number of rings between two consecutive cm does not exceed 30% (corresponding to the coefficient of variation of HOLZ (1972), ε_k); and **(2)** difference between successive rings does not exceed 0.50 mm. These two specifications are compiled by all musical instruments, except for the Portuguese harpsichord (MNM0373), which consists of some boards with δ values above 0.50.

ROCABOY and BUCUR (1990) proposed that the regularity index (r_i) for the resonance wood species should be lower than 0.70. There are very few boards in the Portuguese instruments that come under this limit. There were no boards with index values below this threshold in four instruments: clavichord (MNM0406) and three fortepianos (MNM0425, MNM0468 and MNM0833). The French Taskin harpsichord (MNM1096) and the Dutch harpsichord (MNM0374) present almost all their boards classified as resonance woods. The only instrument for all boards with an index less than 0.70 is the German clavichord (MNM0419). This index does not evaluate the rings' distribution along the board since it considers only the difference of the two extreme annual rings widths to the yearly maximum ring spacing in the specimen.

The latewood proportion in a tree ring (LW) is also a parameter to be considered in the macroscopic evaluation of resonance woods since it is directly correlated to the acoustic constant (KRZYSIK 1968). The best resonance woods have less than 25% latewood (KRZYSIK, 1968), but a broader variety of values can be found, for example: LW<35% (KRZYSIK, 1968); 10%<LW<30% (HOLZ, 1972); LW<25% (GHELMEZIU and BELDIE,1970; ROCABOY and BUCUR,1990); LW=20% (BUKSNOWITZ *et al.*, 2007); LW=26% (DINULICĂ *et al.*, 2015); LW=10% (BUCUR, 2016). The data collected in the musical instruments examined match well within the reference limits, except for the Portuguese clavichord of uncertain attribution (MNM0406) with a latewood ratio of more than 40% (Table 35). There are four soundboards totally composed by boards with average latewood ratio values less than 25% leading to presumed good acoustics – fortepianos from Henry van Casteel (MNM0425) and Mathias Bostem (CRMM and MNM0648) and the harpsichord attributed to Joaquim José Antunes (MNM0372).

This data analysis facilitates the visualisation of soundboards with a very homogeneous appearance and construction, meaning a board selection that is effective in terms of acoustics. However, experts can determine the acoustic efficiency of each instrument, with the wood measures provided in this analysis acting as a backup.

Table 35. Regularity indexes of soundboards from the keyboard instruments, by board [(a) - tangential cut; (b) - few rings for Δ# determination].

MUSICAL INSTRUMENT [INVENTORY NUMBER]	**COEFFICIENT OF VARIATION (ad)**		**DIFFERENCE BETWEEN CONSECUTIVE GROWTH RINGS, δ (mm)**	**REGULARITY INDEX, ri (ad)**	**LW (%) (AVG±DVP)**
	VARIANT TREE RING WIDTH, εJ	**VARIANT NUMBER TREE RINGS, εk**			
PORTUGUESE INSTRUMENTS					
Clavichord [MNM0406]					
MNM0406001	28	23	0.77	0.83	43±10
MNM0406002	32	29	0.86	0.83	37±2
Clavichord [MNM0407]					
MNM0407001	13	21	0.25	0.62	22±7
MNM0407002	15	23	0.29	0.72	25±6
MNM0406003	17	25	0.37	0.73	24±9
Fortepiano [MNM0425]					
MNM0425001	20	30	0.16	0.83	17±7
MNM0425002	10	14	0.14	0.93	19±8
MNM0425003	13	12	0.12	0.87	17±6
MNM0425004	20	16	0.11	0.82	17±5
MNM0425005	15	13	0.15	0.83	23±7
MNM0425006	20	13	0.13	0.85	21±9
MNM0425007	22	12	0.09	0.85	26±12
Fortepiano [CRMM]					
CRMM001	18	19	0.24	0.75	19±6
CRMM002	19	19	0.27	0.87	14±5
CRMM003	17	23	0.17	0.80	11±5
CRMM004	18	20	0.16	0.82	12±5
CRMM005	17	10	0.20	0.50	13±4
Fortepiano [MNM0648]					
MNM0648001	15	27	0.16	0.94	17±8
MNM0648002	18	12	0.23	0.87	21±7
MNM0648003	17	17	0.18	0.86	18±9
MNM0648004	17	11	0.26	0.86	17±7
MNM0648005	14	18	0.14	0.83	14±4
MNM0648006	19	(b)	0.13	0.87	22±8
MNM0648007	19	14	0.17	0.85	20±8
Fortepiano [MNM0833]					
MNM0833001	(a)	(a)	(a)	(a)	(a)
MNM0833002	27	14	0.37	0.85	21±9
MNM0833003	18	11	0.19	0.87	23±7
MNM0833004	17	11	0.14	0.68	26±8
MNM0833005	18	7	0.23	0.88	20±7
MNM0833006	20	19	0.16	0.82	22±7
MNM0833007	20	16	0.18	0.84	26±8
MNM0833008	22	17	0.17	0.85	28±8
MNM0833009	21	11	0.28	0.86	22±9
Harpsichord [MNM0372]					
MNM0372001	18	54	1.25	0.31	15±5
MNM0372002	29	30	1.05	0.73	23±7
MNM0372003	36	39	1.57	0.80	24±10

MUSICAL INSTRUMENT [INVENTORY NUMBER]	COEFFICIENT OF VARIATION (ad)		DIFFERENCE BETWEEN CONSECUTIVE GROWTH RINGS, δ (mm)	REGULARITY INDEX, ri (ad)	LW (%) (AVG±DVP)
	VARIANT TREE RING WIDTH, εJ	VARIANT NUMBER TREE RINGS, εk			
MNM0372004	19	20	0.82	0.68	17±6
MNM0372005	29	29	0.93	0.84	23±8
MNM0372006	25	29	1.09	0.81	24±6
MNM0372007	20	41	1.01	0.52	14±4
MNM0372008	19	25	0.86	0.52	15±6
MNM0372009	20	0	0.92	0.44	14±6
Harpsichord [MNM0373]					
MNM0373001	19	(b)	0.11	0.45	35±7
MNM0373002	22	(b)	0.35	0.52	30±7
MNM0373003	18	26	0.40	0.79	20±8
MNM0373004	26	25	0.57	0.70	24±6
MNM0373005	19	21	0.22	0.54	21±7
MNM0373006	25	27	0.47	0.86	21±9
MNM0373007	21	27	0.26	0.79	21±12
MNM0373008	26	26	0.44	0.87	21±9
MNM0373009	23	22	0.35	0.83	22±8
MNM0373010	28	21	0.47	0.79	21±8
MNM0373011	20	25	0.57	0.82	19±10
MNM0373012	24	20	0.61	0.69	26±17
MNM0373013	23	22	0.70	0.72	21±8
MNM0373014	32	15	0.52	0.83	25±8
MNM0373015	18	12	0.15	0.63	35±10
Harpsichord [MNM0681]					
MNM0681001	24	11	0.30	0.53	19±4
MNM0681002	19	15	0.26	0.76	19±6
MNM0681003	18	12	0.26	0.58	25±6
MNM0681004	18	21	0.21	0.82	21±5
MNM0681005	19	32	0.24	0.82	20±7
MNM0681006	19	21	0.28	0.81	19±7
MNM0681007	19	31	0.35	0.84	22±5
MNM0681008	(a)	(a)	(a)	(a)	(a)
MNM0681009	17	19	0.29	0.81	29±10
MNM0681010	(a)	(a)	(a)	(a)	(a)
MNM0681011	20	28	0.34	0.83	19±6
MNM0681012	17	20	0.24	0.80	28±8
MNM0681013	17	24	0.18	0.71	20±6
MNM0681014	(a)	(a)	(a)	(a)	(a)
MNM0681015	21	30	0.25	0.74	28±8
MNM0681016	19	22	0.30	0.70	20±6
MNM0681017	18	27	0.26	0.88	27±9
MNM0681018	18	25	0.26	0.73	23±7
MNM0681019	21	22	0.25	0.65	29±8
FOREIGNERS INSTRUMENTS					
Clavichord [MNM0419]					
MNM0419001	13	15	0.19	0.90	21±6
MNM0419002	13	13	0.19	0.90	28±6
MNM0419003	13	9	0.18	0.92	26±5
Harpsichord [MNM1096]					
MNM01096001	11	16	0.29	0.46	29±6
MNM01096002	15	11	0.31	0.51	27±6
MNM01096003	21	21	0.42	0.54	24±6
MNM01096004	16	20	0.24	0.54	39±9
MNM01096005	25	15	0.42	0.77	23±8

MUSICAL INSTRUMENT [INVENTORY NUMBER]	COEFFICIENT OF VARIATION (ad)		DIFFERENCE BETWEEN CONSECUTIVE GROWTH RINGS, δ (mm)	REGULARITY INDEX, ri (ad)	LW (%) (AVG±DVP)
	VARIANT TREE RING WIDTH, εJ	VARIANT NUMBER TREE RINGS, εk			
MNM01096006	23	15	0.30	0.69	23±8
MNM01096007	21	11	0.37	0.60	16±6
Harpsichord [MNM0374]					
MNM0374001	22	16	0.31	0.70	24±6
MNM0374002	16	32	0.25	0.59	30±7
MNM0374003	17	17	0.22	0.60	29±9
MNM0374004	17	11	0.26	0.61	42±8
MNM0374005	23	30	0.32	0.69	13±5
MNM0374006	19	26	0.25	0.71	31±8
Virginal [MNM0395]					
MNM0395001	24	22	0.27	0.83	31±10
MNM0395002	28	19	0.35	0.87	32±9
MNM0395003	28	24	0.39	0.68	28±7

2.3.3.5. Indented rings identification in the soundboards

Indented rings are considered an anatomical anomaly that can be justified by an abnormal growth rate change (NOCETTI and ROMAGNOLI, 2008). It is not a constant anomaly alongin the stem, and it occurs casually at various tree ages. Anatomically, the synchronisation of tracheids is greatly affected, and the number of rays and the amount of a single ray increases considerably. The tracheids turn away from the longitudinal direction and bend sharply in the radial direction and slightly in the tangential direction (BONAMINI *et al.*, 1991). This anomaly in the growth pattern can be observed in several *Picea* species, including Norway spruce, *P. orientalis* Link. and *P. sitchensis* Carr., as well as in other conifers, namely cypress (*Cupressus* sp.), fir (*Abies* sp.), larch (*Larix* sp.), Douglas fir (*Pseudotsuga menziesii* Franco), pine (*Pinus* sp.), yew (*Taxus baccata* L.) and in some species of non-European origin (BONAMINI *et al.*, 1991; ROMAGNOLI *et al.*, 2003). Indented rings in spruce wood were also favoured by prominent luthiers since the XVII century (BONAMINI *et al.*, 1991; NOCETTI and ROMAGNOLI, 2008; BUKSNOWITZ *et al.*, 2012), as exemplified in Figure 95, probably due to the significant differences in mechanical properties associated with this anomaly (BUKSNOWITZ *et al.*, 2012). Aside from giving a distinctive appearance to the musical instrument (BUKSNOWITZ *et al.*, 2012), the inclusion of "indented rings" influences the wood's physical, mechanical, and acoustic properties (BONAMINI *et al.*, 1991; ROMAGNOLI *et al.*, 2003; BUCUR, 2006; BUKSNOWITZ *et al.*, 2012). According to BUCUR (2006), the volumetric proportion of indented rings is directly connected with the ultrasonic velocity in three sections – radial, tangential, and transverse. Despite the decreased anisotropy in woods with indented rings, no experimental research demonstrated that these are better woods for soundboard construction.

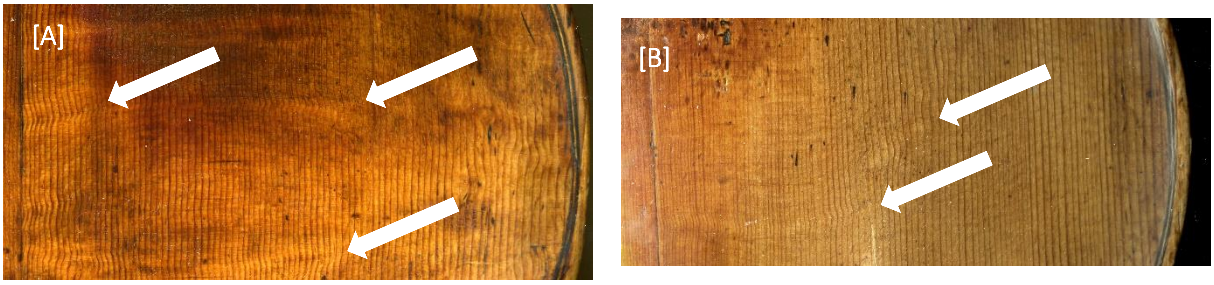


Figure 95. Treble sides with intended rings (white arrows) in two Italian violins attributed to: **[A]** Guarneri's workshop; and **[B]** Domenico Montagnana [SOURCE: private collections].

Indented rings were identified in the soundboards of four Portuguese instruments (CRMM, MNM0425, MNM0648 and MNM1096) (Figure 96). Since the increase in density is associated with indented rings (ROMAGNOLI *et al.*, 2003) and there is a change in acoustic and mechanical properties, intended rings should not be underestimated in future studies of these Portuguese musical instruments, mainly the acoustic properties of resonance materials.

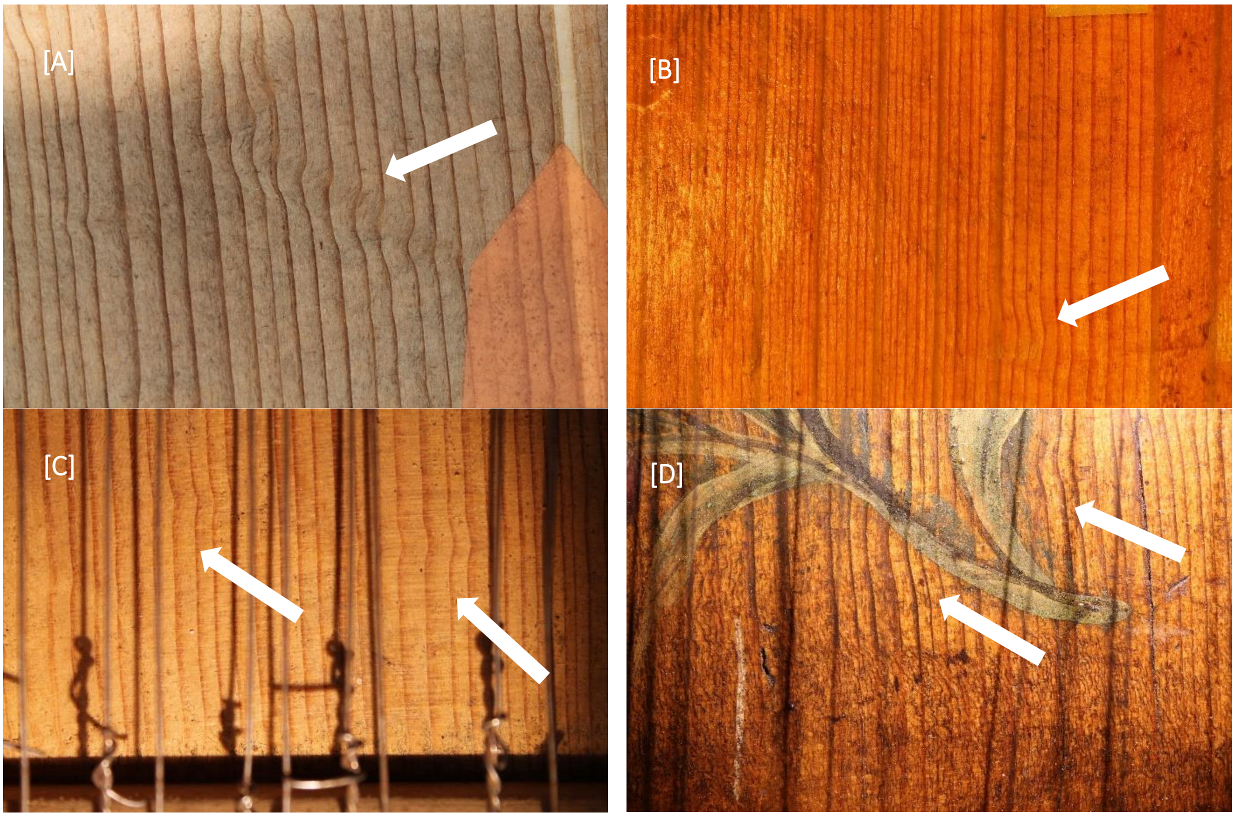


Figure 96. Indented rings identified (white arrows) in: **[A]** board II in the Portuguese fortepiano (CRMM), assigned to Mathias Bostem, dated 1777; **[B]** board III in the Portuguese fortepiano (MNM0425), assigned to Henry van Casteel, dated 1763; **[C]** board II in the Portuguese fortepiano (MNM0648), assigned to Mathias Bostem, dated 1786; and **[D]** board III in the French harpsichord [MNM1096] assigned to Pascal Taskin, dated 1782.

CONCLUSIONS AND FUTURE WORK

The dendrochronological research applied to the Portuguese heritage focused on Portuguese and Flemish paintings as well as on musical instruments brought new evidence on their making regarding attribution, dating and production methods. In numerous cases, the dendrochronological results corroborate historical sources. This research also identified several qualities attributed to dendrochronology such as chronological precision, assistance in ensuring quality of interpretation, and promotion and stimulation of research. Even if dendrochronology was inconclusive or produced no results in some cases for different reasons, this did not undermine the value and interest of this methodology.

The dendrochronological research carried out here on original Flemish and Portuguese paintings from two public collections defined the *terminus post quem* of all the artworks, according to the available databases. The results for 15 Flemish paintings and two Portuguese altarpieces agreed with the historical dates mentioned in the museum catalogue and literature, while also provided a dataset that can be used as reference values for future dendrochronological dating of other artworks. The data allowed to establish a new oak chronology (PORTHER001) that should be viewed in a context of continuous improvement, with future addition of new data collected over time on various types of works of art. Links and cooperation between dendrochronological research teams and heritage stakeholders (e.g., museums, public and private companies/laboratories dedicated to the conservation and restoration of cultural heritage and antiquarians) to access artworks from various Portuguese workshops, regardless of their level of relevance in the artistic scene, are essential to achieve these goals.

The oak boards that compose the support for the paintings should be considered as a valuable dataset for the ongoing research into the historic timber trade between Portugal and Europe. From a dendrochronological perspective, it was not possible to detail the source timber used in the Portuguese paintings from the XV and XVI centuries, although this research suggests that eastern Baltic wood material was most used. As more chronologies will be established from imported oak timber identified in the Portuguese heritage artworks and a more geographically distributed network of chronologies becomes available for areas of the Baltic region, it is hoped that tree-ring evidence concerning the original sources of such timber will be further developed. In other words, a more precise indication will arise on the location of the woodland areas that supplied timber for the trade with the Iberian Peninsula, specifically with Portugal. The imported wood mentioned in the various historical records that were consulted in this research seems to have had as one of its purposes the construction of artworks. Therefore, several Portuguese paintings from the mediaeval and early modern periods (the XV and XVI centuries) should be regarded as substantial evidence of oak panels as a commodity traded throughout Northern Europe.

This research also demonstrated that a dendrochronological approach can be used with musical instruments, namely to date violins and cellos made in Portuguese workshops in the XVII and XIX centuries. An experimental set-up was designed for data image acquisition and several cases proved the meaningful contribution made by the close examination of growth tree-rings when researching the scientific and historical context of these instruments, which is especially useful for confirming attribution to a specific maker and identifying forgeries. The current investigation considered that wood bundles coming from the Alps, as well as semi-finished wooden pieces, that supplied the Italian ports of Venice and Trieste in the XVIII and XIX centuries and were destined to Portugal, were partially allocated to the construction of musical instruments, particularly of violins and cellos. As a result, it concludes that dendroprovenance is an excellent tool for substantiating the historical records pertaining to Portuguese maritime trade with Europe, particularly with Italian ports.

In the case of larger musical instruments, such as harpsichords and pianofortes, the effectiveness of re-adapting photographic and video accessories was demonstrated ensuring the acquisition of images of the soundboards for dendrochronological analysis without handling the instruments. Considering the lack of information about the wood selection used in the soundboards of these instruments built in Portuguese workshops between the XVIII and XIX centuries, the current study provided objective answers about board assemblage criteria, growth tree-ring type and wood provenance. Although no conclusions could be drawn regarding the exact origin of the wood, it could be concluded, as with violins and cellos, that the vast area of the Alps was the primary source of this raw material and these woods were most likely exported from the Italian ports of Liorne, Genoa, Palermo, and Sicily to Portugal, specifically to Lisbon. Given these results, it can be inferred that BRAUCHLI's (1998) hypothesis that most materials used in XVIII century Portuguese keyboard instruments were of local origin, especially the spruce or pine wood used in the soundboard, was not entirely correct. Nonetheless, one of the factors that may explain the impossibility to date some of the instruments by Portuguese builders chosen for this study is the possible use of local woods.

This research opens the way for future work, such as the study of other musical instruments collections, and the development of a methodology for identifying the wood species that takes the existing limitations into account, thereby contributing to the evaluation of the effect of the wood nature of soundboards on tone.

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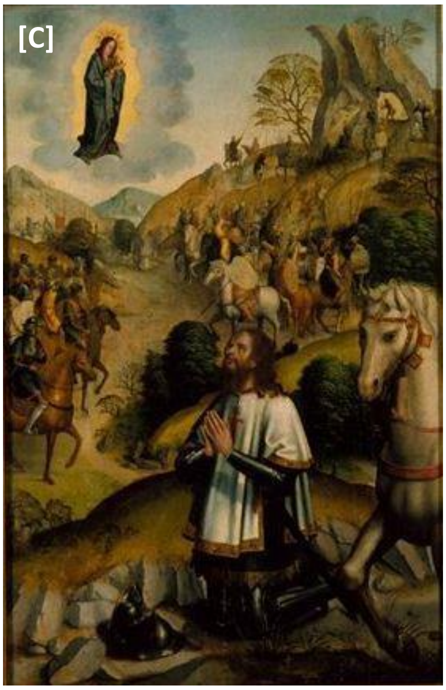
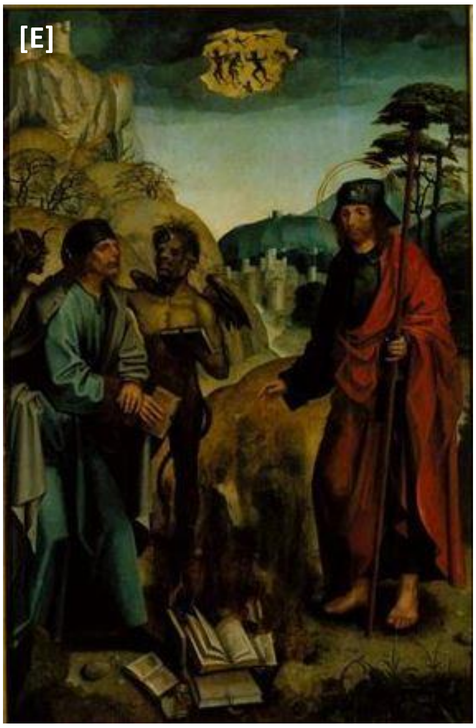
ANNEXES

ANNEX 1. Portuguese paintings from *Vida de S. Tiago* altarpiece

[A] *Investidura de um Mestre da Ordem de Santiago* (16 Pint); **[B]** *Entrega da bandeira a um Mestre da Ordem de Santiago* (17 Pint)[75]; **[C]** *Aparição da Virgem a um Mestre da Ordem de Santiago* (18 Pint); **[D]** *São Tiago combatendo os mouros* (19 Pint); **[E]** *Conversão de Hermógenes* (20 Pint); **[F]** *O Corpo de S. Tiago conduzido ao Paço da Rainha Loba* (21 Pint); **[G]** *Cristo envia S. Tiago e S. João em Missão Apostólica* (22 Pint); and **[H]** *Pregação de S. Tiago*[75] (24 Pint) (SOURCE: MatrizNet).



[75] Not studied due to the state of conservation


[E]

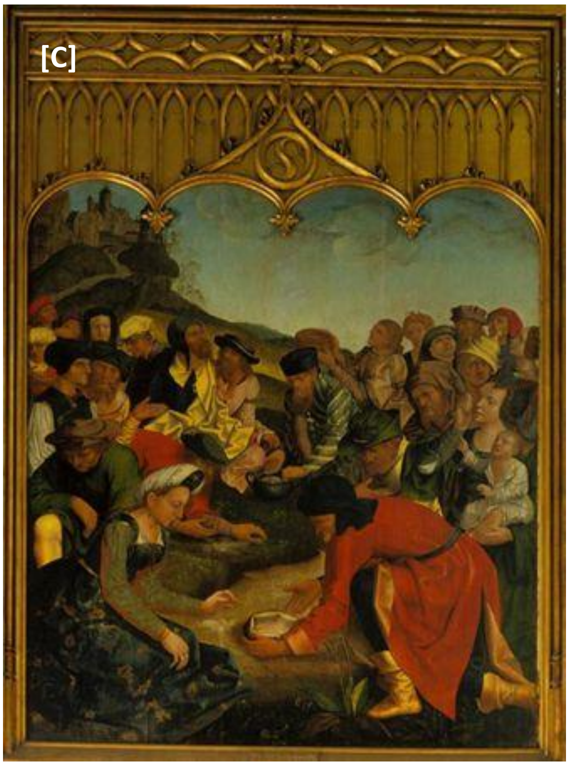

[F]


[G]


[H]

ANNEX 2. Portuguese paintings from *S. Francisco de Évora* altarpiece

[A] *Degolação dos Cinco Mártires de Marrocos* (89 Pint); **[B]** *Missa de São Gregório* (91 Pint); **[C]** *Apanha do Maná no Deserto* (92 Pint); **[D]** *Encontro de Abraão e Melquisedeque* (93 Pint); **[E]** *Última Ceia* (94 Pint); **[F]** *Descida da Cruz* (95 pint); **[G]** *Cristo a Caminho do Calvário* (96 Pint); **[H]** *Cristo no Horto* (97 Pint); **[I]** *Deposição de Cristo no Túmulo* (98 Pint); **[J]** *São Boaventura e São Luís de Tolosa* (99 Pint); and **[K]** *São Bernardino de Siena e Santo António* (293 Pint) (SOURCE: MatrizNet).



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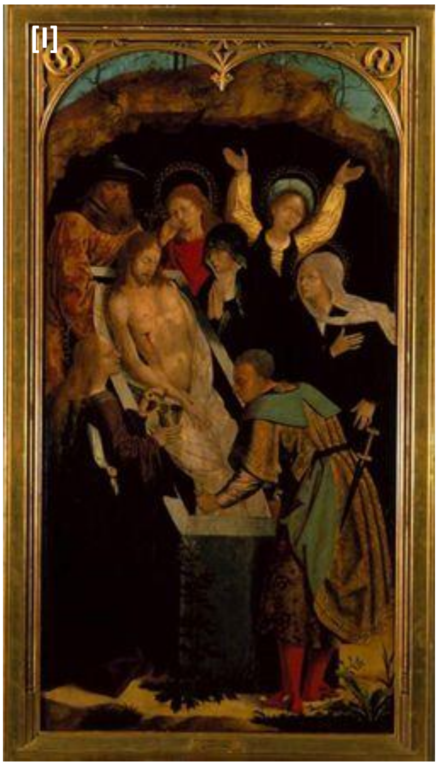

[I]


[J]


[K]

ANNEX 3. Musical instruments_violins and cellos

Figure 1. Violins from Portuguese workshops from XVIII and XIX centuries **[A]** MNM0067, attribution to António Joaquim Sanhudo, Porto, dated 1860 (Photo credits: ©José Pessoa/ADF-DGPC); **[B]** MNM0069, attribution to António Joaquim Sanhudo, Porto, dated 1849 (Photo credits: ©José Pessoa/ADF-DGPC); **[C]** MNM0078, attribution to Joaquim José Galrão, Lisbon, dated 1768 (Photo credits: ©José Pessoa/ADF-DGPC); **[D]** MNM0185, attribution to António Joaquim Sanhudo, Porto, dated 1867 (SOURCE: MatrizNet); **[E]** MNM0070, attribution to Henrique Monteiro & Son, Lisbon, Porto, dated 1892 (Photo credits: ©José Pessoa/ADF-DGPC); **[F]** MNM0073, attribution to Henrique Monteiro & Son, Lisbon, Porto, dated 1891 (Source: MatrizNet); **[G]** MNM0074, attribution to Joaquim José Galrão, Lisbon, dated 1794 (Source: MatrizNet); and **[H]** MNM0075, attribution to Joaquim José Galrão, Lisbon, dated 1780 (SOURCE: MatrizNet).

Figure 2. Cellos from Portuguese workshops from XVIII and XIX centuries **[A]** MNM0041, attribution to António Joaquim Sanhudo, Porto, dated 1862 (SOURCE: MatrizNet); **[B]** MNM0043, attribution to Felix António Diniz, Lisbon, dated 1797 (SOURCE: MatrizNet); **[C]** MNM0044, attribution to Joannes Petrus Hausz, Lisbon dated 1750 (SOURCE: MatrizNet); **[D]** MNM0040, attribution to Joaquim José Galrão, Lisbon, dated 1769 (Photo credits: ©José Pessoa/ADF-DGPC); and **[E]** MNM0046, attribution to Henrique Monteiro & Son, Lisbon, Porto, dated 1781 (Photo credits: ©José Pessoa/ADF-DGPC).

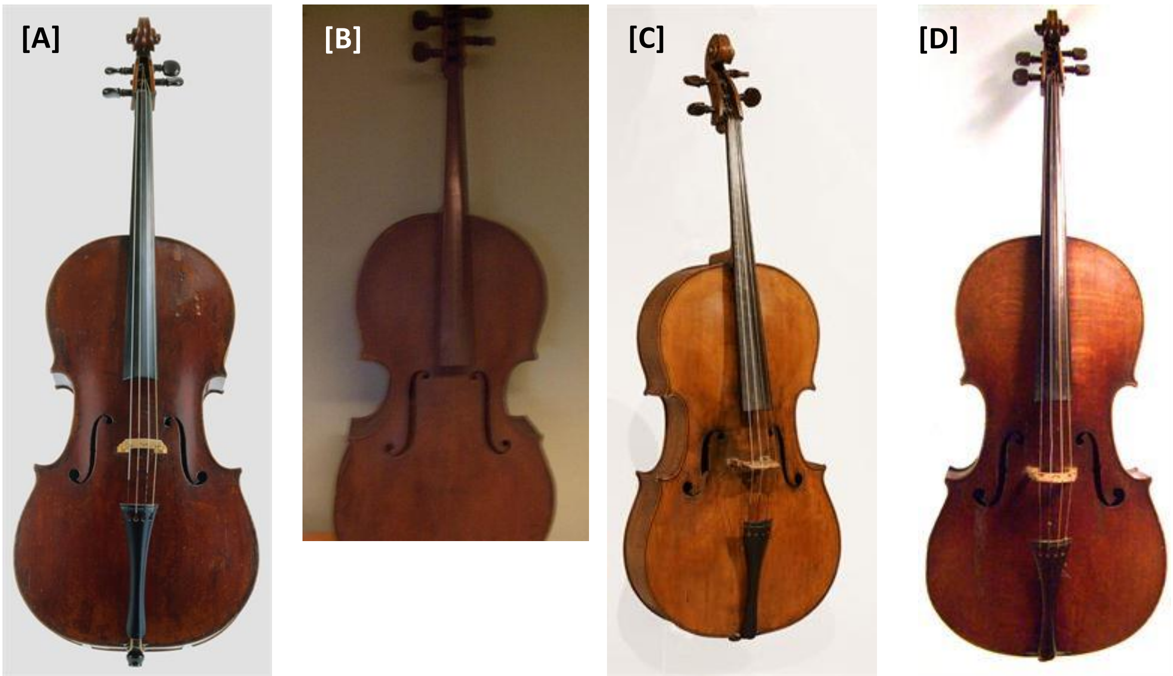


Figure 3. Cellos from foreign workshops from XVIII century **[A]** MNM0047, attribution to Antonio Stradivari, Italy, dated 1725 (Photo credits: ©José Pessoa/ADF-DGPC); **[B]** MNM1300, attribution to Christian Friedrich Mann, Germany, dated 1791 (SOURCE: MatrizNet); **[C]** MNM0039, attribution to Henry Lockey Hill, England (SOURCE: MatrizNet); and **[D]** MNM0799, unknown attribution, Germany, XIX century (SOURCE: MatrizNet).

ANNEX 4. Musical instruments_clavichords, harpsichords and fortepianos

Figure 1. [A] Portuguese clavichord (MNM0406, MNM), unknown attribution, from second quarter of the XVIII century (SOURCE: MatrizNet); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[C]** Grid beam graph representing the tree ring widths of each board.

Figure 2. [A] Portuguese clavichord (MNM0407, MNM), unknown attribution, from 1750-1790 (SOURCE: MatrizNet); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[C]** Grid beam graph representing the tree ring widths of each board.

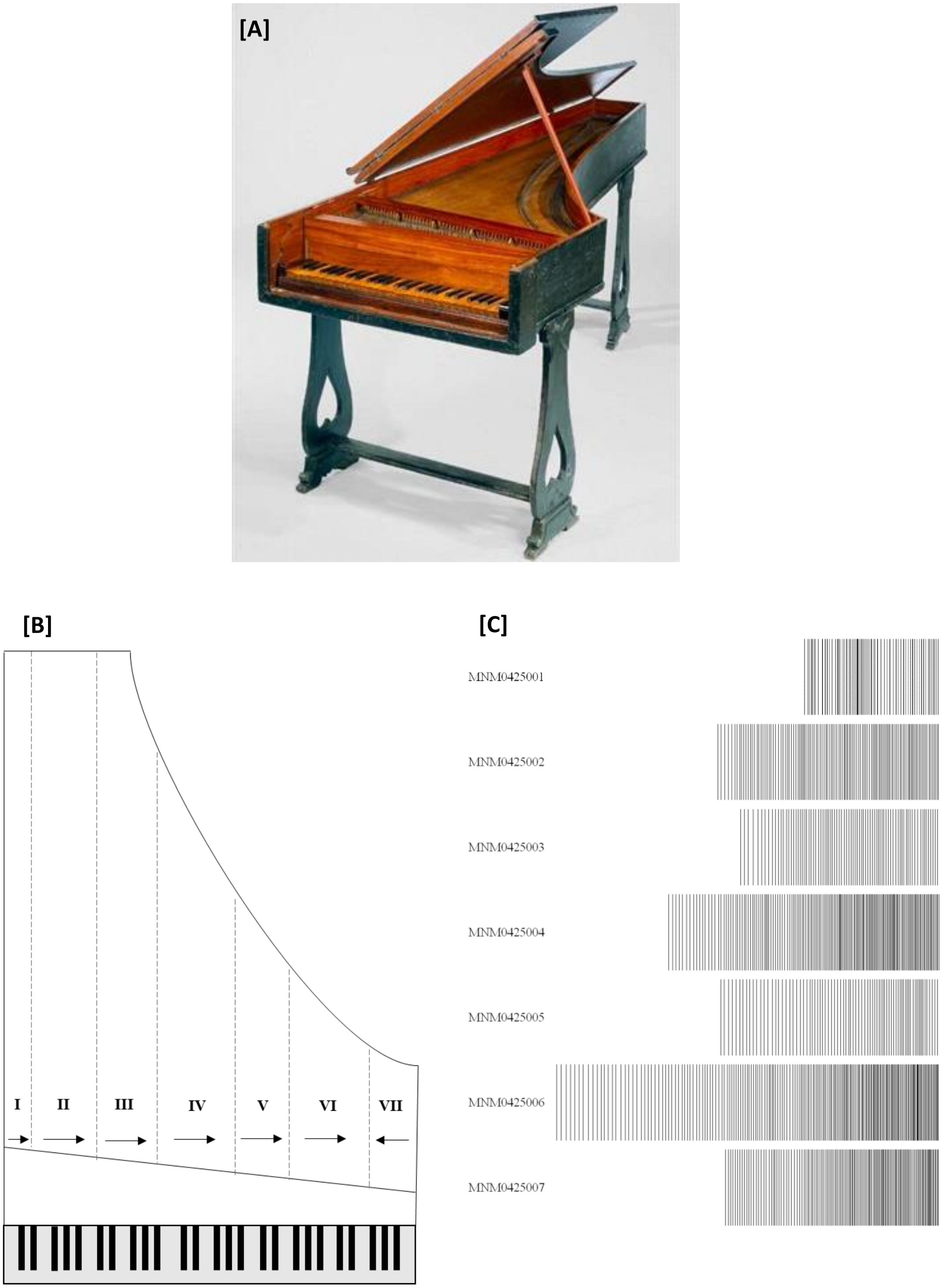


Figure 3. [A] Portuguese fortepiano (MNM0425, MNM), assigned to Henry van Casteel, dated 1763 (Photo credits: ©José Pessoa/ADF-DGPC); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[C]** Grid beam graph representing the tree ring widths of each board.

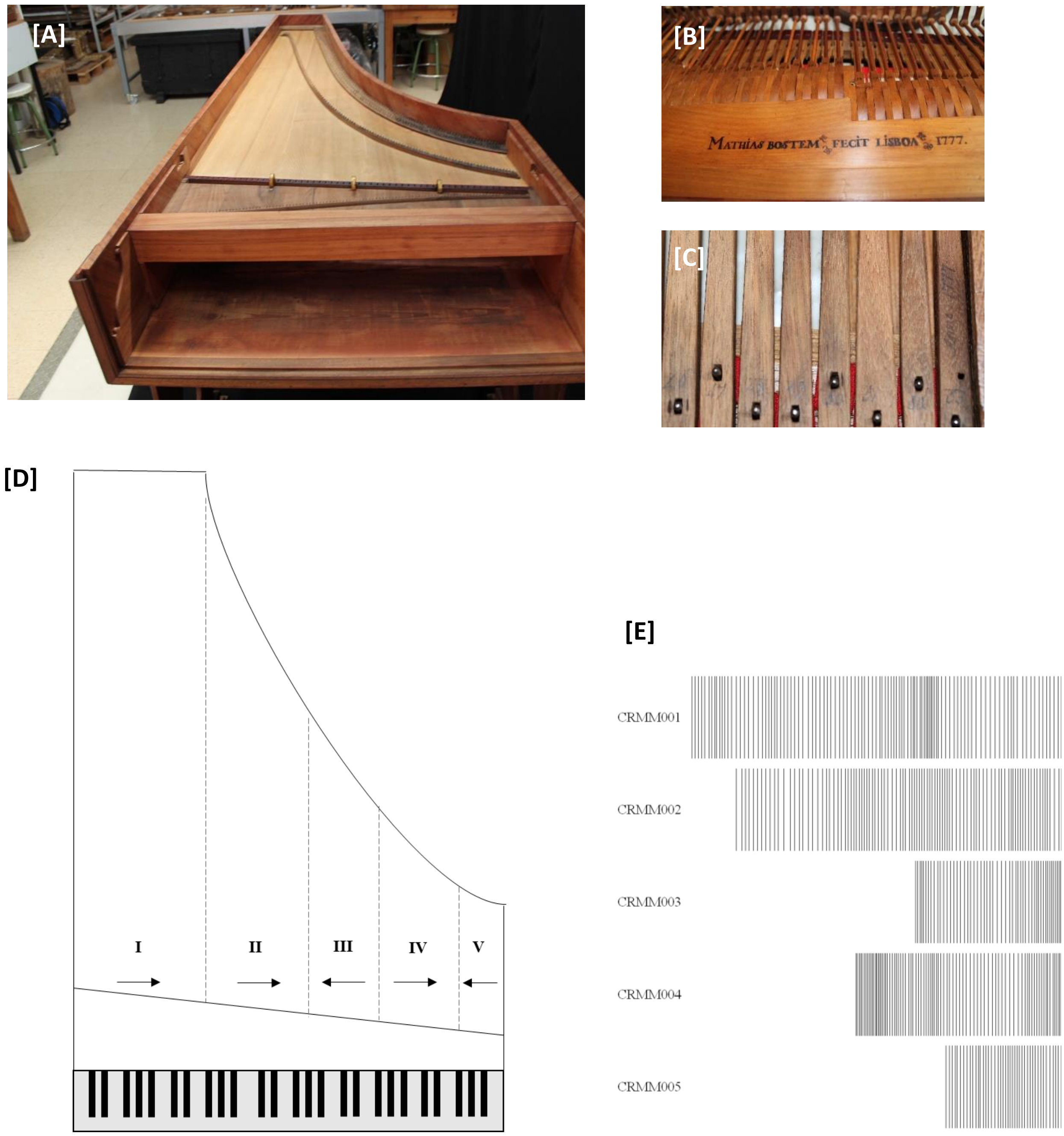


Figure 4. **[A]** Portuguese fortepiano (CRMM), assigned to Mathias Bostem, dated 1777 (Photo credits: ©Alexandra Lauw/CEF-ISA); **[B]** "MATHIAS BOSTEM FECIT LISBOA 1777" inscription on the veneer of the upper surface of the front block of the hammer rack (Photo credits: ©Alexandra Lauw/CEF-ISA); **[C]** "Anno 1777" written in ink on the key lever 53 (Photo credits: ©Alexandra Lauw/CEF-ISA); **[D]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[E]** Grid beam graph representing the tree ring widths of each board.

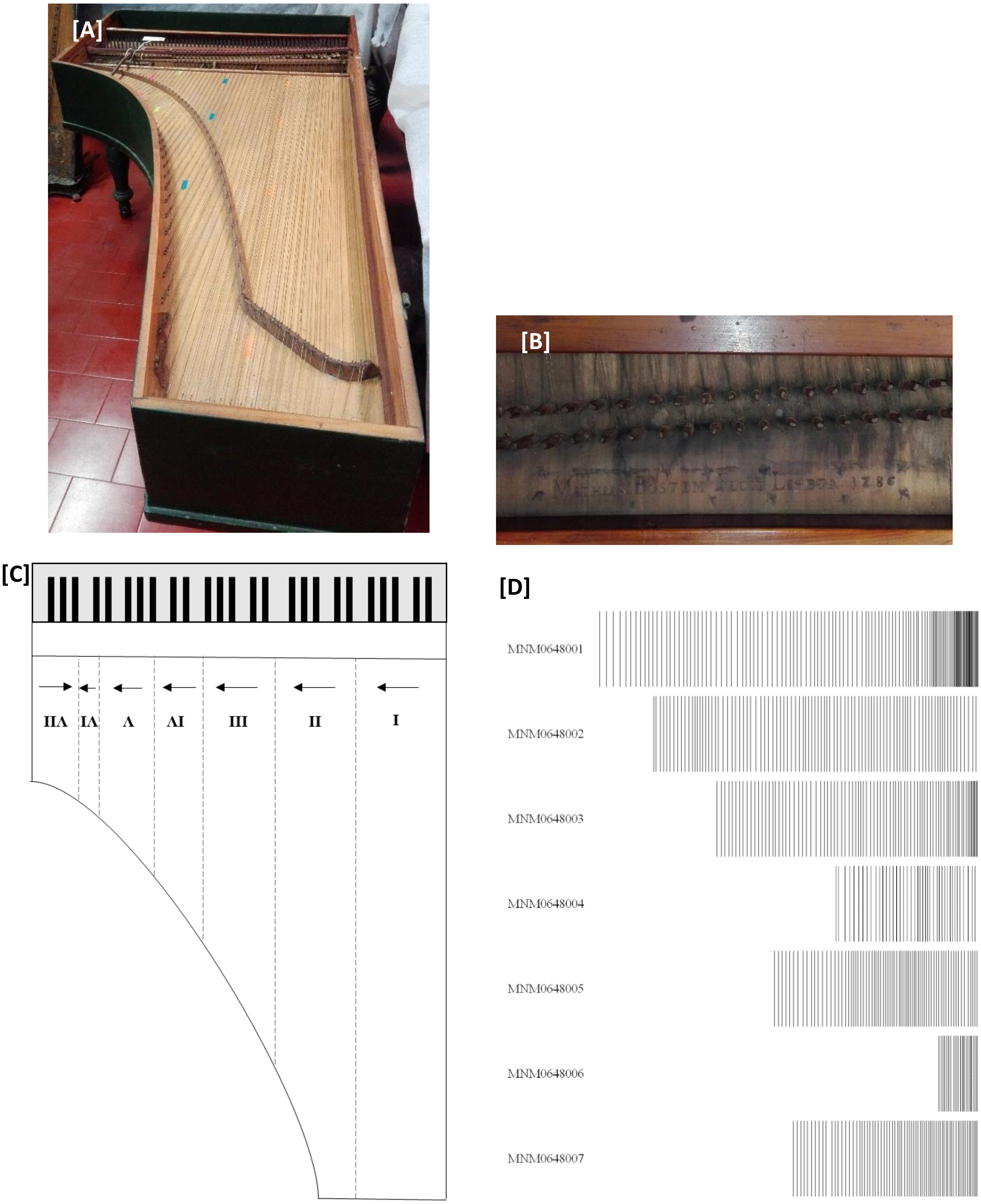


Figure 5. [A] Portuguese fortepiano (MNM0648, MNM), assigned to Mathias Bostem, dated 1786 (Photo credits: ©Helena Patrício/CEF-ISA); **[B]** "*MATHIAS BOSTEM FECIT LISBOA 1786*" inscription on the wrestplank (Photo credits: ©Helena Patrício/CEF-ISA); **[C]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[D]** Grid beam graph representing the tree ring widths of each board.

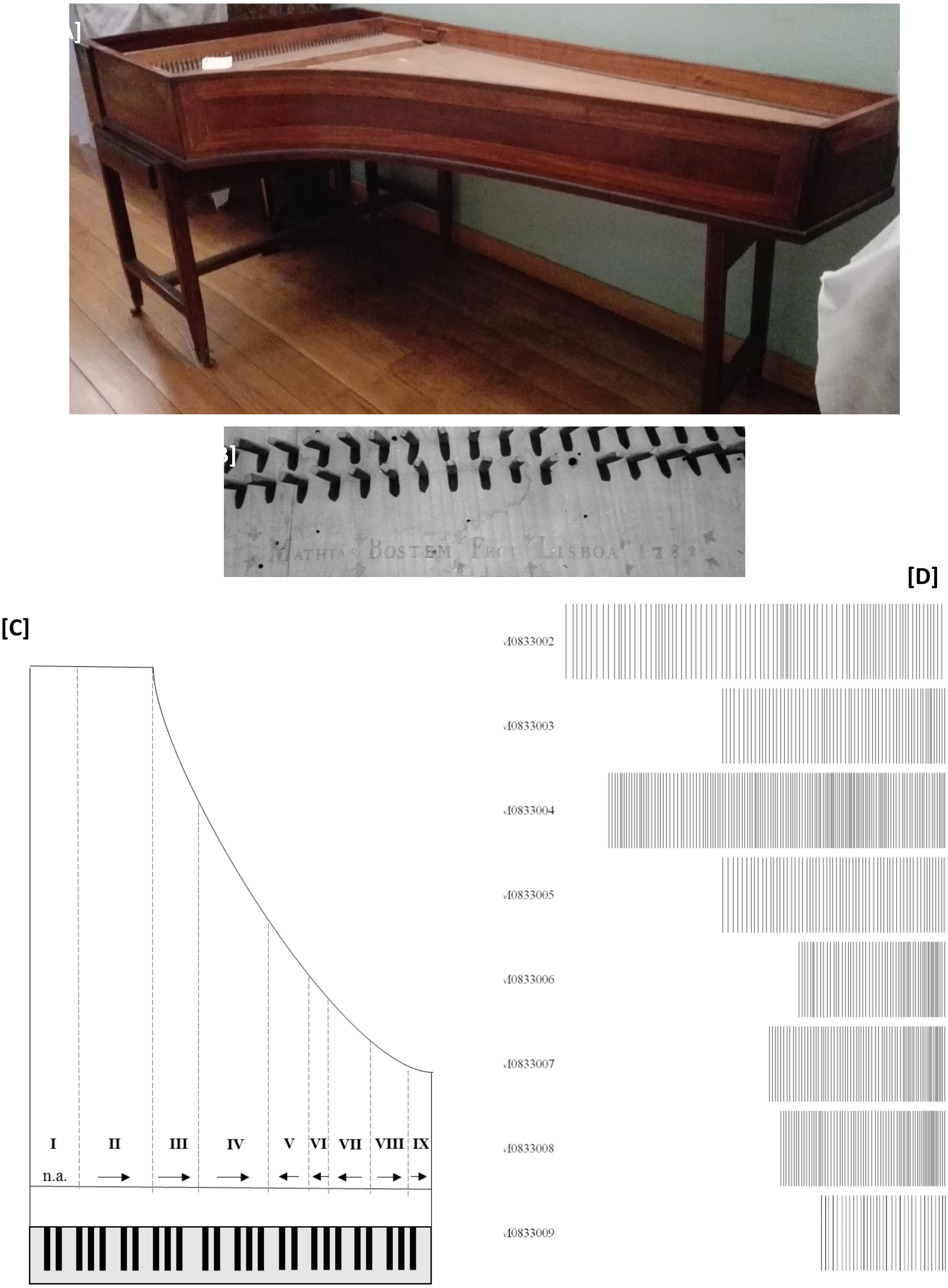


Figure 6. [A] Portuguese fortepiano (MNM0833, MNM), assigned to Mathias Bostem, dated 1789 (Photo credits: ©Helena Patrício/CEF-ISA); **[B]** "*MATHIAS BOSTEM FECI LISBOA 1789*" inscription on the wrestplank (Photo credits: ©Helena Patrício/CEF-ISA); **[C]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[D]** Grid beam graph representing the tree ring widths of each board.

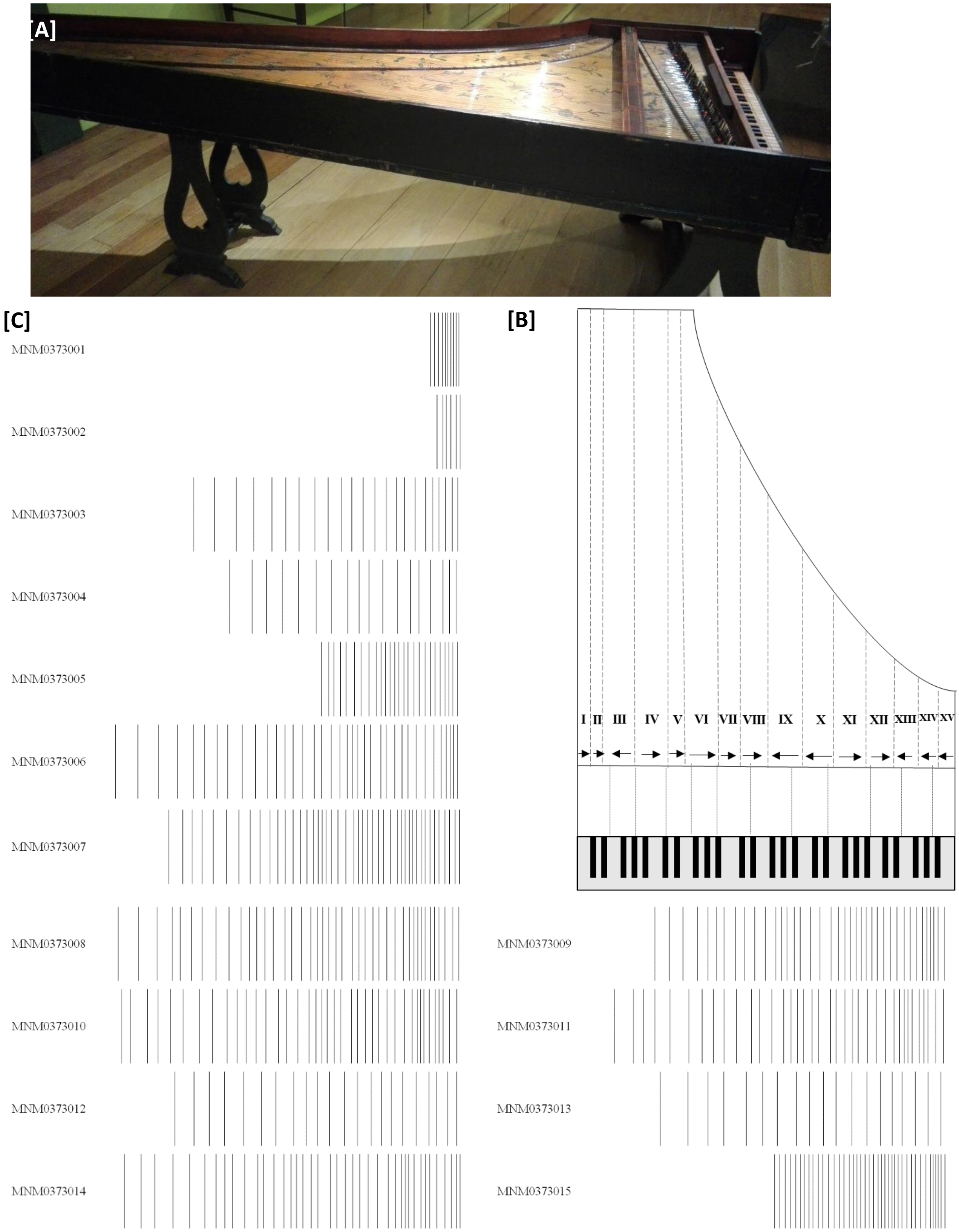


Figure 7. [A] Portuguese harpsichord (MNM0373), MNM, assigned to João Baptista Antunes, dated 1789 (Photo credits: ©Helena Patrício/CEF-ISA); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[C]** Grid beam graph representing the tree ring widths of each board.

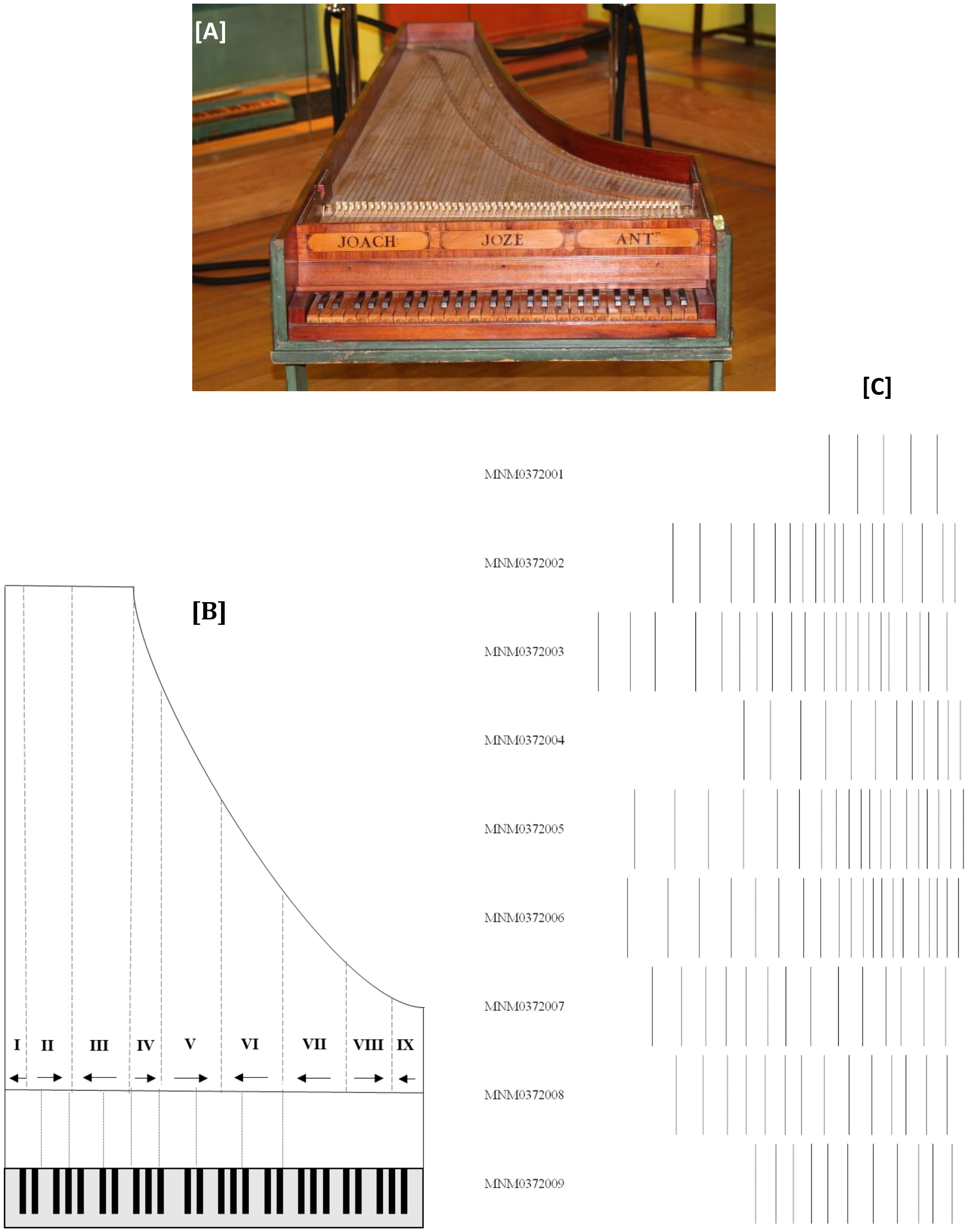


Figure 8. [A] Portuguese harpsichord (MNM0372, MNM), assigned to Joaquim José Antunes, dated 1758 (Photo credits: ©Helena Patrício/CEF-ISA); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[C]** Grid beam graph representing the tree ring widths of each board.

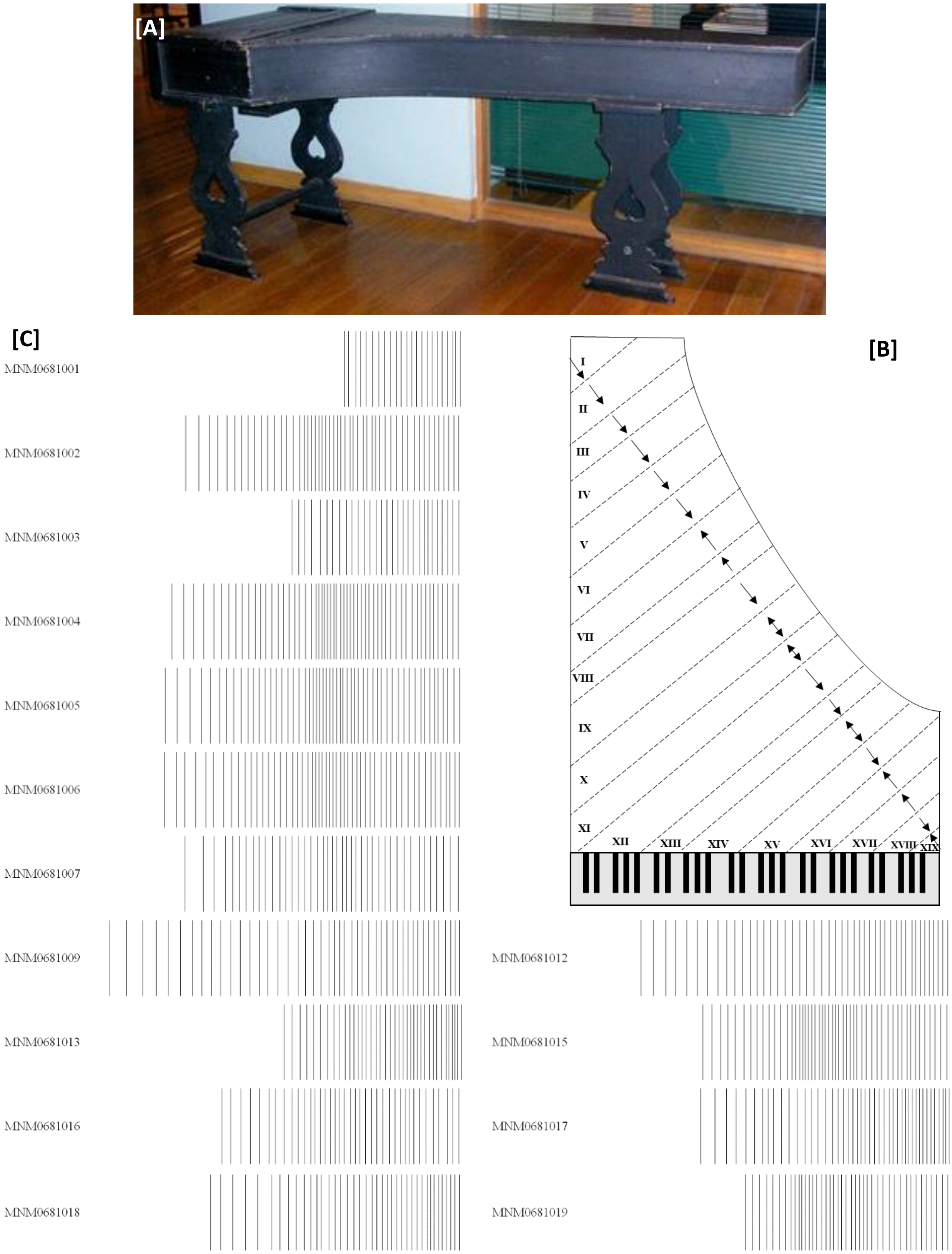


Figure 9. [A] Portuguese harpsichord (MNM0681, MNM), unknown attribution (Photo credits: ©Helena Patrício/CEF-ISA); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction; boards #4, #10, #11 and #14 presented tangential cut]; and **[C]** Grid beam graph representing the tree ring widths of each board.

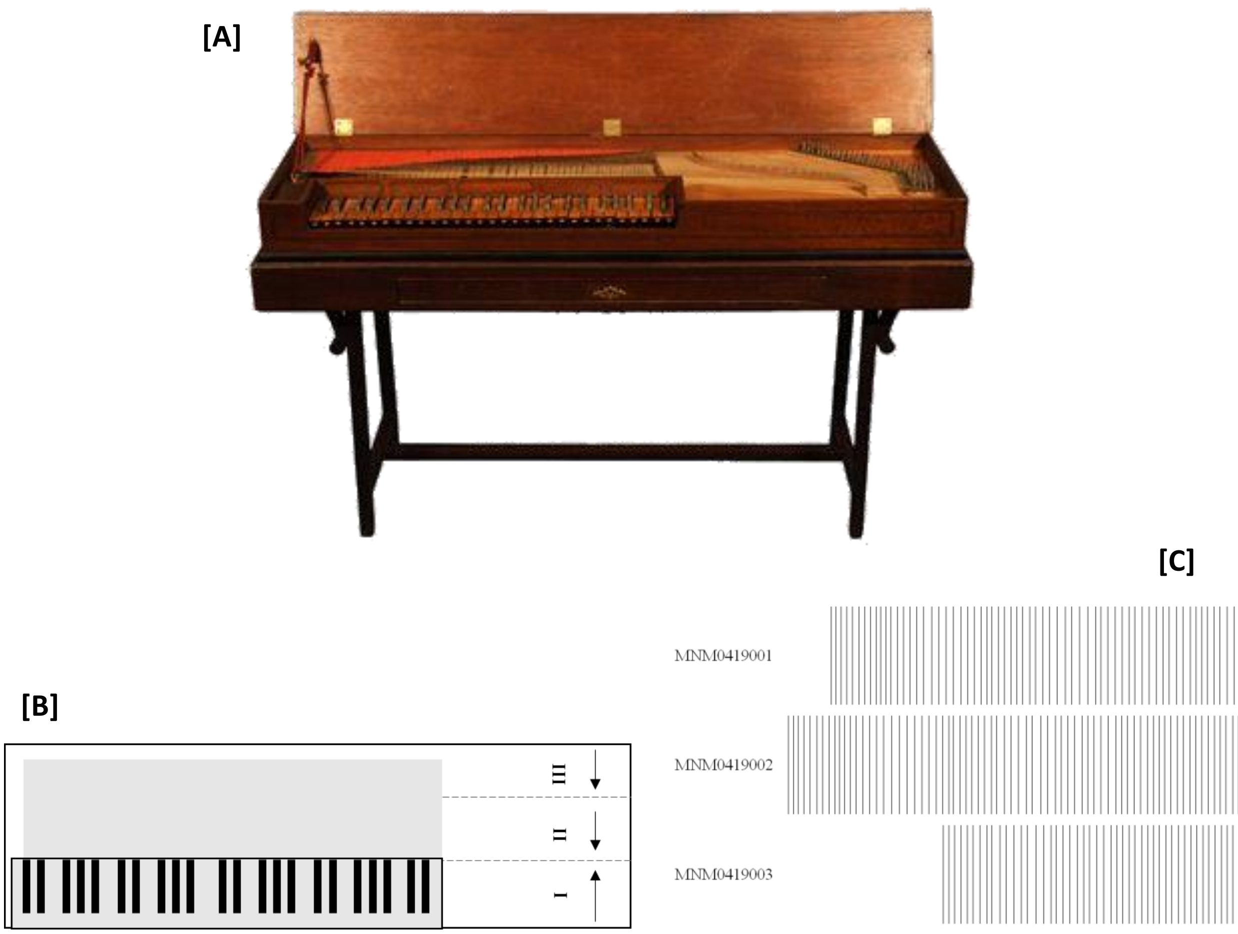


Figure 10. [A] German harpsichord (MNM0419, MNM), unknown attribution, from the XVIII century (SOURCE: MatrizNet); **[B]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[C]** Grid beam graph representing the tree ring widths of each board.

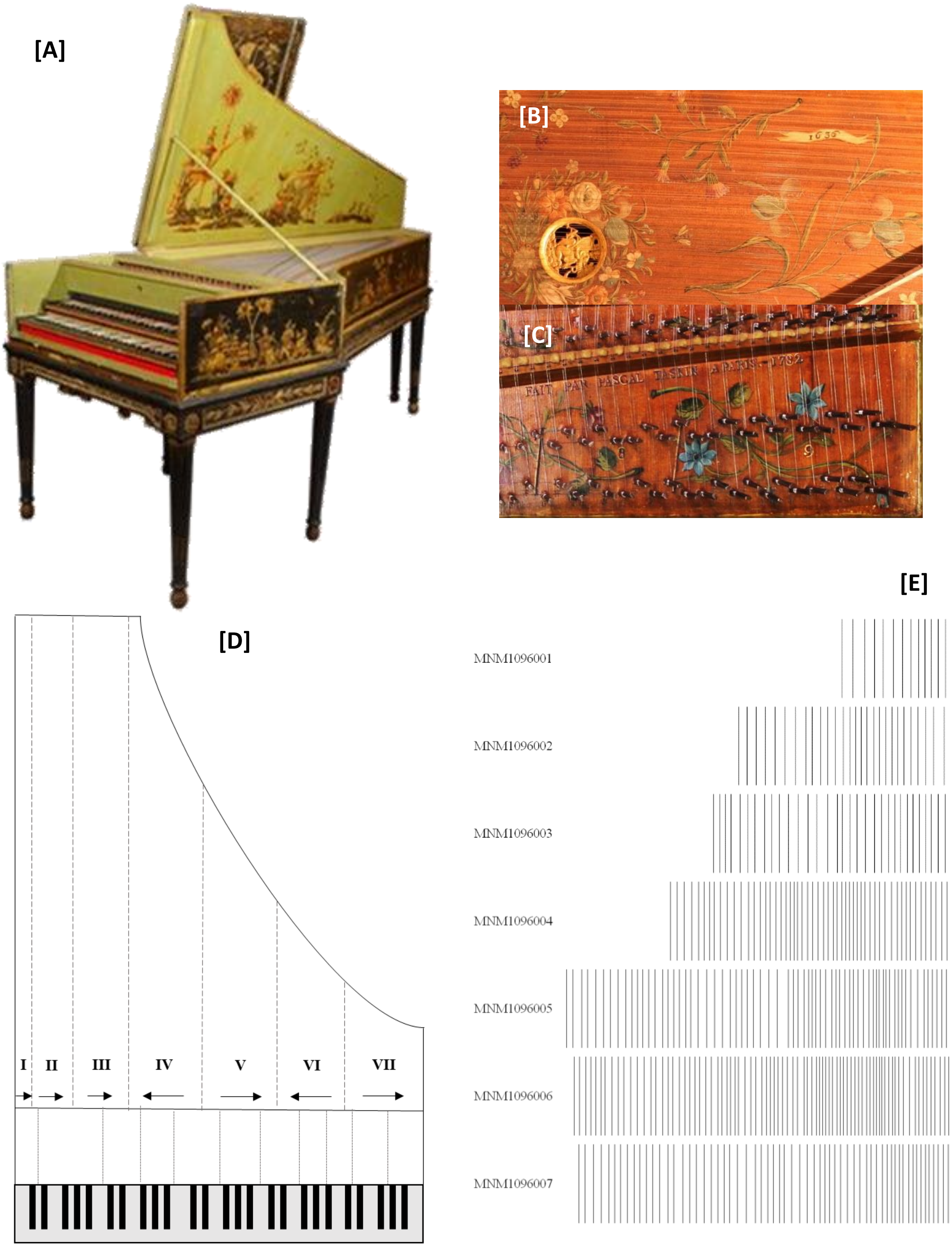


Figure 11. [A] French harpsichord (MNM1096, MNM), assigned to Joseph-Pascal Taskin, dated 1782 (Photo credits: ©José Pessoa/ADF-DGPC); **[B]** "*1636*" date inscription on the soundboard (Photo credits: ©Helena Patrício/CEF-ISA) **[C]** "*1782*" date inscription on the wrestplank century; **[D]** Layout of the boards on the soundboard [the arrow indicates the growth direction] and wrestplank; and **[E]** Grid beam graph representing the tree ring widths of each board from the soundboard.

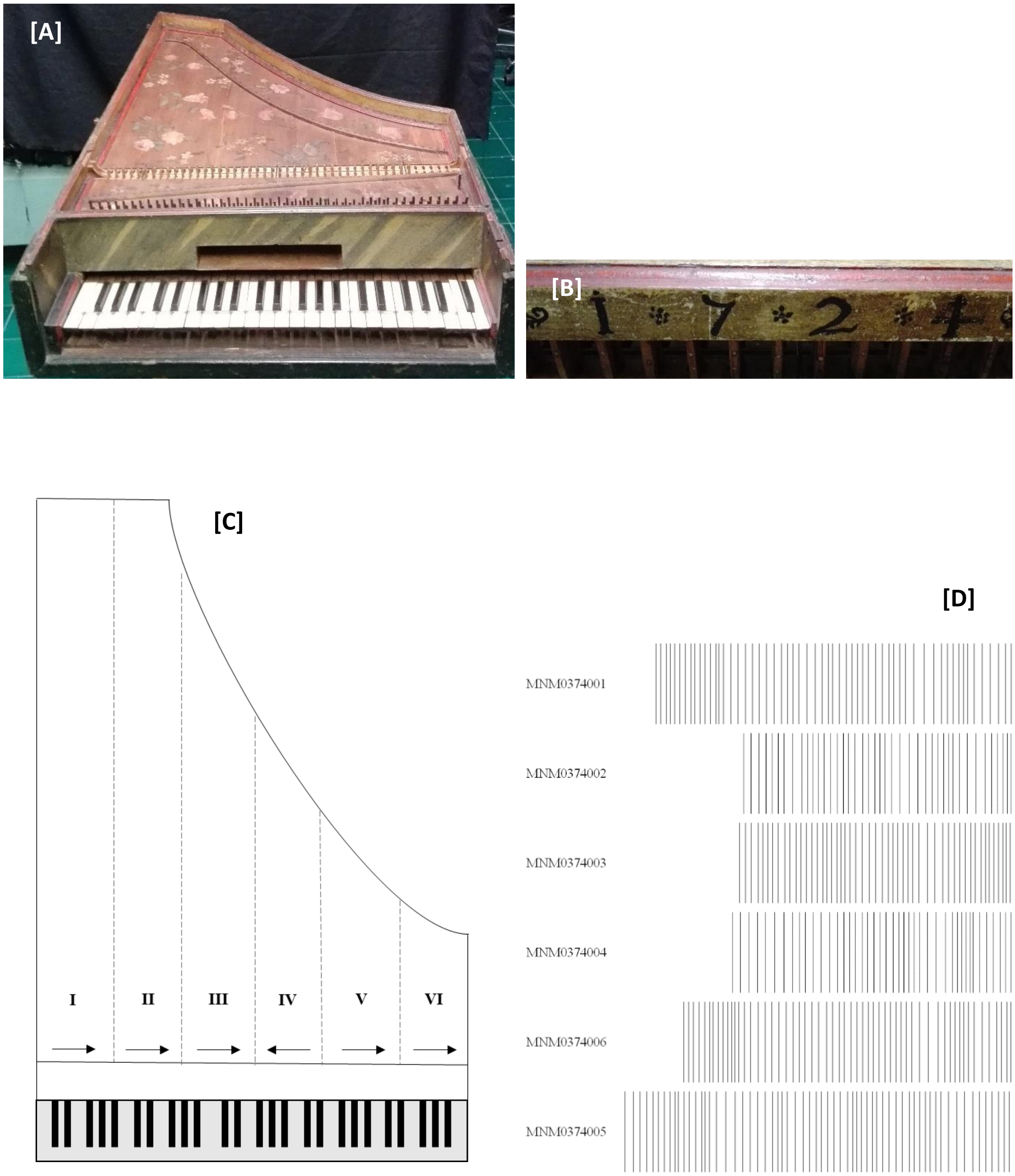


Figure 12. [A] Italian (or Portuguese) harpsichord (MNM0374, MNM), unknown attribution, dated 1724 (Photo credits: ©Helena Patrício/CEF-ISA); **[B]** "1724" date inscription on the front surface of the jack rail (Photo credits: ©Helena Patrício/CEF-ISA); **[C]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[D]** Grid beam graph representing the tree ring widths of each board.

Figure 13. [A] Dutch virginal (MNM0395, MNM), assigned to Hans Ruckers family, from XVI/XVII century (Photo credits: ©José Pessoa/DGPC-ADF); **[B]** inscriptions "HANS RUCKERS MÊ FECIT ANTWERPIAE ANNO 1620" (Photo credits: ©Alexandra Lauw/CEF-ISA); **[C]** Layout of the boards on the soundboard [the arrow indicates the growth direction]; and **[D]** Grid beam graph representing the tree ring widths of each board.

ANNEX 5. Dendrochronological dating of the Portuguese paintings.

Table 1. Cross-matching of the dendrochronological sequences obtained in the *Vida de S. Tiago* altarpiece, curated at the National Museum of Ancient Art (Lisbon), against published and unpublished individual and reference chronologies (t_{BP} ≥ 5.0 and *P*≥0.999).

PCEF0102020150 (1293-1405)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
113	66	6.0	0.999665	PCEF2310040085	1187-1416	CEF-ISA database (unpublished)
106	70	5.7	0.999981	PCEF0604010010	1300-1447	CEF-ISA database (unpublished)
113	70	5.2	0.999989	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
113	67	5.2	0.999850	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
113	71	5.1	0.999996	BALTIC2	1257-1615	HILLAM and TYERS (1995)

PCEF0102020157 (1332-1487)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
156	69	8.8	0.999999	NL Baltic A	1030-1602	Jansma (pers, communication)
156	63	7.8	0.999418	BALTIC1	1156-1597	HILLAM and TYERS (1995)
156	64	7.5	0.999765	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
152	68	7.2	0.999995	BOWHILL-B	1161-1483	GROVES (2004)
153	66	7.1	0.999963	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
147	65	7.0	0.999862	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
156	64	6.9	0.999765	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
140	64	6.9	0.999539	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
156	67	6.6	0.999989	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
141	65	6.6	0.999816	P1102020048	1276-1472	IJF-DGPC database (unpublished)
133	64	6.4	0.999379	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
147	65	6.2	0.999862	P1102020047	1278-1479	IJF-DGPC database (unpublished)
156	64	6.2	0.999765	PCEF1410010067-068	1302-1494	CEF-ISA database (unpublished)
122	70	6.1	0.999995	PCEF1102020223	1355-1476	CEF-ISA database (unpublished)
155	64	5.9	0.999755	P0102010053	1307-1486	IJF-DGPC database (unpublished)
134	65	5.8	0.999742	P0202010192	1322-1465	IJF-DGPC database (unpublished)
133	66	5.6	0.999902	PCEF0602010183	1318-1464	CEF-ISA database (unpublished)
154	65	5.6	0.999888	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
150	64	5.6	0.999697	PCEF1102020206	1273-1481	CEF-ISA database (unpublished)
113	70	5.3	0.999989	PCEF1603010017-22	1352-1464	CEF-ISA database (unpublished)
145	63	5.2	0.999128	P0202010190	1230-1476	IJF-DGPC database (unpublished)
114	67	5.0	0.999858	P1604020121	1207-1445	IJF-DGPC database (unpublished)

PCEF0102020158 (1354-1439)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
86	66	6.5	0.999099	BALTIC1	1156-1597	HILLAM and TYERS (1995)
86	68	5.9	0.999579	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)

PCEF0102020141-143-160 (1252-1434)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
183	68	9.7	0.999999	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
183	70	8.9	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)

PCEF0102020141-143-160 (1252-1434)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
183	70	8.6	1.000000	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
183	66	8.4	0.999993	BALTIC1	1156-1597	HILLAM and TYERS (1995)
155	66	8.0	0.999966	PCEF2802020116	1280-1469	CEF-ISA database (unpublished)
183	65	6.8	0.999975	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
118	64	6.8	0.998824	PCEF1802010036	1317-1534	CEF-ISA database (unpublished)
183	63	6.5	0.999782	P1604020131	1233-1437	IJF-DGPC database (unpublished)
109	72	6.2	0.999998	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
183	63	6.1	0.999782	P1102010064	1207-1457	IJF-DGPC database (unpublished)
148	68	6.0	0.999994	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
183	64	6.0	0.999924	PCEF2802020121-122	1201-1471	CEF-ISA database (unpublished)
66	69	6.0	0.998990	PCEF1116010002	1369-1505	CEF-ISA database (unpublished)
155	61	5.8	0.999755	PCEF1102020210	1280-1479	CEF-ISA database (unpublished)
94	67	5.8	0.999510	P0406010015	1341-1510	IJF-DGPC database (unpublished)
183	62	5.8	0.999416	P0202010195	1195-1464	IJF-DGPC database (unpublished)
128	64	5.8	0.999232	P0102010053	1307-1486	IJF-DGPC database (unpublished)
159	62	5.8	0.998762	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
179	67	5.7	0.999748	PCEF1702040027	1256-1445	CEF-ISA database (unpublished)
183	64	5.6	0.999924	BOWHILL-B	1161-1483	GROVES (2004)
183	64	5.5	0.999924	P0202010191	1246-1459	IJF-DGPC database (unpublished)
157	65	5.4	0.999915	P1102020047	1278-1479	IJF-DGPC database (unpublished)
173	63	5.4	0.999687	PCEF1702040028	1262-1468	CEF-ISA database (unpublished)
113	64	5.4	0.998542	P0202010192	1322-1465	IJF-DGPC database (unpublished)
123	68	5.3	0.999968	OS842cr	1312-1533	TYERS (2014b)
94	67	5.3	0.999510	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
165	62	5.2	0.998975	PCEF2310040085	1187-1416	CEF-ISA database (unpublished)
138	64	5.1	0.999498	P0102010055	1295-1484	IJF-DGPC database (unpublished)
88	66	5.1	0.998659	P1102020046	1347-1484	IJF-DGPC database (unpublished
178	66	5.0	0.999990	BALTIC2	1257-1615	HILLAM and TYERS (1995)
161	63	5.0	0.999515	PCEF0602010187	1274-1486	CEF-ISA database (unpublished)

PCEF0102020142-159 (1279-1489)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
211	70	10.4	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
211	64	9.3	0.999921	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
211	63	9.0	0.999976	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
211	66	8.9	0.999998	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
211	69	8.7	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
174	64	8.6	0.999889	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
205	64	7.8	0.999970	BOWHILL-B	1161-1483	GROVES (2004)
200	69	7.5	1.000000	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
211	64	7.5	0.999976	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
168	65	7.2	0.999950	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
209	63	6.8	0.999915	OS842ar	1281-1518	TYERS (2014b)
177	67	6.7	0.999997	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
211	64	6.6	0.999976	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
202	63	6.6	0.999890	P0602010026	1288-1498	IJF-DGPC database (unpublished)
142	65	6.3	0.999825	P0111020167	1306-1447	IJF-DGPC database (unpublished)
203	61	6.3	0.999139	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
206	65	6.2	0.999992	PCEF1410040075-076	1270-1484	CEF-ISA database (unpublished)
188	64	6.2	0.999938	PCEF1410010067-068	1302-1494	CEF-ISA database (unpublished)
149	64	6.1	0.999684	P0116020170	1297-1445	IJF-DGPC database (unpublished)

PCEF0102020142-159 (1279-1489)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
162	63	6.0	0.999532	P0502010016	1328-1490	IJF-DGPC database (unpublished)
160	65	5.9	0.999926	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
146	66	5.8	0.999945	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
128	69	5.7	0.999991	PCEF0604010014	1362-1494	CEF-ISA database (unpublished)
211	63	5.6	0.999921	PCEF2505020098	1197-1490	CEF-ISA database (unpublished)
98	70	5.5	0.999962	P0202010193	1221-1376	IJF-DGPC database (unpublished)
120	67	5.5	0.999902	P0802010104	1370-1506	IJF-DGPC database (unpublished)
162	62	5.5	0.998874	WHTOWR4	1245-1440	MILES (2007)
133	63	5.5	0.999063	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
201	67	5.4	0.999999	PCEF2110010055-059	1289-1525	CEF-ISA database (unpublished)
149	66	5.4	0.999953	PCEF2410040092	1310-1458	CEF-ISA database (unpublished)
208	63	5.2	0.999912	PCEF2210010062	1282-1508	CEF-ISA database (unpublished)
208	63	5.1	0.999912	PCEF1410010065	1272-1486	CEF-ISA database (unpublished)
163	63	5.1	0.999549	P1604020112	1297-1459	IJF-DGPC database (unpublished)
200	63	5.0	0.999882	P1102020047	1278-1479	IJF-DGPC database (unpublished)
202	62	5.0	0.999676	PCEF1410040074	1187-1480	CEF-ISA database (unpublished)

PCEF0102020144-147-148-161 (1348-1487)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
140	69	9.7	0.999997	BALTIC1	1156-1597	HILLAM and TYERS (1995)
140	67	9.7	0.999971	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
140	73	8.1	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
140	63	8.1	0.998952	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
127	66	8.0	0.999845	P0802010030	1319-1474	IJF-DGPC database (unpublished)
131	66	7.6	0.999875	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
140	63	7.3	0.998952	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
140	63	7.2	0.998952	PCEF2110010054-056	1342-1511	CEF-ISA database (unpublished)
140	64	7.0	0.999539	PCEF2110010055-059	1289-1525	CEF-ISA database (unpublished)
133	68	6.8	0.999984	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
140	64	6.7	0.999539	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
140	67	6.6	0.999971	P0102010018	1337-1509	IJF-DGPC database (unpublished)
139	67	6.5	0.999969	PCEF1410010065	1272-1486	CEF-ISA database (unpublished)
124	66	6.3	0.999817	P1009010037	1364-1542	IJF-DGPC database (unpublished)
140	63	6.2	0.998952	P0602010026	1288-1498	IJF-DGPC database (unpublished)
103	73	6.1	0.999998	PCEF0602010192	1364-1466	CEF-ISA database (unpublished)
109	68	6.1	0.999915	PCEF1710040048-049	1379-1500	CEF-ISA database (unpublished)
140	67	6.0	0.999971	PCEF2110010052-053	1333-1506	CEF-ISA database (unpublished)
118	65	6.0	0.999441	P0802010104	1370-1506	IJF-DGPC database (unpublished)
140	65	5.9	0.999807	P0502010016	1328-1490	IJF-DGPC database (unpublished)
134	65	5.9	0.999742	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
96	72	5.7	0.999992	OS833br	1392-1546	TYERS (2014a)
137	66	5.7	0.999910	PCEF1410040075-076	1270-1484	CEF-ISA database (unpublished)
129	66	5.7	0.999861	P1009010036	1359-1544	IJF-DGPC database (unpublished)
140	66	5.6	0.999924	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
118	66	5.6	0.999746	P0111020172	1226-1465	IJF-DGPC database (unpublished)
138	66	5.3	0.999915	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
139	65	5.2	0.999798	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
138	65	5.2	0.999788	PCEF1410040079-080-081	1244-1485	CEF-ISA database (unpublished)
134	63	5.2	0.998693	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
97	70	5.1	0.999959	PCEF1410010066-069	1391-1493	CEF-ISA database (unpublished)
121	65	5.0	0.999517	P0110010071	1376-1543	IJF-DGPC database (unpublished)

PCEF0102020144-147-148-161 (1348-1487)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
112	65	5.0	0.999251	P1009010031	1376-1514	IJF-DGPC database (unpublished)
110	65	5.0	0.999174	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)

PCEF0102020145-155 (1329-1488)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
160	67	9.9	0.999991	BALTIC1	1156-1597	HILLAM and TYERS (1995)
160	66	9.2	0.999974	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
160	67	8.7	0.999991	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
160	64	8.4	0.999801	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
160	69	8.1	0.999999	0520006M	1115-1643	ECKSTEIN *et al.* (1975)
156	67	7.8	0.999989	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
158	68	7.6	0.999997	P0102010053	1307-1486	IJF-DGPC database (unpublished)
98	70	7.6	0.999962	PCEF1410010066-069	1391-1493	CEF-ISA database (unpublished)
155	62	7.6	0.998596	BOWHILL-B	1161-1483	GROVES (2004)
160	65	7.3	0.999926	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
146	66	6.8	0.999945	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
160	65	6.7	0.999926	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
157	64	6.7	0.999775	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
103	66	6.7	0.999418	PCEF0602010192	1364-1466	CEF-ISA database (unpublished)
160	62	6.4	0.998800	P0502010016	1328-1490	IJF-DGPC database (unpublished)
148	64	6.3	0.999671	P0406010015	1341-1510	IJF-DGPC database (unpublished)
156	68	6.2	0.999997	P0102010055	1295-1484	IJF-DGPC database (unpublished)
153	66	6.2	0.999962	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
133	63	6.2	0.998643	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
150	67	6.1	0.999984	P1102020047	1278-1479	IJF-DGPC database (unpublished)
138	67	6.1	0.999968	P1009010034	1351-1534	IJF-DGPC database (unpublished)
143	63	6.0	0.999062	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
119	65	5.9	0.999467	P0802010104	1370-1506	IJF-DGPC database (unpublished)
160	62	5.9	0.998800	OS842cr	1312-1533	TYERS (2014b)
144	73	5.8	1.000000	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
113	68	5.8	0.999935	P1009010031	1376-1514	IJF-DGPC database (unpublished)
125	67	5.8	0.999928	P1009010037	1364-1542	IJF-DGPC database (unpublished)
156	66	5.7	0.999968	PCEF2110010052-053	1333-1506	CEF-ISA database (unpublished)
129	67	5.7	0.999944	P1102010064	1207-1457	IJF-DGPC database (unpublished)
160	62	5.7	0.998800	OS842ar	1281-1518	TYERS (2014b)
147	64	5.3	0.999657	PCEF1410010064	1342-1488	CEF-ISA database (unpublished)
118	66	5.2	0.999746	P0102010054	1261-1446	IJF-DGPC database (unpublished)
130	67	5.1	0.999947	P1009010036	1359-1544	IJF-DGPC database (unpublished)
144	64	5.1	0.999610	P1102010063rev	1201-1472	IJF-DGPC database (unpublished)
126	64	5.1	0.999164	0520004M	1363-1643	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
160	62	5.1	0.998800	PCEF2110010055-059	1289-1525	CEF-ISA database (unpublished)
114	65	5.0	0.999320	P1009010038	1375-1531	IJF-DGPC database (unpublished)

PCEF0102020146-156 (1348-1487)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
140	69	9.7	0.999997	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
140	66	9.4	0.999924	BALTIC1	1156-1597	HILLAM and TYERS (1995)
140	70	7.9	0.999999	0520003M	1173-1616	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)

PCEF0102020146-156 (1348-1487)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
127	65	7.8	0.999639	P0802010030	1319-1474	IJF-DGPC database (unpublished)
131	66	7.7	0.999875	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
140	64	7.1	0.999539	PCEF2110010054-056	1342-1511	CEF-ISA database (unpublished)
140	66	7.0	0.999924	PCEF2110010055-059	1289-1525	CEF-ISA database (unpublished)
140	67	6.9	0.999971	P0102010018	1337-1509	IJF-DGPC database (unpublished)
133	69	6.7	0.999994	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
140	63	6.6	0.998952	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
124	65	6.4	0.999582	P1009010037	1364-1542	IJF-DGPC database (unpublished)
139	68	6.3	0.999989	PCEF1410010065	1272-1486	CEF-ISA database (unpublished)
103	72	6.1	0.999996	PCEF0602010192	1364-1466	CEF-ISA database (unpublished)
109	67	5.8	0.999807	PCEF1710040048-049	1379-1500	CEF-ISA database (unpublished)
140	64	5.8	0.999539	P0502010016	1328-1490	IJF-DGPC database (unpublished)
134	64	5.8	0.999405	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
137	66	5.7	0.999910	PCEF1410040075-076	1270-1484	CEF-ISA database (unpublished)
118	66	5.7	0.999746	P0802010104	1370-1506	IJF-DGPC database (unpublished)
129	65	5.7	0.999672	P1009010036	1359-1544	IJF-DGPC database (unpublished)
140	64	5.7	0.999539	PCEF2110010052-053	1333-1506	CEF-ISA database (unpublished)
96	73	5.5	0.999997	OS833br	1392-1546	TYERS (2014a)
118	66	5.5	0.999746	P0111020172	1226-1465	IJF-DGPC database (unpublished)
140	66	5.4	0.999924	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
133	66	5.4	0.999888	P0112010079_I	1355-1546	IJF-DGPC database (unpublished)
138	65	5.3	0.999788	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
139	64	5.3	0.999519	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
97	69	5.1	0.999909	PCEF1410010066-069	1391-1493	CEF-ISA database (unpublished)
138	65	5.0	0.999788	PCEF1410040079-080-081	1244-1485	CEF-ISA database (unpublished)
121	65	5.0	0.999517	P0110010071	1376-1543	IJF-DGPC database (unpublished)

PCEF0102020149-151 (1331-1497)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
144	69	10.4	0.999997	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
167	64	9.9	0.999852	BALTIC1	1156-1597	HILLAM and TYERS (1995)
167	68	9.4	0.999998	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
154	66	9.3	0.999964	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
103	69	9.0	0.999943	PCEF1410010066-069	1391-1493	CEF-ISA database (unpublished)
167	64	8.6	0.999852	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
167	64	8.6	0.999852	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
161	62	8.6	0.998838	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
144	65	7.9	0.999841	P0802010030	1319-1474	IJF-DGPC database (unpublished)
167	66	7.7	0.999982	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
138	64	7.6	0.999498	P1102020046	1347-1484	IJF-DGPC database (unpublished
142	71	7.3	1.000000	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
151	68	7.1	0.999995	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
133	63	6.8	0.998643	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
123	64	6.6	0.999050	P1009010038	1375-1531	IJF-DGPC database (unpublished)
148	65	6.5	0.999869	P1102020047	1278-1479	IJF-DGPC database (unpublished)
156	64	6.5	0.999765	P0102010053	1307-1486	IJF-DGPC database (unpublished)
141	63	6.5	0.998990	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
155	64	6.4	0.999755	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
167	66	6.3	0.999982	OS842ar	1281-1518	TYERS (2014b)
154	63	6.3	0.999373	P0102010055	1295-1484	IJF-DGPC database (unpublished)
134	65	6.2	0.999742	P0112010080-81	1364-1553	IJF-DGPC database (unpublished)

PCEF0102020149-151 (1331-1497)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
139	63	6.0	0.998913	P1009010036	1359-1544	IJF-DGPC database (unpublished)
82	69	5.8	0.999710	OS0569bl	1390-1471	TYERS (2014a)
150	63	5.8	0.999275	PCEF1305010096	1209-1480	CEF-ISA database (unpublished)
167	65	5.6	0.999947	MEMEL	1288-1580	BRAZAUSKAS (2005)
146	64	5.6	0.999642	PCEF1603010019	1257-1476	CEF-ISA database (unpublished)
150	67	5.5	0.999984	PCEF2505020099	1203-1480	CEF-ISA database (unpublished)
157	62	5.5	0.998682	P0406010015	1341-1510	IJF-DGPC database (unpublished)
160	63	5.4	0.999497	P0502010016	1328-1490	IJF-DGPC database (unpublished)
158	63	5.4	0.999459	OS0508b	1340-1578	TYERS (2014c)
145	64	5.2	0.999626	P1009010033	1353-1538	IJF-DGPC database (unpublished)
157	67	5.1	0.999990	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
128	65	5.1	0.999656	PCEF2505020162	1370-1497	CEF-ISA database (unpublished)
135	63	5.1	0.998740	0520004M	1363-1643	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
136	63	5.0	0.998786	PCEF1102020211	1347-1482	CEF-ISA database (unpublished)

PCEF0102020152-153-154 (1383-1504)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
122	76	10.6	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
122	74	10.2	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
113	67	8.6	0.999849	OS833br	1392-1546	TYERS (2014a)
114	73	8.1	1.000000	PCEF0117040167	1391-1509	CEF-ISA database (unpublished)
122	69	8.1	0.999986	P0802010104	1370-1506	IJF-DGPC database (unpublished)
103	72	8.0	0.999996	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
92	72	7.9	0.999988	P0802010030	1319-1474	IJF-DGPC database (unpublished)
122	65	7.7	0.999539	P1009010037	1364-1542	IJF-DGPC database (unpublished)
122	75	7.6	1.000000	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)
116	66	7.6	0.999716	OS0833cr	1389-1543	TYERS (2014a)
122	69	7.4	0.999986	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
108	66	7.4	0.999559	P0802010103	1363-1490	IJF-DGPC database (unpublished)
122	67	7.2	0.999913	P0102010023	1294-1523	IJF-DGPC database (unpublished)
81	70	7.2	0.999841	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
122	66	7.2	0.999796	P1009010036	1359-1544	IJF-DGPC database (unpublished)
105	71	7.1	0.999992	PCEF1102020225	1317-1487	CEF-ISA database (unpublished)
101	70	7.1	0.999971	BOWHILL-B	1161-1483	GROVES (2004)
122	68	7.1	0.999965	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
99	71	6.6	0.999985	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
90	71	6.6	0.999966	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
122	64	6.6	0.999008	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
102	75	6.5	1.000000	P0102010055	1295-1484	IJF-DGPC database (unpublished)
122	66	6.5	0.999796	PCEF2110010052-053	1333-1506	CEF-ISA database (unpublished)
107	65	6.2	0.999043	PCEF1102020201	1317-1489	CEF-ISA database (unpublished)
110	69	6.1	0.999966	PCEF1102020207	1305-1492	CEF-ISA database (unpublished)
122	65	6.1	0.999539	P0802010102	1380-1514	IJF-DGPC database (unpublished)
110	65	6.1	0.999174	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
109	65	6.0	0.999132	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
122	69	5.9	0.999986	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
103	68	5.9	0.999871	PCEF1410010066-069	1391-1493	CEF-ISA database (unpublished)
122	68	5.8	0.999965	P1009010038	1375-1531	IJF-DGPC database (unpublished)
108	71	5.6	0.999994	P0502010016	1328-1490	IJF-DGPC database (unpublished)
90	69	5.6	0.999844	P1102020048	1276-1472	IJF-DGPC database (unpublished)

PCEF0102020152-153-154 (1383-1504)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
116	67	5.4	0.999875	P0602010026	1288-1498	IJF-DGPC database (unpublished)
94	66	5.4	0.999041	PCEF1305010095	1255-1476	CEF-ISA database (unpublished)
96	69	5.1	0.999902	P1102020047	1278-1479	IJF-DGPC database (unpublished)
102	66	5.1	0.999385	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)

Table 2. Cross-matching of the dendrochronological sequences obtained in the *S. Francisco de Évora* altarpiece, curated at the National Museum of Ancient Art (Lisbon), against published and unpublished individual and reference chronologies (t_{BP}≥5.0 and *P*≥0.999)

PCEF2802020109 (1315-1475)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
161	74	10.8	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
161	68	10.8	0.999998	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
157	68	9.2	0.999997	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
112	68	9.2	0.999930	P1009010037	1364-1542	IJF-DGPC database (unpublished)
117	67	8.9	0.999882	P1009010036	1359-1544	IJF-DGPC database (unpublished)
158	68	8.8	0.999997	P1102020048	1276-1472	IJF-DGPC database (unpublished)
161	71	8.4	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
161	69	8.4	0.999999	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
161	63	8.3	0.999515	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
161	65	8.2	0.999930	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
150	63	8.2	0.999275	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
135	63	8.2	0.998740	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
161	66	8.0	0.999975	P1102020047	1278-1479	IJF-DGPC database (unpublished)
129	68	7.9	0.999978	P1102020046	1347-1484	IJF-DGPC database (unpublished
129	68	7.9	0.999978	PCEF1102020211	1347-1482	CEF-ISA database (unpublished)
161	64	7.9	0.999809	P0102010055	1295-1484	IJF-DGPC database (unpublished)
161	66	7.7	0.999975	BOWHILL-B	1161-1483	GROVES (2004)
161	68	7.5	0.999998	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
156	69	7.3	0.999999	P0802010030	1319-1474	IJF-DGPC database (unpublished)
158	68	7.3	0.999997	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
159	70	7.2	1.000000	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
161	69	7.1	0.999999	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
123	68	6.9	0.999967	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
161	63	6.7	0.999515	PCEF1410010067-068	1302-1494	CEF-ISA database (unpublished)
92	71	6.6	0.999972	PCEF1116010003	1384-1521	CEF-ISA database (unpublished)
115	68	6.5	0.999943	P0202010186	1361-1484	IJF-DGPC database (unpublished)
154	64	6.5	0.999744	PCEF1702040028	1262-1468	CEF-ISA database (unpublished)
113	71	6.4	0.999996	0520004M	1363-1643	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
94	67	6.4	0.999510	VILQURO1	1208-1408	PUKIENÉ (2002)
161	62	6.2	0.998838	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
135	64	6.0	0.999430	P1408040089	1341-1511	IJF-DGPC database (unpublished)
97	67	5.9	0.999594	PCEF1710040048-049	1379-1500	CEF-ISA database (unpublished)
161	63	5.9	0.999515	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
87	69	5.8	0.999803	OS0833cr	1389-1543	TYERS (2014a)
161	63	5.8	0.999515	P0602010026	1288-1498	IJF-DGPC database (unpublished)

PCEF2802020109 (1315-1475)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
132	66	5.6	0.999882	P0102010052	1344-1496	IJF-DGPC database (unpublished)
121	64	5.6	0.998965	P0112010079_I	1355-1546	IJF-DGPC database (unpublished)
155	63	5.4	0.999396	PCEF0602010195	1256-1469	CEF-ISA database (unpublished)
110	67	5.3	0.999819	P1102010062	1366-1490	IJF-DGPC database (unpublished)
136	63	5.3	0.998786	P0110010068	1200-1450	IJF-DGPC database (unpublished)
158	66	5.1	0.999971	PCEF0103010024-25	1292-1472	CEF-ISA database (unpublished)
98	70	5.1	0.999962	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)
161	66	5.0	0.999975	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
144	65	5.0	0.999841	P0202010192	1322-1465	IJF-DGPC database (unpublished)

PCEF2802020111-114 (1365-1460)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
96	76	10.4	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
96	77	10.1	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
96	75	9.4	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
96	73	8.8	0.999997	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
96	67	8.4	0.999568	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
96	70	8.3	0.999956	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
96	73	8.1	0.999997	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
96	71	7.9	0.999981	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
85	77	7.5	1.000000	P1009010031	1376-1514	IJF-DGPC database (unpublished)
96	68	7.2	0.999790	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
96	71	7.0	0.999981	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
96	69	7.0	0.999902	BOWHILL-B	1161-1483	GROVES (2004)
96	67	7.0	0.999568	PCEF1102020225	1317-1487	CEF-ISA database (unpublished)
96	70	6.9	0.999956	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
86	69	6.7	0.999787	P1009010038	1375-1531	IJF-DGPC database (unpublished)
96	66	6.7	0.999142	PCEF1102020206	1273-1481	CEF-ISA database (unpublished)
95	72	6.5	0.999991	P1102010062	1366-1490	IJF-DGPC database (unpublished)
96	71	6.3	0.999981	P1009010037	1364-1542	IJF-DGPC database (unpublished)
96	66	5.9	0.999142	P0202010190	1230-1476	IJF-DGPC database (unpublished)
96	68	5.8	0.999790	0520004M	1363-1643	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
96	68	5.7	0.999790	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
82	67	5.6	0.998961	P0111020171	1295-1446	IJF-DGPC database (unpublished)
91	68	5.4	0.999703	P0802010104	1370-1506	IJF-DGPC database (unpublished)
96	67	5.4	0.999568	P0102010055	1295-1484	IJF-DGPC database (unpublished)
96	66	5.4	0.999142	P0802010030	1319-1474	IJF-DGPC database (unpublished)
85	71	5.1	0.999946	P1009010032	1372-1532	IJF-DGPC database (unpublished)
83	70	5.1	0.999866	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)
96	68	5.1	0.999790	P0602010026	1288-1498	IJF-DGPC database (unpublished)
81	69	5.0	0.999687	P0802010102	1380-1514	IJF-DGPC database (unpublished)

PCEF2802020112 (1309-1459)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
151	66	6.1	0.999958	BALTIC1	1156-1597	HILLAM and TYERS (1995)
151	64	5.6	0.999710	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
151	67	5.4	0.999985	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)

PCEF2802020112 (1309-1459)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
151	63	5.3	0.999301	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
151	63	5.2	0.999301	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
151	66	5.1	0.999958	PCEF1102020206	1273-1481	CEF-ISA database (unpublished)

PCEF2802020116 (1280-1469)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
190	79	11.2	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
173	68	9.4	0.999999	P0102010055	1295-1484	IJF-DGPC database (unpublished)
167	70	9.1	1.000000	P0102010054	1261-1446	IJF-DGPC database (unpublished)
144	69	8.8	0.999997	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
190	68	8.3	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
183	71	8.0	1.000000	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
190	71	7.8	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
123	70	7.7	0.999995	P1102020046	1347-1484	IJF-DGPC database (unpublished
190	66	7.7	0.999995	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
163	63	7.7	0.999549	P0102010053	1307-1486	IJF-DGPC database (unpublished)
190	70	7.6	1.000000	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
190	69	7.4	1.000000	P1102020048	1276-1472	IJF-DGPC database (unpublished)
144	66	7.4	0.999938	P0202010192	1322-1465	IJF-DGPC database (unpublished)
129	66	7.3	0.999861	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
183	63	7.3	0.999782	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
190	65	7.1	0.999982	PCEF1102020206	1273-1481	CEF-ISA database (unpublished)
189	70	6.8	1.000000	PCEF1702040028	1262-1468	CEF-ISA database (unpublished)
190	66	6.6	0.999995	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
101	69	6.6	0.999933	PCEF1116010002	1369-1505	CEF-ISA database (unpublished)
190	63	6.6	0.999831	P1102020047	1278-1479	IJF-DGPC database (unpublished)
129	66	6.5	0.999861	P1408040089	1341-1511	IJF-DGPC database (unpublished)
113	70	6.4	0.999989	PCEF1603010017-22	1352-1464	CEF-ISA database (unpublished)
166	64	6.4	0.999845	PCEF1702040027	1256-1445	CEF-ISA database (unpublished)
115	68	6.3	0.999943	PCEF1102020223	1355-1476	CEF-ISA database (unpublished)
161	65	6.3	0.999930	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
190	67	6.2	0.999999	BOWHILL-B	1161-1483	GROVES (2004)
126	68	6.2	0.999973	P0102010052	1344-1496	IJF-DGPC database (unpublished)
148	68	6.1	0.999994	PCEF0604010010	1300-1447	CEF-ISA database (unpublished)
158	64	6.1	0.999784	P1604020131	1233-1437	IJF-DGPC database (unpublished)
190	62	6.1	0.999530	PCEF1102020210	1280-1479	CEF-ISA database (unpublished)
190	70	5.9	1.000000	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
173	65	5.9	0.999960	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
92	70	5.7	0.999938	P0102010022	1378-1513	IJF-DGPC database (unpublished)
171	64	5.7	0.999875	P0110010068	1200-1450	IJF-DGPC database (unpublished)
153	63	5.7	0.999350	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
150	64	5.6	0.999697	P1604020114	1248-1429	IJF-DGPC database (unpublished)
190	63	5.5	0.999831	P1102010063rev	1201-1472	IJF-DGPC database (unpublished)
178	62	5.5	0.999318	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
190	68	5.3	1.000000	BALTIC2	1257-1615	HILLAM and TYERS (1995)
96	69	5.3	0.999902	WMNSTR14	1137-1375	MILES and BRIDGE (2008)
129	67	5.2	0.999944	VILQURO1	1208-1408	PUKIENÉ (2002)
190	63	5.1	0.999831	PCEF0602010187	1274-1486	CEF-ISA database (unpublished)
95	68	5.1	0.999775	P1009010038	1375-1531	IJF-DGPC database (unpublished)
90	70	5.0	0.999926	PCEF1603010023	1287-1376	CEF-ISA database (unpublished)

PCEF2802020116 (1280-1469)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE

PCEF2802020119 (1377-1434)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
58	85	6.4	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
58	83	6.1	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
58	72	5.8	0.999597	P1009010037	1364-1542	IJF-DGPC database (unpublished)
58	75	5.6	0.999930	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
58	80	5.5	0.999998	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
58	79	5.2	0.999995	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
58	75	5.2	0.999930	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
58	72	5.1	0.999597	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
56	75	5.0	0.999909	P0602010028	1371-1432	IJF-DGPC database (unpublished)

PCEF2802020125 (1228-1458)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
231	66	7.7	0.999999	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
148	71	6.9	1.000000	PCEF0604010012	1311-1484	CEF-ISA database (unpublished)
231	67	6.3	1.000000	P0202010195	1195-1464	IJF-DGPC database (unpublished)
229	65	6.3	0.999997	P0202010190	1230-1476	IJF-DGPC database (unpublished)
231	62	6.0	0.999868	BOWHILL-B	1161-1483	GROVES (2004)
231	60	6.0	0.998816	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
231	61	5.9	0.999587	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
216	65	5.8	0.999995	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
231	64	5.6	0.999990	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
208	64	5.6	0.999973	PCEF2410040090	1251-1471	CEF-ISA database (unpublished)
183	64	5.4	0.999924	P1102020048	1276-1472	IJF-DGPC database (unpublished)
231	60	5.4	0.998816	PCEF2410040089-091	1186-1468	CEF-ISA database (unpublished)
227	60	5.4	0.998708	P0202010184	1157-1454	IJF-DGPC database (unpublished)
204	63	5.3	0.999898	P1604020136	1255-1460	IJF-DGPC database (unpublished)
172	63	5.2	0.999675	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
118	65	5.2	0.999441	P1408040089	1341-1511	IJF-DGPC database (unpublished)
231	61	5.1	0.999587	PCEF1116010001	1224-1508	CEF-ISA database (unpublished)
231	66	5.0	0.999999	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
183	65	5.0	0.999975	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)

PCEF2802020126 (1337-1485)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
149	73	8.6	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
149	74	8.3	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
149	72	8.3	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
149	70	7.9	0.999999	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
149	66	7.1	0.999953	PCEF2505020098	1197-1490	CEF-ISA database (unpublished)
145	66	7.0	0.999942	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
122	65	6.9	0.999539	P1009010037	1364-1542	IJF-DGPC database (unpublished)
148	72	6.4	1.000000	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
149	65	6.4	0.999875	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
147	70	6.3	0.999999	BOWHILL-B	1161-1483	GROVES (2004)

PCEF2802020126 (1337-1485)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
149	67	6.1	0.999983	PCEF1410040079-080-081	1244-1485	CEF-ISA database (unpublished)
142	65	6.1	0.999825	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
149	63	6.1	0.999247	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
145	68	6.0	0.999993	P0202010185	1291-1481	IJF-DGPC database (unpublished)
149	63	5.7	0.999247	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
111	67	5.6	0.999830	P0111020167	1306-1447	IJF-DGPC database (unpublished)
149	63	5.6	0.999247	P0602010026	1288-1498	IJF-DGPC database (unpublished)
149	63	5.6	0.999247	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
116	64	5.4	0.998718	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
144	66	5.3	0.999938	P0202010196	1298-1480	IJF-DGPC database (unpublished)
136	65	5.3	0.999766	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
133	64	5.3	0.999379	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
149	65	5.2	0.999875	P0102010023	1294-1523	IJF-DGPC database (unpublished)
108	66	5.2	0.999559	P1604020120	1229-1444	IJF-DGPC database (unpublished)
145	64	5.1	0.999626	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)

PCEF2802020129 (1266-1472)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
207	64	8.4	0.999972	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
207	62	6.4	0.999723	BALTIC1	1156-1597	HILLAM and TYERS (1995)
207	63	6.3	0.999908	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
186	62	6.2	0.999468	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
196	64	6.1	0.999956	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
197	65	6.0	0.999987	P1102020048	1276-1472	IJF-DGPC database (unpublished)
207	64	5.9	0.999972	BOWHILL-B	1161-1483	GROVES (2004)
207	64	5.9	0.999972	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
185	63	5.7	0.999797	P0110010068	1200-1450	IJF-DGPC database (unpublished)
113	65	5.7	0.999286	PCEF1603010017-22	1352-1464	CEF-ISA database (unpublished)
131	70	5.6	0.999998	PCEF1410010064	1342-1488	CEF-ISA database (unpublished)
126	64	5.5	0.999164	P1102020046	1347-1484	IJF-DGPC database (unpublished
199	62	5.3	0.999645	PCEF0602010187	1274-1486	CEF-ISA database (unpublished)
195	61	5.2	0.998937	P1102020047	1278-1479	IJF-DGPC database (unpublished)

PCEF2802020130 (1282-1485)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
204	78	13.3	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
204	74	12.0	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
202	71	10.7	1.000000	BOWHILL-B	1161-1483	GROVES (2004)
204	71	10.4	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
204	69	10.4	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
156	74	9.8	1.000000	P0802010030	1319-1474	IJF-DGPC database (unpublished)
204	69	9.3	1.000000	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
133	66	9.3	0.999888	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
168	71	8.6	1.000000	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
204	69	8.6	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
190	66	8.5	0.999995	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
191	65	8.3	0.999983	P1102020048	1276-1472	IJF-DGPC database (unpublished)
197	64	8.1	0.999958	P1102020047	1278-1479	IJF-DGPC database (unpublished)

PCEF2802020130 (1282-1485)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
173	63	8.1	0.999687	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
190	65	8.0	0.999982	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
108	72	7.9	0.999998	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)
204	70	7.7	1.000000	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
183	70	7.6	1.000000	P1604020117	1246-1464	IJF-DGPC database (unpublished
95	73	7.5	0.999996	PCEF0117040167	1391-1509	CEF-ISA database (unpublished)
191	66	7.5	0.999995	PCEF1102020224	1190-1472	CEF-ISA database (unpublished)
204	70	7.4	1.000000	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
133	64	7.4	0.999379	P0111020179	1331-1463	IJF-DGPC database (unpublished)
184	69	7.3	1.000000	P0111020172	1226-1465	IJF-DGPC database (unpublished)
145	68	7.3	0.999993	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
138	65	7.1	0.999788	P1102020046	1347-1484	IJF-DGPC database (unpublished
199	66	7.0	0.999997	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
159	67	6.9	0.999991	WHTOWR4	1245-1440	MILES (2007)
136	67	6.9	0.999963	PCEF1102020211	1347-1482	CEF-ISA database (unpublished)
165	65	6.9	0.999942	P0102010054	1261-1446	IJF-DGPC database (unpublished)
179	64	6.8	0.999910	P0102010053	1307-1486	IJF-DGPC database (unpublished)
204	65	6.7	0.999991	PCEF1410040079-080-081	1244-1485	CEF-ISA database (unpublished)
164	66	6.6	0.999979	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
117	73	6.3	1.000000	PCEF1116010002	1369-1505	CEF-ISA database (unpublished)
116	67	6.3	0.999875	P0802010104	1370-1506	IJF-DGPC database (unpublished)
120	66	6.3	0.999772	P1102010062	1366-1490	IJF-DGPC database (unpublished)
106	67	6.3	0.999768	P0802010102	1380-1514	IJF-DGPC database (unpublished)
163	65	6.2	0.999936	P1604020112	1297-1459	IJF-DGPC database (unpublished)
197	63	6.2	0.999869	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
123	65	6.2	0.999561	P0802010103	1363-1490	IJF-DGPC database (unpublished)
107	65	6.2	0.999043	PCEF1710040048-049	1379-1500	CEF-ISA database (unpublished)
184	61	6.2	0.998579	PCEF1410010067-068	1302-1494	CEF-ISA database (unpublished)
153	67	6.1	0.999987	PCEF2110010052-053	1333-1506	CEF-ISA database (unpublished)
180	63	6.1	0.999757	PCEF1102020226-227	1193-1461	CEF-ISA database (unpublished)
148	71	6.0	1.000000	P1604020114	1248-1429	IJF-DGPC database (unpublished)
178	68	6.0	0.999999	P0202010191	1246-1459	IJF-DGPC database (unpublished)
185	64	6.0	0.999930	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
204	67	5.9	0.999999	OS842ar	1281-1518	TYERS (2014b)
149	69	5.9	0.999998	P0102010018	1337-1509	IJF-DGPC database (unpublished)
173	64	5.9	0.999885	P0202010184	1157-1454	IJF-DGPC database (unpublished)
122	66	5.9	0.999796	P1009010037	1364-1542	IJF-DGPC database (unpublished)
94	68	5.9	0.999759	OS833br	1392-1546	TYERS (2014a)
198	65	5.8	0.999988	P0602010026	1288-1498	IJF-DGPC database (unpublished)
186	65	5.8	0.999979	PCEF1710010043_044	1252-1467	CEF-ISA database (unpublished)
171	69	5.7	1.000000	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
163	67	5.7	0.999993	P1604020120	1229-1444	IJF-DGPC database (unpublished)
188	64	5.7	0.999938	PCEF1410040080	1244-1469	CEF-ISA database (unpublished)
170	63	5.7	0.999651	P0110010066	1176-1451	IJF-DGPC database (unpublished)
188	62	5.7	0.999500	PCEF0602010195	1256-1469	CEF-ISA database (unpublished)
132	64	5.7	0.999352	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
160	66	5.6	0.999974	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
158	66	5.6	0.999971	P0502010016	1328-1490	IJF-DGPC database (unpublished)
147	66	5.6	0.999948	P0110010069	1329-1475	IJF-DGPC database (unpublished)
188	63	5.6	0.999818	PCEF0602010184	1257-1469	CEF-ISA database (unpublished)
188	67	5.5	0.999998	P0102010055	1295-1484	IJF-DGPC database (unpublished)
179	67	5.5	0.999997	PCEF2505020097	1236-1460	CEF-ISA database (unpublished)
127	67	5.5	0.999936	P1009010036	1359-1544	IJF-DGPC database (unpublished)
124	64	5.5	0.999089	P0202010186	1361-1484	IJF-DGPC database (unpublished)

PCEF2802020130 (1282-1485)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
181	66	5.4	0.999992	PCEF0103010024-25	1292-1472	CEF-ISA database (unpublished)
132	66	5.4	0.999882	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
192	62	5.4	0.999559	P0102010023	1294-1523	IJF-DGPC database (unpublished)
108	69	5.3	0.999961	PCEF1116010004	1378-1510	CEF-ISA database (unpublished)
144	65	5.3	0.999841	P0202010192	1322-1465	IJF-DGPC database (unpublished)
145	68	5.2	0.999993	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
204	64	5.2	0.999968	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
163	65	5.2	0.999936	P1604020145	1247-1444	IJF-DGPC database (unpublished)
122	67	5.2	0.999913	P0112010077	1364-1536	IJF-DGPC database (unpublished)
164	62	5.2	0.998942	P1604020121	1207-1445	IJF-DGPC database (unpublished)
97	72	5.1	0.999993	OS0833cr	1389-1543	TYERS (2014a)
195	62	5.1	0.999598	P0202010190	1230-1476	IJF-DGPC database (unpublished)
180	66	5.0	0.999991	P1604020146	1274-1461	IJF-DGPC database (unpublished)
110	65	5.0	0.999174	P1009010031	1376-1514	IJF-DGPC database (unpublished)

PCEF2802020131 (1254-1469)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
163	63	5.9	0.999549	OS0833ar	1307-1534	TYERS (2014a)
216	66	5.7	0.999999	BALTIC1	1156-1597	HILLAM and TYERS (1995)
216	63	5.3	0.999934	BOWHILL-B	1161-1483	GROVES (2004)
191	62	5.1	0.999545	P1604020120	1229-1444	IJF-DGPC database (unpublished)
199	62	5.0	0.999645	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)

PCEF2802020132 (1271-1466)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
196	74	9.5	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
196	70	8.7	1.000000	BOWHILL-B	1161-1483	GROVES (2004)
196	69	8.0	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
196	68	7.7	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
196	67	7.7	0.999999	P0202010190	1230-1476	IJF-DGPC database (unpublished)
196	73	7.4	1.000000	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
196	68	7.3	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
174	62	6.6	0.999227	P1604020120	1229-1444	IJF-DGPC database (unpublished)
175	63	6.5	0.999709	PCEF0103010024-25	1292-1472	CEF-ISA database (unpublished)
194	66	6.4	0.999996	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
164	64	6.3	0.999832	PCEF0604010011	1303-1480	CEF-ISA database (unpublished)
192	63	6.2	0.999843	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
196	63	6.1	0.999864	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
196	66	6.0	0.999996	PCEF2410040090	1251-1471	CEF-ISA database (unpublished)
138	68	5.8	0.999988	P0110010069	1329-1475	IJF-DGPC database (unpublished)
196	65	5.6	0.999987	PCEF1410040079-080-081	1244-1485	CEF-ISA database (unpublished)
193	62	5.6	0.999572	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
196	61	5.6	0.998965	PCEF2210010061	1250-1490	CEF-ISA database (unpublished)
180	70	5.3	1.000000	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
141	71	5.3	1.000000	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
126	70	5.3	0.999996	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
176	63	5.3	0.999719	P0102010054	1261-1446	IJF-DGPC database (unpublished)
118	65	5.3	0.999441	PCEF0604010009	1327-1444	CEF-ISA database (unpublished)

PCEF2802020132 (1271-1466)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
193	61	5.2	0.998880	PCEF0602010187	1274-1486	CEF-ISA database (unpublished)
196	65	5.1	0.999987	PCEF1410040080	1244-1469	CEF-ISA database (unpublished)
195	65	5.1	0.999986	P0116020172	1226-1465	IJF-DGPC database (unpublished)
182	64	5.1	0.999921	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
196	65	5.0	0.999987	PCEF1410040077-078-082	1203-1482	CEF-ISA database (unpublished)
149	63	5.0	0.999247	PCEF2410040092	1310-1458	CEF-ISA database (unpublished)
167	62	5.0	0.999037	P1604020131	1233-1437	IJF-DGPC database (unpublished)

PCEF2802020133 (1275-1406)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
132	73	8.1	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
132	68	7.4	0.999982	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
132	68	7.1	0.999982	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
132	68	6.7	0.999982	BOWHILL-B	1161-1483	GROVES (2004)
132	67	6.5	0.999953	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
132	65	6.0	0.999716	PCEF2410040090	1251-1471	CEF-ISA database (unpublished)
132	69	5.7	0.999994	P0202010190	1230-1476	IJF-DGPC database (unpublished)
90	72	5.7	0.999985	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
132	67	5.7	0.999953	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
132	67	5.7	0.999953	P1604020113	1257-1443	IJF-DGPC database (unpublished)
132	66	5.7	0.999882	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
132	68	5.4	0.999982	P1604020120	1229-1444	IJF-DGPC database (unpublished)
132	69	5.3	0.999994	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
88	69	5.3	0.999818	P0802010030	1319-1474	IJF-DGPC database (unpublished)
132	65	5.3	0.999716	P1604020117	1246-1464	IJF-DGPC database (unpublished
132	65	5.3	0.999716	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
100	67	5.1	0.999663	OS0833ar	1307-1534	TYERS (2014a)
132	66	5.0	0.999882	P1604020121	1207-1445	IJF-DGPC database (unpublished)

PCEF2802020134 (1284-1477)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
194	72	9.6	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
194	70	8.6	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
161	69	8.3	0.999999	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
156	69	8.3	0.999999	P0802010030	1319-1474	IJF-DGPC database (unpublished)
157	66	8.3	0.999970	WHTOWR4	1245-1440	MILES (2007)
194	71	8.2	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
194	73	8.1	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
164	71	7.6	1.000000	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
194	69	7.6	1.000000	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
194	67	7.6	0.999999	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
165	69	7.4	0.999999	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
194	64	7.1	0.999952	BOWHILL-B	1161-1483	GROVES (2004)
189	63	6.9	0.999824	P1102020048	1276-1472	IJF-DGPC database (unpublished)
142	69	6.7	0.999997	P0116020167	1306-1447	IJF-DGPC database (unpublished)
137	71	6.3	1.000000	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
178	66	6.3	0.999990	P1604020146	1274-1461	IJF-DGPC database (unpublished)
188	64	6.2	0.999938	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)

PCEF2802020134 (1284-1477)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
102	74	6.1	0.999999	P1009010031	1376-1514	IJF-DGPC database (unpublished)
169	65	6.1	0.999952	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
125	70	6.0	0.999996	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
137	68	6.0	0.999987	P1408040089	1341-1511	IJF-DGPC database (unpublished)
108	76	5.9	1.000000	P0802010104	1370-1506	IJF-DGPC database (unpublished)
149	69	5.9	0.999998	P0116020170	1297-1445	IJF-DGPC database (unpublished)
194	62	5.9	0.999585	OS842ar	1281-1518	TYERS (2014b)
166	67	5.8	0.999994	OS842cr	1312-1533	TYERS (2014b)
147	66	5.8	0.999948	P0110010069	1329-1475	IJF-DGPC database (unpublished)
152	73	5.7	1.000000	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
112	67	5.6	0.999840	P1102010062	1366-1490	IJF-DGPC database (unpublished)
186	62	5.6	0.999468	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
194	65	5.5	0.999985	PCEF1305010096	1209-1480	CEF-ISA database (unpublished)
194	64	5.5	0.999952	P1102020047	1278-1479	IJF-DGPC database (unpublished)
194	63	5.5	0.999853	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
194	65	5.4	0.999985	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
190	65	5.4	0.999982	P0602010026	1288-1498	IJF-DGPC database (unpublished)
183	64	5.4	0.999924	P1604020161	1243-1466	IJF-DGPC database (unpublished
124	68	5.3	0.999969	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
131	67	5.3	0.999950	P1102020046	1347-1484	IJF-DGPC database (unpublished
117	69	5.2	0.999980	PCEF0403010015	1326-1484	CEF-ISA database (unpublished)
184	64	5.2	0.999927	PCEF1710010043_044	1252-1467	CEF-ISA database (unpublished)
157	64	5.2	0.999775	PCEF0102010173	1321-1486	CEF-ISA database (unpublished)
109	71	5.1	0.999994	PCEF1116010002	1369-1505	CEF-ISA database (unpublished)
181	62	5.1	0.999379	P1604020117	1246-1464	IJF-DGPC database (unpublished
147	63	5.1	0.999190	PCEF0602010183	1318-1464	CEF-ISA database (unpublished)
115	71	5.0	0.999997	P0802010103	1363-1490	IJF-DGPC database (unpublished)
85	71	5.0	0.999946	PCEF0102010178	1393-1566	CEF-ISA database (unpublished)

PCEF2802020136 (AD 1279-1482)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
204	61	7.5	0.999162	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
204	67	7.1	0.999999	BALTIC1	1156-1597	HILLAM and TYERS (1995)
204	61	7.0	0.999162	BOWHILL-B	1161-1483	GROVES (2004)
163	63	6.6	0.999549	P1604020112	1297-1459	IJF-DGPC database (unpublished)
166	65	6.2	0.999945	P1604020120	1229-1444	IJF-DGPC database (unpublished)
186	63	6.0	0.999804	P1604020117	1246-1464	IJF-DGPC database (unpublished
159	62	6.0	0.998762	P1604020131	1233-1437	IJF-DGPC database (unpublished)
204	61	5.9	0.999162	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
204	66	5.8	0.999998	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
204	62	5.8	0.999696	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
186	64	5.4	0.999933	P0102010055	1295-1484	IJF-DGPC database (unpublished)
202	65	5.3	0.999990	OS842ar	1281-1518	TYERS (2014b)
184	65	5.3	0.999976	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
185	64	5.3	0.999930	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
149	64	5.2	0.999684	PCEF2410040092	1310-1458	CEF-ISA database (unpublished)
183	61	5.2	0.998540	P0202010196	1298-1480	IJF-DGPC database (unpublished)
187	61	5.1	0.998687	P0116020172	1226-1465	IJF-DGPC database (unpublished)

PCEF2802020138 (1289-1473)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
185	69	8.0	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
185	67	7.4	0.999998	BALTICIMPORT	1167-1637	JANSMA *et al.* (2004)
174	66	7.1	0.999988	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
185	68	6.9	1.000000	BOWHILL-B	1161-1483	GROVES (2004)
185	67	6.8	0.999998	BALTIC1	1156-1597	HILLAM and TYERS (1995)
185	63	6.7	0.999797	PCEF0602010187	1274-1486	CEF-ISA database (unpublished)
183	65	6.5	0.999975	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
171	62	6.5	0.999151	PCEF0604010011	1303-1480	CEF-ISA database (unpublished)
177	64	6.1	0.999902	P0102010055	1295-1484	IJF-DGPC database (unpublished)
185	65	6.0	0.999978	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
185	63	6.0	0.999797	0520003M	1173-1616	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
157	63	5.9	0.999439	PCEF1702040027	1256-1445	CEF-ISA database (unpublished)
113	66	5.7	0.999665	P0202010186	1361-1484	IJF-DGPC database (unpublished)
145	68	5.6	0.999993	P0110010069	1329-1475	IJF-DGPC database (unpublished)
184	61	5.6	0.998579	P1102010063rev	1201-1472	IJF-DGPC database (unpublished)
183	61	5.6	0.998540	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
185	65	5.3	0.999978	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
185	64	5.1	0.999930	P0202010190	1230-1476	IJF-DGPC database (unpublished)
185	66	5.0	0.999993	PCEF1410040079-080-081	1244-1485	CEF-ISA database (unpublished)
157	64	5.0	0.999775	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)

PCEF2802020115-118 (1293-1479)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
187	75	11.6	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
187	74	11.6	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
187	71	9.9	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
145	72	9.5	1.000000	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
156	72	9.1	1.000000	P0802010030	1319-1474	IJF-DGPC database (unpublished)
187	67	9.1	0.999998	BOWHILL-B	1161-1483	GROVES (2004)
116	67	8.5	0.999875	P1009010037	1364-1542	IJF-DGPC database (unpublished)
187	63	8.2	0.999811	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
133	69	8.1	0.999994	PCEF1102020211	1347-1482	CEF-ISA database (unpublished)
121	70	7.7	0.999995	P1009010036	1359-1544	IJF-DGPC database (unpublished)
89	73	7.6	0.999993	PCEF0117040167	1391-1509	CEF-ISA database (unpublished)
167	65	7.5	0.999947	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
126	72	7.4	1.000000	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
127	71	7.4	0.999999	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
187	66	7.4	0.999994	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
102	76	7.3	1.000000	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)
133	71	7.3	0.999999	P1102020046	1347-1484	IJF-DGPC database (unpublished
187	62	7.3	0.999485	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
125	67	7.2	0.999928	P0112010079_I	1355-1546	IJF-DGPC database (unpublished)
179	65	7.1	0.999970	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
91	76	7.0	1.000000	OS0833cr	1389-1543	TYERS (2014a)
180	64	6.9	0.999914	P1102020048	1276-1472	IJF-DGPC database (unpublished)
159	66	6.8	0.999973	PCEF0102010173	1321-1486	CEF-ISA database (unpublished)
129	65	6.8	0.999672	P1009010034	1351-1534	IJF-DGPC database (unpublished)
116	67	6.7	0.999875	P0112010077	1364-1536	IJF-DGPC database (unpublished)
178	63	6.7	0.999739	PCEF1410010067-068	1302-1494	CEF-ISA database (unpublished)
116	66	6.7	0.999716	P0112010080-81	1364-1553	IJF-DGPC database (unpublished)

PCEF2802020115-118 (1293-1479)						
OVERLAP (YEARS)	Glk (%)	t_{BP}	P	REFERENCE CHRONOLOGY		
				CODE	SPANNING	PUBLICATION REFERENCE
187	68	6.6	1.000000	P0202010185	1291-1481	IJF-DGPC database (unpublished)
142	63	6.6	0.999027	P0111020167	1306-1447	IJF-DGPC database (unpublished)
164	68	6.5	0.999998	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
152	64	6.5	0.999722	P0502010016	1328-1490	IJF-DGPC database (unpublished)
187	66	6.4	0.999994	P0602010026	1288-1498	IJF-DGPC database (unpublished)
184	65	6.4	0.999976	PCEF1305010095	1255-1476	CEF-ISA database (unpublished)
143	65	6.4	0.999833	P0102010018	1337-1509	IJF-DGPC database (unpublished)
186	68	6.3	1.000000	P0102010023	1294-1523	IJF-DGPC database (unpublished)
183	62	6.3	0.999416	P0102010055	1295-1484	IJF-DGPC database (unpublished)
156	68	6.2	0.999997	PCEF1102020212	1324-1489	CEF-ISA database (unpublished)
114	71	6.2	0.999996	P1102010062	1366-1490	IJF-DGPC database (unpublished)
180	63	6.1	0.999757	PCEF0103010024-25	1292-1472	CEF-ISA database (unpublished)
122	64	6.1	0.999008	PCEF1102020223	1355-1476	CEF-ISA database (unpublished)
187	62	5.9	0.999485	PCEF1410040077-078-082	1203-1482	CEF-ISA database (unpublished)
186	62	5.9	0.999468	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
126	64	5.8	0.999164	PCEF0604010008	1354-1506	CEF-ISA database (unpublished)
133	64	5.7	0.999379	P0111020173	1322-1454	IJF-DGPC database (unpublished)
104	68	5.6	0.999879	P1009010031	1376-1514	IJF-DGPC database (unpublished)
186	63	5.6	0.999804	P1102020047	1278-1479	IJF-DGPC database (unpublished)
110	65	5.6	0.999174	P0802010104	1370-1506	IJF-DGPC database (unpublished)
187	61	5.6	0.998687	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
103	70	5.5	0.999975	PCEF0602010192	1364-1466	CEF-ISA database (unpublished)
163	64	5.5	0.999825	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
187	62	5.5	0.999485	MEMEL	1288-1580	BRAZAUSKAS (2005)
138	63	5.5	0.998872	PCEF2110010054-056	1342-1511	CEF-ISA database (unpublished)
129	69	5.3	0.999992	P0116020166	1314-1442	IJF-DGPC database (unpublished)
100	67	5.2	0.999663	P0802010102	1380-1514	IJF-DGPC database (unpublished)
187	61	5.2	0.998687	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
175	63	5.1	0.999709	PCEF1102020207	1305-1492	CEF-ISA database (unpublished)

PCEF2802020117-120 (1367-1489)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
123	75	10.3	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
123	75	10.1	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
123	70	8.5	0.999995	P1009010037	1364-1542	IJF-DGPC database (unpublished)
123	68	8.5	0.999967	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
123	68	8.3	0.999967	P1009010036	1359-1544	IJF-DGPC database (unpublished)
123	67	8.2	0.999919	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
123	70	7.3	0.999995	P0502010016	1328-1490	IJF-DGPC database (unpublished)
100	72	7.3	0.999995	PCEF0602010192	1364-1466	CEF-ISA database (unpublished)
117	68	7.3	0.999951	BOWHILL-B	1161-1483	GROVES (2004)
123	72	7.0	0.999999	P0112010077	1364-1536	IJF-DGPC database (unpublished)
123	66	6.9	0.999807	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
119	69	6.8	0.999983	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
123	66	6.8	0.999807	MEMEL	1288-1580	BRAZAUSKAS (2005)
112	66	6.8	0.999646	P0102010057	1251-1478	IJF-DGPC database (unpublished)
120	66	6.7	0.999772	P0802010104	1370-1506	IJF-DGPC database (unpublished)
108	74	6.6	1.000000	P0802010030	1319-1474	IJF-DGPC database (unpublished)
123	68	6.6	0.999967	PCEF1102020212	1324-1489	CEF-ISA database (unpublished)

PCEF2802020117-120 (1367-1489)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
123	66	6.6	0.999807	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
111	70	6.5	0.999987	PCEF1710040048-049	1379-1500	CEF-ISA database (unpublished)
121	64	6.4	0.998965	PCEF1116010002	1369-1505	CEF-ISA database (unpublished)
123	67	6.3	0.999919	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
121	65	6.3	0.999517	PCEF1102020225	1317-1487	CEF-ISA database (unpublished)
101	71	6.2	0.999988	OS0833cr	1389-1543	TYERS (2014a)
108	68	6.1	0.999908	PCEF2505020164	1379-1486	CEF-ISA database (unpublished)
120	68	5.9	0.999960	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
115	67	5.9	0.999867	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
123	64	5.9	0.999050	P1009010033	1353-1538	IJF-DGPC database (unpublished)
118	64	5.9	0.999823	P1102020046	1347-1484	IJF-DGPC database (unpublished
123	68	5.8	0.999967	P0112010079_I	1355-1546	IJF-DGPC database (unpublished)
112	67	5.8	0.999840	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
123	64	5.8	0.999050	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
118	67	5.7	0.999889	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
106	67	5.7	0.999768	P1102020048	1276-1472	IJF-DGPC database (unpublished)
110	72	5.6	0.999998	P0802010102	1380-1514	IJF-DGPC database (unpublished)
98	72	5.6	0.999993	OS833br	1392-1546	TYERS (2014a)
123	66	5.6	0.999807	P0602010026	1288-1498	IJF-DGPC database (unpublished)
106	67	5.6	0.999768	PCEF1116010003	1384-1521	CEF-ISA database (unpublished)
123	65	5.6	0.999561	PCEF1102020207	1305-1492	CEF-ISA database (unpublished)
103	66	5.6	0.999418	PCEF0602010184	1257-1469	CEF-ISA database (unpublished)
112	65	5.6	0.999251	PCEF0117040166-168	1378-1513	CEF-ISA database (unpublished)
123	65	5.5	0.999561	P0102010021	1364-1504	IJF-DGPC database (unpublished)
123	65	5.5	0.999561	P0802010103	1363-1490	IJF-DGPC database (unpublished)
97	69	5.4	0.999909	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
120	67	5.4	0.999902	PCEF0102010173	1321-1486	CEF-ISA database (unpublished)
123	64	5.4	0.999050	P0112010080-81	1364-1553	IJF-DGPC database (unpublished)
119	66	5.3	0.999759	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
94	66	5.3	0.999041	PCEF2505020097	1236-1460	CEF-ISA database (unpublished)
114	67	5.2	0.999858	P1009010031	1376-1514	IJF-DGPC database (unpublished)
115	69	5.1	0.999977	P0202010185	1291-1481	IJF-DGPC database (unpublished)
123	68	5.0	0.999967	P0102010018	1337-1509	IJF-DGPC database (unpublished)
106	67	5.0	0.999768	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)

PCEF2802020121-122 (1201-1471)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
271	75	16.3	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
271	77	14.6	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
271	74	13.4	1.000000	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
271	73	13.2	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
271	72	12.1	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
205	71	11.1	1.000000	P1604020131	1233-1437	IJF-DGPC database (unpublished)
264	65	10.6	0.999999	P0202010195	1195-1464	IJF-DGPC database (unpublished)
257	69	10.0	1.000000	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
196	67	9.7	0.999999	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
271	68	9.6	1.000000	BOWHILL-B	1161-1483	GROVES (2004)
216	70	8.8	1.000000	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
196	69	8.8	1.000000	P1102020048	1276-1472	IJF-DGPC database (unpublished)

PCEF2802020121-122 (1201-1471)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
254	62	8.7	0.999935	P0202010184	1157-1454	IJF-DGPC database (unpublished)
185	65	8.5	0.999978	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
207	69	8.1	1.000000	PCEF1702040028	1262-1468	CEF-ISA database (unpublished)
198	69	7.8	1.000000	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
186	70	7.7	1.000000	P0102010054	1261-1446	IJF-DGPC database (unpublished)
194	67	7.7	0.999999	P1102020047	1278-1479	IJF-DGPC database (unpublished)
190	66	7.7	0.999995	PCEF1702040027	1256-1445	CEF-ISA database (unpublished)
214	63	7.6	0.999929	P0202010191	1246-1459	IJF-DGPC database (unpublished)
131	70	7.4	0.999998	P1408040089	1341-1511	IJF-DGPC database (unpublished)
146	63	7.3	0.999160	P1604020134	1191-1346	IJF-DGPC database (unpublished)
236	67	7.1	1.000000	PCEF1702040031	1236-1508	CEF-ISA database (unpublished)
148	63	6.9	0.999219	PCEF0604010010	1300-1447	CEF-ISA database (unpublished)
240	63	6.8	0.999972	P0111020172	1226-1465	IJF-DGPC database (unpublished)
180	64	6.7	0.999914	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
192	61	6.7	0.998850	PCEF1102020210	1280-1479	CEF-ISA database (unpublished)
271	66	6.6	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
175	68	6.6	0.999999	P0102010055	1295-1484	IJF-DGPC database (unpublished)
182	66	6.6	0.999992	P1604020114	1248-1429	IJF-DGPC database (unpublished)
128	70	6.5	0.999997	P0102010052	1344-1496	IJF-DGPC database (unpublished)
250	64	6.5	0.999995	P0110010068	1200-1450	IJF-DGPC database (unpublished)
81	72	6.4	0.999963	PCEF1410010066-069	1391-1493	CEF-ISA database (unpublished)
125	67	6.4	0.999928	P1102020046	1347-1484	IJF-DGPC database (unpublished
129	66	6.2	0.999861	P0111020166	1314-1442	IJF-DGPC database (unpublished)
165	65	6.1	0.999942	OS0833ar	1307-1534	TYERS (2014a)
271	60	6.1	0.999503	PCEF1102020224	1190-1472	CEF-ISA database (unpublished)
155	63	5.9	0.999396	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
125	64	5.9	0.999127	PCEF1102020211	1347-1482	CEF-ISA database (unpublished)
226	63	5.8	0.999954	PCEF1410010071_072	1246-1482	CEF-ISA database (unpublished)
215	64	5.7	0.999980	BALTIC2	1257-1615	HILLAM and TYERS (1995)
143	66	5.6	0.999935	P0110010069	1329-1475	IJF-DGPC database (unpublished)
90	70	5.6	0.999926	PCEF1603010023	1287-1376	CEF-ISA database (unpublished)
246	62	5.6	0.999916	P1604020139	1041-1446	IJF-DGPC database (unpublished)
111	65	5.5	0.999213	P0202010186	1361-1484	IJF-DGPC database (unpublished)
82	67	5.5	0.998961	OS0569bl	1390-1471	TYERS (2014a)
163	68	5.4	0.999998	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
216	63	5.4	0.999934	P1604020120	1229-1444	IJF-DGPC database (unpublished)
205	63	5.4	0.999901	GRIMSBY1	1100-1405	GROVES (1992)
161	63	5.4	0.999515	PCEF0604010012	1311-1484	CEF-ISA database (unpublished)
184	62	5.4	0.999434	P0602010026	1288-1498	IJF-DGPC database (unpublished)
218	61	5.4	0.999419	P0202010189	1254-1480	IJF-DGPC database (unpublished)
113	69	5.3	0.999973	PCEF1603010017-22	1352-1464	CEF-ISA database (unpublished)
222	61	5.3	0.999477	PCEF2210010061	1250-1490	CEF-ISA database (unpublished)
161	68	5.2	0.999998	OS842br	1311-1524	TYERS (2014b)
118	67	5.1	0.999889	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
131	66	5.1	0.999875	P0406010015	1341-1510	IJF-DGPC database (unpublished)
204	62	5.1	0.999696	P30-P455-01-ech	1203-1404	FRAITURE (2011)
145	64	5.1	0.999626	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
242	62	5.0	0.999906	P0202010190	1230-1476	IJF-DGPC database (unpublished)
240	61	5.0	0.999673	P1604020142	1137-1440	IJF-DGPC database (unpublished)
271	60	5.0	0.999503	0670108M	725-1985	WAZNY (1990)

PCEF2802020123-124 (1250-1472)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
223	75	10.2	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
223	75	9.1	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
223	75	8.9	1.000000	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
216	70	8.6	1.000000	BALTIC2	1257-1615	HILLAM and TYERS (1995)
223	71	8.5	1.000000	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
197	68	7.9	1.000000	P1102020048	1276-1472	IJF-DGPC database (unpublished)
223	72	7.8	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
223	64	7.7	0.999986	P0202010190	1230-1476	IJF-DGPC database (unpublished)
223	71	7.6	1.000000	BOWHILL-B	1161-1483	GROVES (2004)
163	63	7.6	0.999549	PCEF2310040083-084	1205-1412	CEF-ISA database (unpublished)
162	70	6.9	1.000000	PCEF0604010012	1311-1484	CEF-ISA database (unpublished)
196	69	6.7	1.000000	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
170	68	6.7	0.999999	PCEF0604010011	1303-1480	CEF-ISA database (unpublished)
205	64	6.7	0.999970	P0202010184	1157-1454	IJF-DGPC database (unpublished)
215	69	6.5	1.000000	P0202010195	1195-1464	IJF-DGPC database (unpublished)
156	67	6.4	0.999989	GRIMSBY1	1100-1405	GROVES (1992)
223	70	6.3	1.000000	0670108M	725-1985	WAZNY (1990)
164	69	6.3	0.999999	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
223	68	6.0	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
223	68	6.0	1.000000	pola006	996-1986	ITRDB
175	66	6.0	0.999988	P0202010196	1298-1480	IJF-DGPC database (unpublished)
185	65	6.0	0.999978	PCEF1702040029	1287-1471	CEF-ISA database (unpublished)
196	63	6.0	0.999864	P1604020121	1207-1445	IJF-DGPC database (unpublished)
186	62	6.0	0.999468	PCEF2505020163	1287-1491	CEF-ISA database (unpublished)
132	63	6.0	0.998592	P1408040089	1341-1511	IJF-DGPC database (unpublished)
182	64	5.9	0.999921	P0202010185	1291-1481	IJF-DGPC database (unpublished)
213	62	5.9	0.999770	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
195	66	5.8	0.999996	P1102020047	1278-1479	IJF-DGPC database (unpublished)
131	63	5.8	0.998539	PCEF2110010054-056	1342-1511	CEF-ISA database (unpublished)
132	74	5.7	1.000000	P0406010015	1341-1510	IJF-DGPC database (unpublished)
223	63	5.7	0.999948	PCEF1305010096	1209-1480	CEF-ISA database (unpublished)
120	70	5.6	0.999994	WMNSTR20	1151-1369	MILES and BRIDGE (2008)
144	67	5.6	0.999977	P0110010069	1329-1475	IJF-DGPC database (unpublished)
201	64	5.6	0.999964	P0110010068	1200-1450	IJF-DGPC database (unpublished)
113	67	5.6	0.999849	PCEF1603010017-22	1352-1464	CEF-ISA database (unpublished)
126	64	5.5	0.999164	P1102020046	1347-1484	IJF-DGPC database (unpublished
147	71	5.3	1.000000	PCEF0602010183	1318-1464	CEF-ISA database (unpublished)
164	67	5.3	0.999993	PCEF1702040026-32	1309-1504	CEF-ISA database (unpublished)
203	63	5.3	0.999894	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)
223	65	5.2	0.999996	PCEF2210010061	1250-1490	CEF-ISA database (unpublished)
185	66	5.2	0.999993	P0602010026	1288-1498	IJF-DGPC database (unpublished)
181	62	5.2	0.999379	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
219	62	5.1	0.999809	P0202010189	1254-1480	IJF-DGPC database (unpublished)
152	64	5.1	0.999722	P0111020177	1317-1468	IJF-DGPC database (unpublished)
195	71	5.0	1.000000	P1604020120	1229-1444	IJF-DGPC database (unpublished)
156	71	5.0	1.000000	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
199	63	5.0	0.999878	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
188	63	5.0	0.999818	P1604020131	1233-1437	IJF-DGPC database (unpublished)
119	66	5.0	0.999759	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
215	61	5.0	0.999372	P1604020117	1246-1464	IJF-DGPC database (unpublished

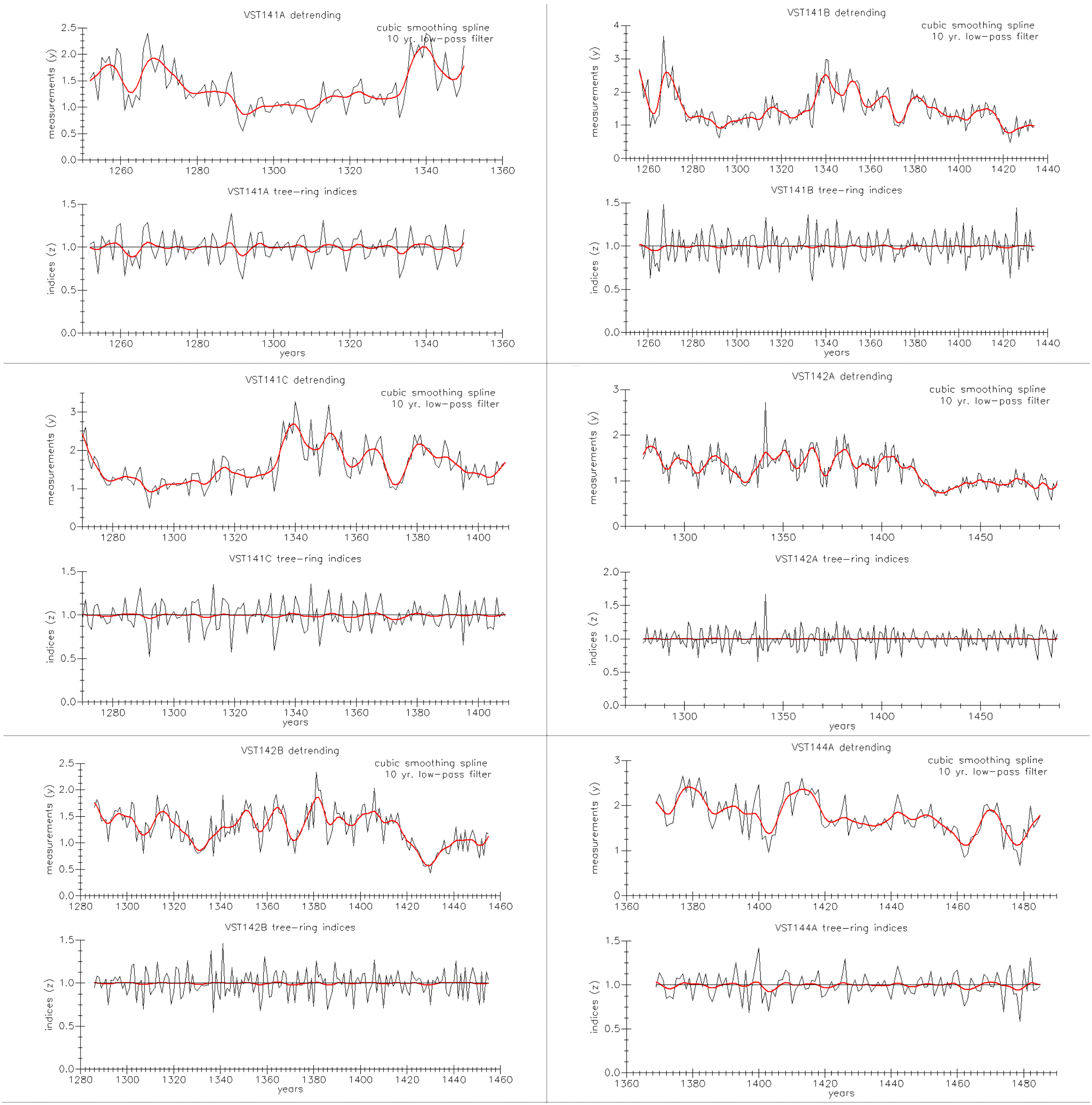
CEF2802020127-137 (1322-1481)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
160	71	10.9	1.000000	BALTIC1	1156-1597	HILLAM and TYERS (1995)
160	72	10.8	1.000000	PCEF3001010222	1317-1484	CEF-ISA database (unpublished)
160	73	10.0	1.000000	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
160	68	9.9	0.999997	PCEF1102020199	1292-1481	CEF-ISA database (unpublished)
160	73	9.7	1.000000	NL BALTIC IMPORT	1167-1637	JANSMA *et al.* (2004)
160	72	9.4	1.000000	BOWHILL-B	1161-1483	GROVES (2004)
160	72	8.7	1.000000	NL Baltic B	1167-1544	E. JANSMA (pers. communication)
153	69	8.7	0.999999	P0802010030	1319-1474	IJF-DGPC database (unpublished)
128	73	8.5	1.000000	PCEF0602010180	1354-1490	CEF-ISA database (unpublished)
151	68	8.4	0.999995	P1102020048	1276-1472	IJF-DGPC database (unpublished)
116	67	8.2	0.999875	P1102010062	1366-1490	IJF-DGPC database (unpublished)
160	67	8.1	0.999991	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
150	66	8.1	0.999956	PCEF1102020209	1276-1471	CEF-ISA database (unpublished)
151	67	8.0	0.999985	PCEF0103010024-25	1292-1472	CEF-ISA database (unpublished)
157	70	7.7	1.000000	P1102020047	1278-1479	IJF-DGPC database (unpublished)
135	68	7.4	0.999986	P1102020046	1347-1484	IJF-DGPC database (unpublished)
129	69	7.1	0.999992	PCEF2410040088	1353-1485	CEF-ISA database (unpublished)
157	66	7.1	0.999970	PCEF2610040101-102	1271-1478	CEF-ISA database (unpublished)
159	72	6.9	1.000000	PCEF1305010096	1209-1480	CEF-ISA database (unpublished)
160	65	6.9	0.999926	0520006M	1146-1491	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
160	66	6.8	0.999974	PCEF0602010179	1313-1492	CEF-ISA database (unpublished)
143	65	6.8	0.999833	P1604020117	1246-1464	IJF-DGPC database (unpublished
143	67	6.7	0.999976	PCEF0602010183	1318-1464	CEF-ISA database (unpublished)
142	65	6.6	0.999825	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
148	64	6.4	0.999671	PCEF0602010195	1256-1469	CEF-ISA database (unpublished)
151	74	6.3	1.000000	PCEF1410040073	1309-1472	CEF-ISA database (unpublished)
141	72	6.3	1.000000	PCEF0602010182	1341-1486	CEF-ISA database (unpublished)
132	68	6.2	0.999982	PCEF1305010093	1343-1474	CEF-ISA database (unpublished)
160	66	6.1	0.999974	PCEF1410010070	1273-1487	CEF-ISA database (unpublished)
137	65	6.1	0.999777	PCEF2410040092	1310-1458	CEF-ISA database (unpublished)
118	64	6.1	0.998823	P1009010037	1364-1542	IJF-DGPC database (unpublished)
147	68	6.0	0.999994	P0110010069	1329-1475	IJF-DGPC database (unpublished)
156	67	6.0	0.999989	PCEF0602010194	1326-1485	CEF-ISA database (unpublished)
122	66	5.9	0.999796	PCEF1102020223	1355-1476	CEF-ISA database (unpublished)
157	63	5.9	0.999439	P0102010057	1251-1478	IJF-DGPC database (unpublished)
160	62	5.9	0.998800	P0602010026	1288-1498	IJF-DGPC database (unpublished)
160	64	5.8	0.999801	PCEF1102020206	1273-1481	CEF-ISA database (unpublished)
113	69	5.7	0.999973	PCEF1603010017-22	1352-1464	CEF-ISA database (unpublished)
121	64	5.7	0.998965	P0202010186	1361-1484	IJF-DGPC database (unpublished)
160	62	5.7	0.998800	OS842ar	1281-1518	TYERS (2014b)
133	63	5.7	0.998643	P0111020173	1322-1454	IJF-DGPC database (unpublished)
160	70	5.6	1.000000	PCEF0102010173	1321-1486	CEF-ISA database (unpublished)
119	68	5.5	0.999957	0520004M	1363-1643	J. BAUCH, D. ECKSTEIN, P. KLEIN (unpublished; pers. communication)
103	65	5.5	0.998835	PCEF1710040048-049	1379-1500	CEF-ISA database (unpublished)
160	65	5.4	0.999926	P0102010055	1295-1484	IJF-DGPC database (unpublished)
160	67	5.2	0.999991	PCEF1702040030	1274-1509	CEF-ISA database (unpublished)
150	67	5.2	0.999984	PCEF2410040090	1251-1471	CEF-ISA database (unpublished)
160	63	5.2	0.999497	PCEF1410040077-078-082	1203-1482	CEF-ISA database (unpublished)
160	69	5.1	0.999999	PCEF1702040026-32	1309-1504	CEF-ISA database (unpublished)
136	67	5.1	0.999963	P1102010064	1207-1457	IJF-DGPC database (unpublished)
160	64	5.1	0.999801	PCEF1102020201	1317-1489	CEF-ISA database (unpublished)
131	65	5.1	0.999702	PCEF1603010021	1237-1452	CEF-ISA database (unpublished)

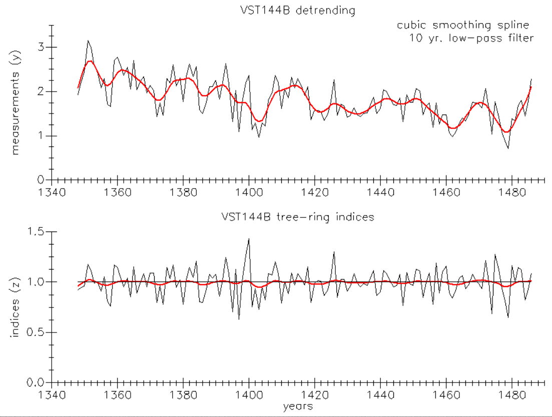
CEF2802020127-137 (1322-1481)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
108	69	5.0	0.999961	P1604020114	1248-1429	IJF-DGPC database (unpublished)
140	66	5.0	0.999924	P1604020146	1274-1461	IJF-DGPC database (unpublished)
160	64	5.0	0.999801	PCEF2505020098	1197-1490	CEF-ISA database (unpublished)
141	64	5.0	0.999558	PCEF1603010018-20	1206-1462	CEF-ISA database (unpublished)
125	64	5.0	0.999127	P0102010054	1261-1446	IJF-DGPC database (unpublished)

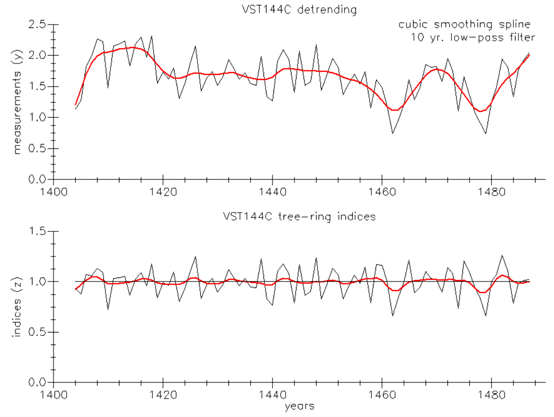
PCEF2802020128-139 (1144-1474)						
OVERLAP (YEARS)	Glk	t_{BP}	P	CHRONOLOGY DESCRIPTION		
				CODE	SPANNING	PUBLICATION REFERENCE
314	59	6.1	0.999288	BOWHILL-B	1161-1483	GROVES (2004)
145	64	6.0	0.999626	PCEF1102020205	1319-1463	CEF-ISA database (unpublished)
331	60	5.9	0.999863	0520003M	1115-1643	ECKSTEIN *et al.* (1975)
331	59	5.2	0.999471	NL Baltic A	1030-1602	E. JANSMA (pers. communication)
269	63	5.0	0.999990	PCEF1102020226-227	1193-1461	CEF-ISA database (unpublished)

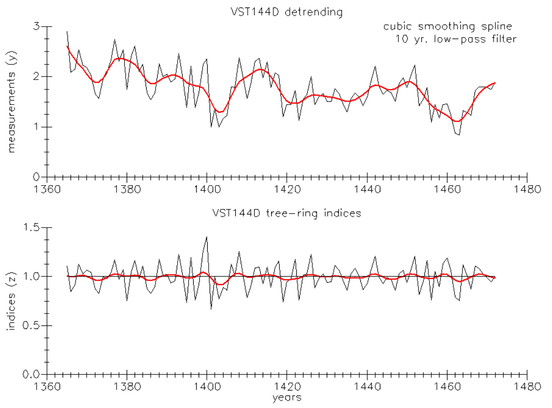
ANNEX 6. Detrending sequences from Portuguese paintings to creat new chronologies

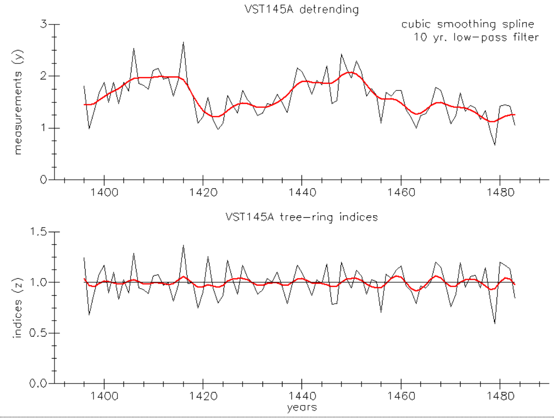
Table 1. Detrending dendrochronological sequences from the *Vida de S. Tiago* altarpiece, curated at the National Museum of Ancient Art (Lisbon), to create a new chronology [Graph by ARSTAN (version 49v1b_MRWE)].

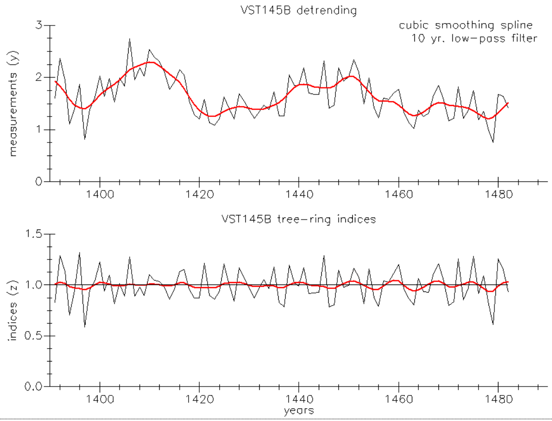


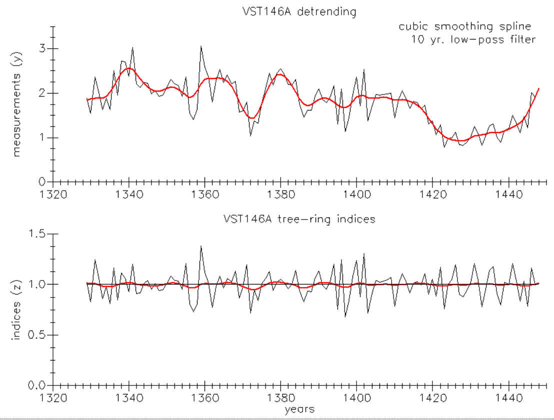

VST144B detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST144B tree-ring indices
indices (z)
years

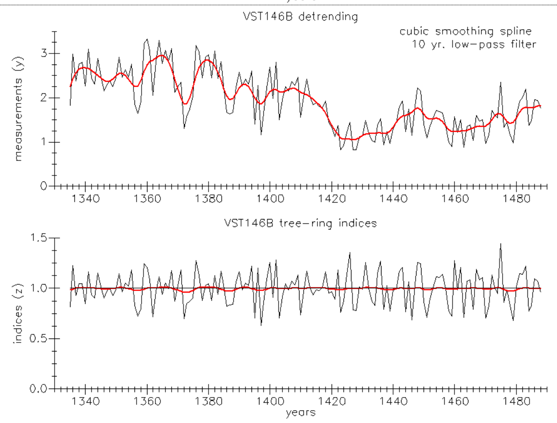

VST144C detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST144C tree-ring indices
indices (z)
years

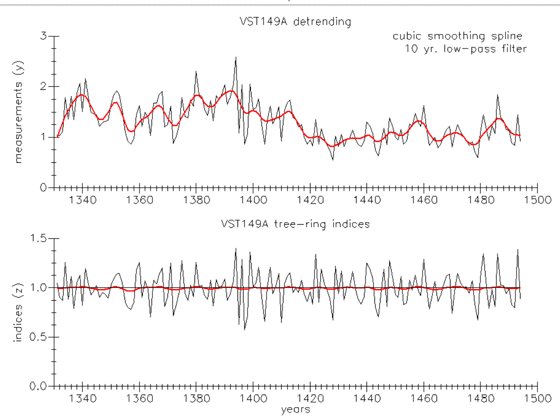

VST144D detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST144D tree-ring indices
indices (z)
years

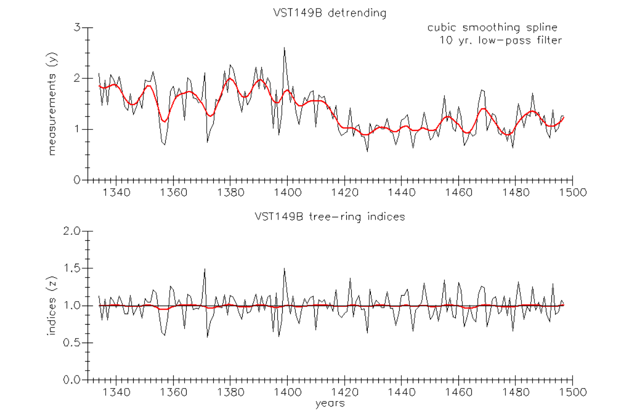

VST145A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST145A tree-ring indices
indices (z)
years

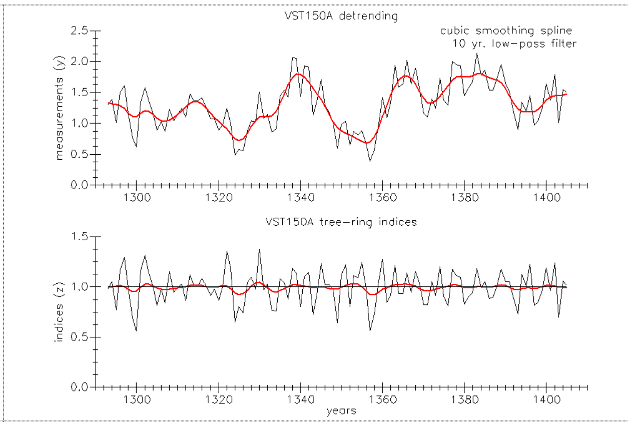

VST145B detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST145B tree-ring indices
indices (z)
years

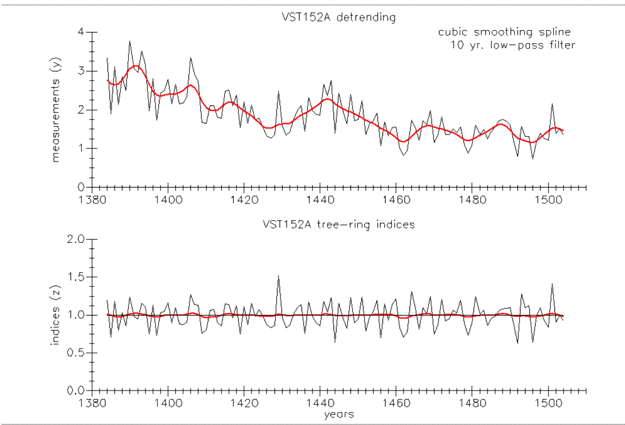

VST146A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST146A tree-ring indices
indices (z)
years

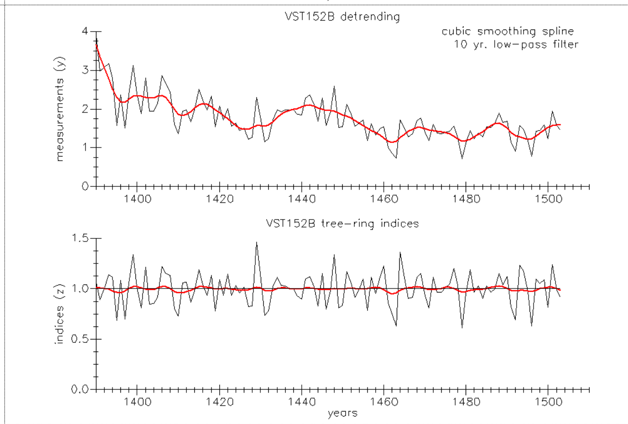

VST146B detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST146B tree-ring indices
indices (z)
years

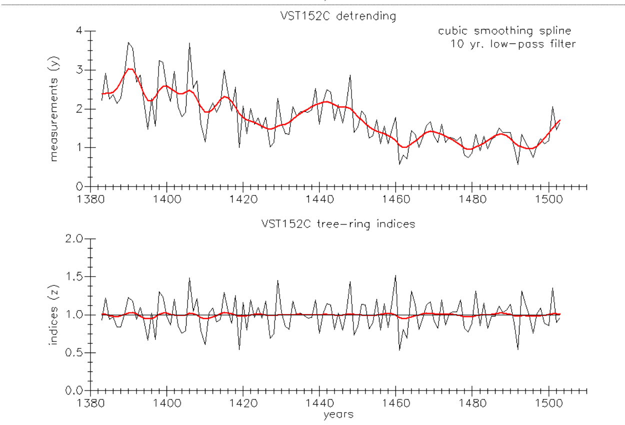

VST149A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST149A tree-ring indices
indices (z)
years

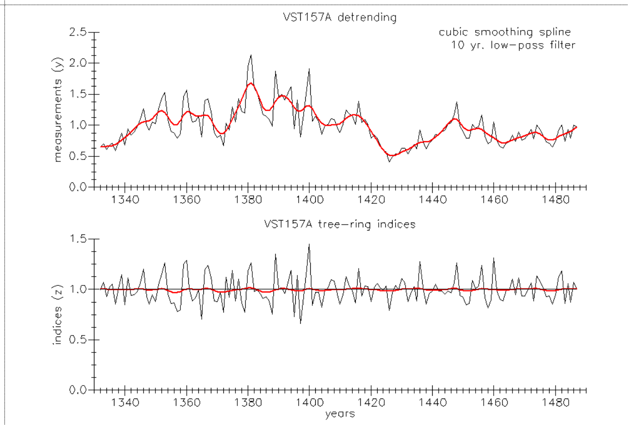

VST149B detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST149B tree-ring indices
indices (z)
years


VST150A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST150A tree-ring indices
indices (z)
years


VST152A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST152A tree-ring indices
indices (z)
years


VST152B detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST152B tree-ring indices
indices (z)
years


VST152C detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST152C tree-ring indices
indices (z)
years


VST157A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST157A tree-ring indices
indices (z)
years

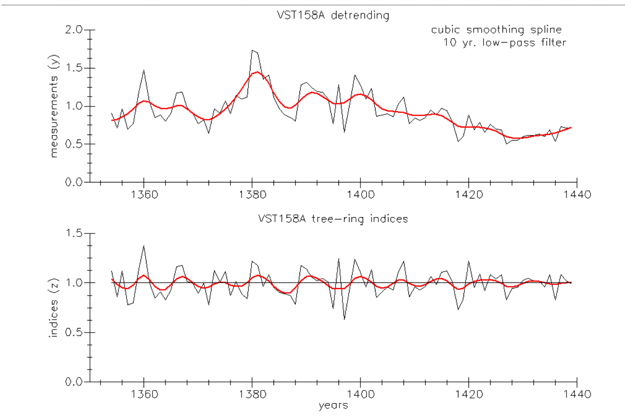
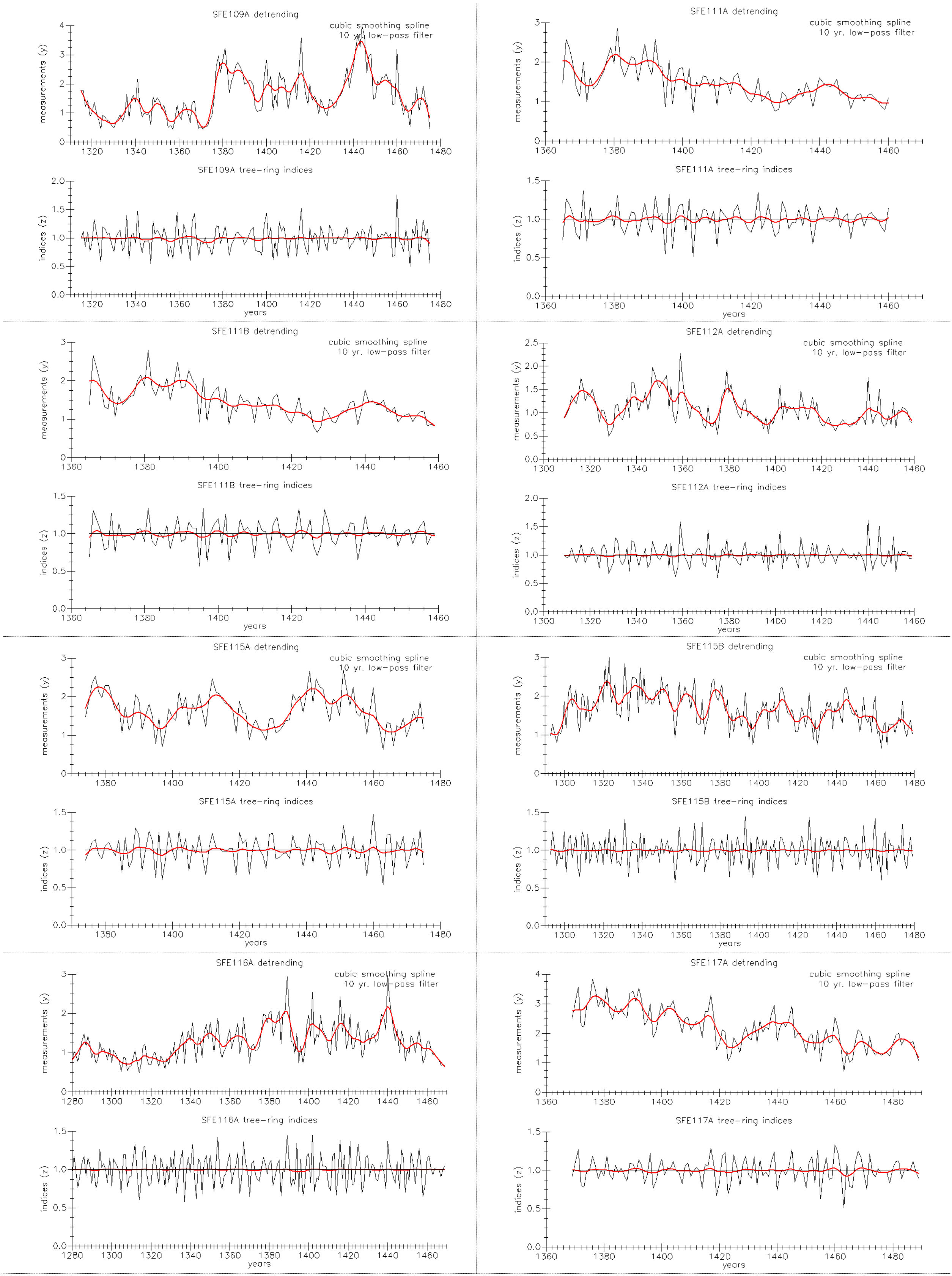
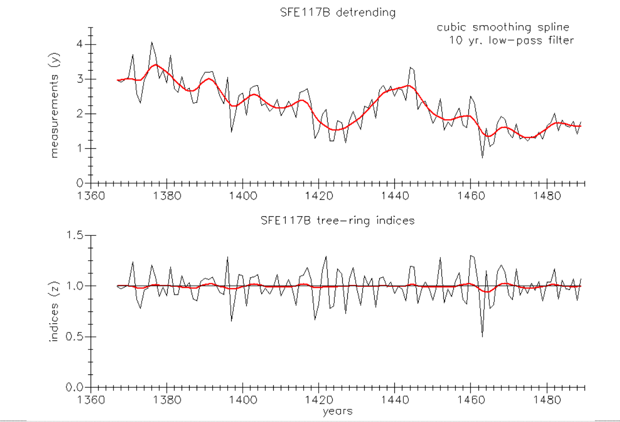
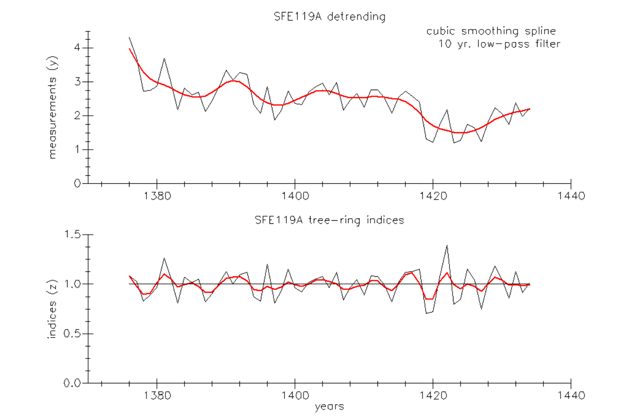
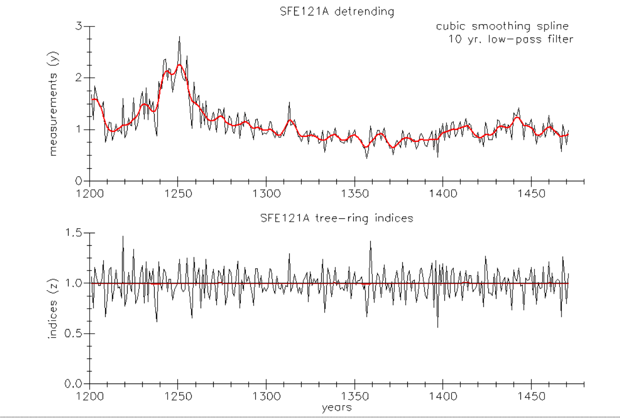

VST158A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
VST158A tree-ring indices
indices (z)
years

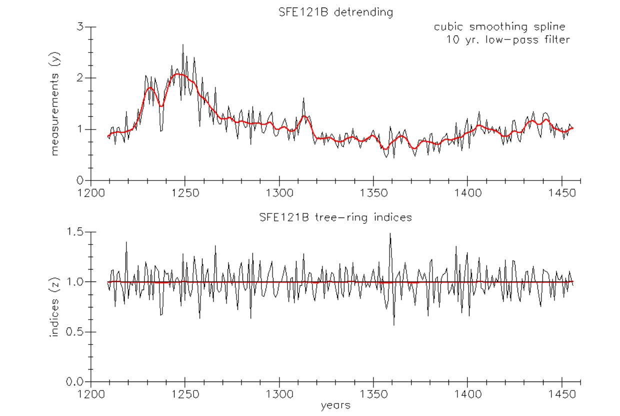
Table 2. Detrending dendrochronological sequences from the *S. Francisco de Évora* altarpiece, curated at the National Museum of Ancient Art (Lisbon), to create a new chronology [Graph by ARSTAN (version 49v1b_MRWE)].

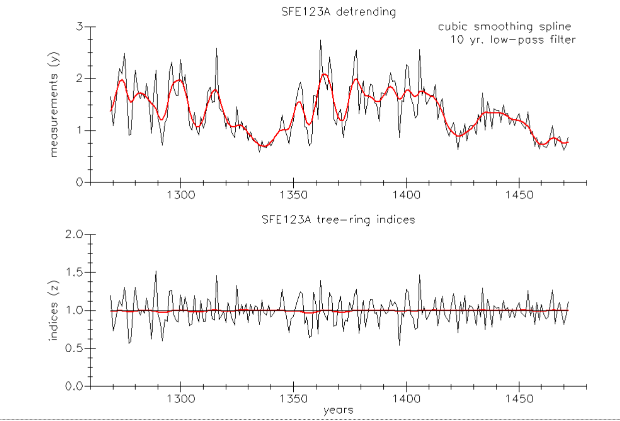


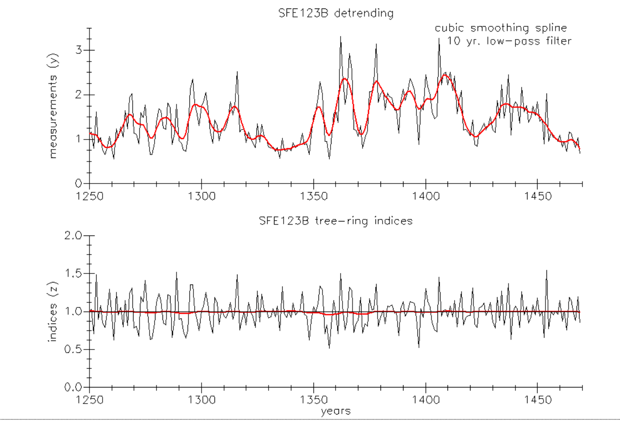

SFE117B detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE117B tree−ring indices
indices (z)
years

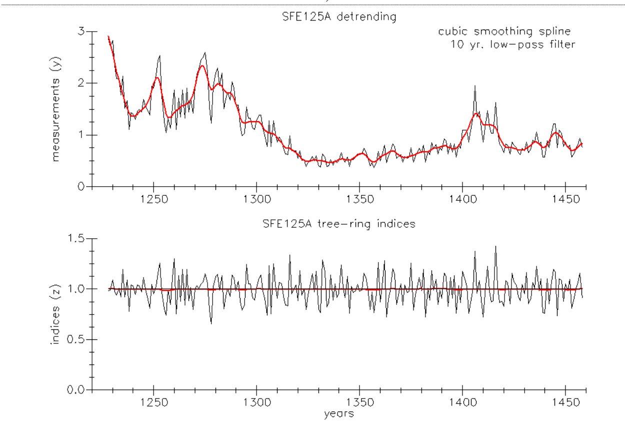

SFE119A detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE119A tree−ring indices
indices (z)
years

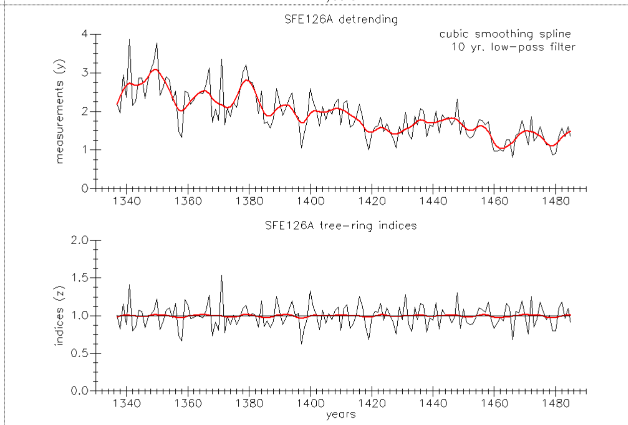

SFE121A detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE121A tree−ring indices
indices (z)
years

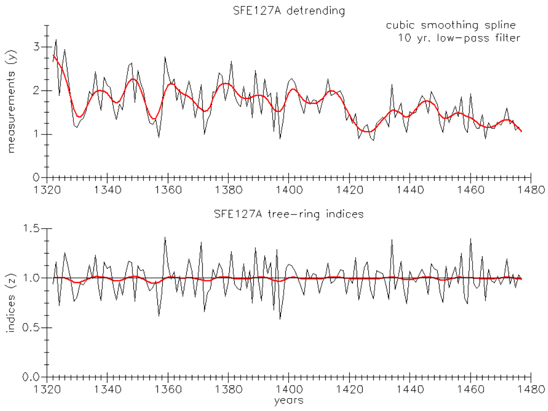

SFE121B detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE121B tree−ring indices
indices (z)
years

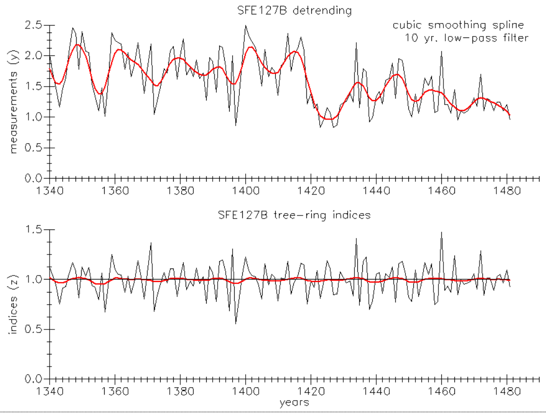

SFE123A detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE123A tree−ring indices
indices (z)
years

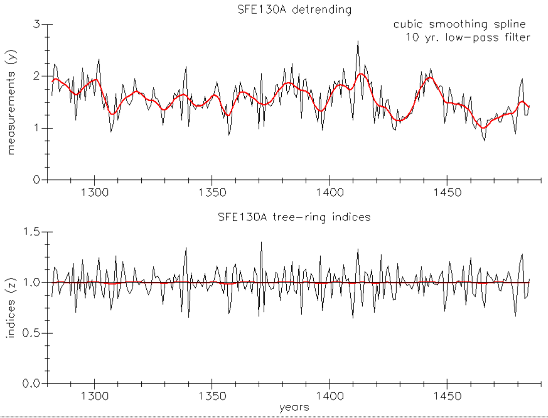

SFE123B detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE123B tree−ring indices
indices (z)
years

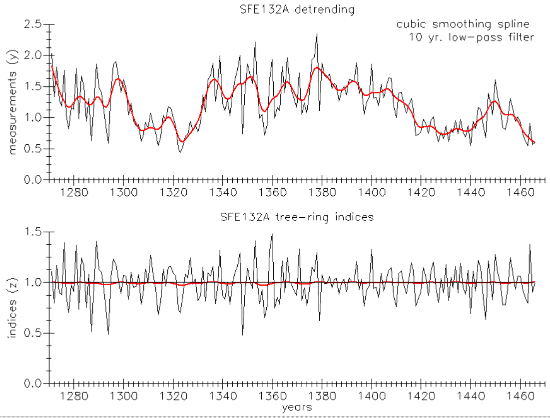

SFE125A detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE125A tree−ring indices
indices (z)
years

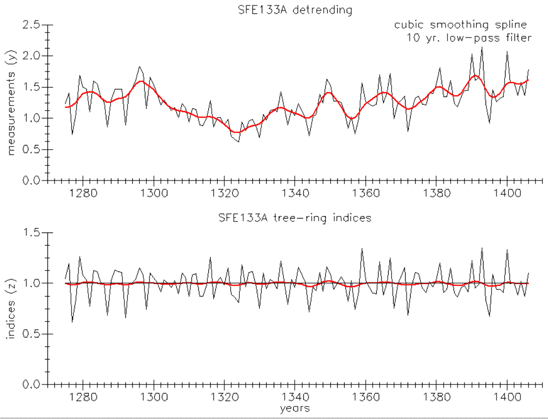

SFE126A detrending
cubic smoothing spline
10 yr. low−pass filter
measurements (y)
SFE126A tree−ring indices
indices (z)
years

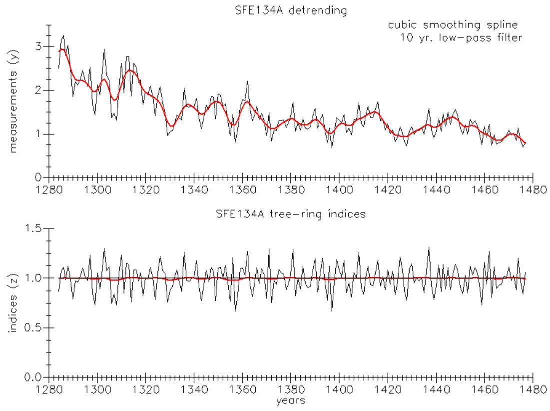

SFE127A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE127A tree-ring indices
indices (z)
years

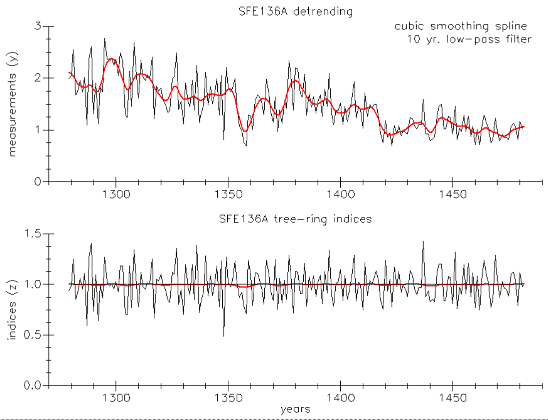

SFE127B detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE127B tree-ring indices
indices (z)
years

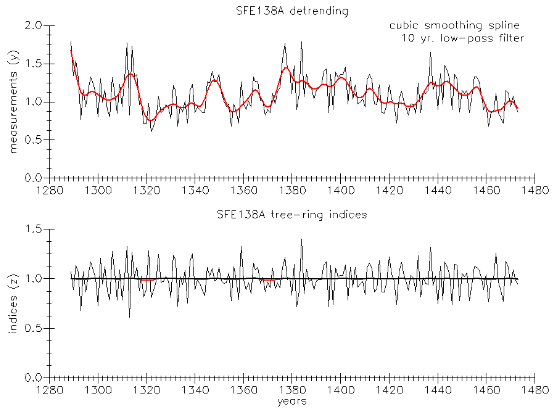

SFE130A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE130A tree-ring indices
indices (z)
years


SFE132A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE132A tree-ring indices
indices (z)
years


SFE133A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE133A tree-ring indices
indices (z)
years


SFE134A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE134A tree-ring indices
indices (z)
years


SFE136A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE136A tree-ring indices
indices (z)
years


SFE138A detrending
cubic smoothing spline
10 yr. low-pass filter
measurements (y)
SFE138A tree-ring indices
indices (z)
years

ANNEX 7. Dendrochronological dating of the clavichords, harpsichords and fortepianos.

Table 1. Cross-matching of the dendrochronological sequences obtained in the fortepiano MNM0425 (Henry van Casteel, Portugal, 1763), curated at the National Museum of Music (Lisbon), against published and unpublished reference chronologies (t_H≥4.0 and *P*≥0.999) [* – description according to the publication reference; n.i. – not identified].

MNM0425003 (1665-1748)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
84	72	6.9	1.000	IM015I	Picea	1617-1812	HOUBRECHTS (2004)
84	72	6.8	1.000	MITT2	Picea	1605-1805	ITRDB
84	77	6.3	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
74	80	5.7	1.000	IM033III	Picea?	1675-1814	HOUBRECHTS (2006)
62	69	5.7	0.999	I03010602T077	n.i.	1555-1726	CEF-ISA database (unpublished)
84	69	5.5	1.000	IM020I	Picea	1646-1813	HOUBRECHTS (2004)
84	69	5.3	1.000	SWIT169	*Picea abies*	1532-1986	ITRDB
84	72	5.1	1.000	I03060801BT006	n.i.	1640-1775	CEF-ISA database (unpublished)
84	67	5.1	0.999	I02090801T042	n.i.	1643-1744	CEF-ISA database (unpublished)
78	69	5.0	1.000	IM008I	Picea	1671-1779	HOUBRECHTS (2004)
84	71	4.9	1.000	IM017III	Picea	1474-1820	HOUBRECHTS (2004)
74	71	4.5	1.000	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
84	69	4.5	1.000	MITT1	Picea	1490-1803	ITRDB
84	71	4.4	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
84	73	4.2	1.000	origHK033402T037	n.i.	1629-1759	CEF-ISA database (unpublished)
84	69	4.2	1.000	I02070702BT021	n.i.	1663-1762	CEF-ISA database (unpublished)
84	72	4.0	1.000	IM023II	Picea	1550-1757	HOUBRECHTS (2004)

MNM0425005 (1669-1750)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
82	77	6.1	1.000	IM005I	Picea?	1667-1805	HOUBRECHTS (2004)
82	71	6.1	1.000	IM015I	Picea	1617-1812	HOUBRECHTS (2004)
82	73	5.9	1.000	IM020I	Picea	1646-1813	HOUBRECHTS (2004)
82	73	5.5	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
71	77	4.9	1.000	I02140702BT095	n.i.	1680-1777	CEF-ISA database (unpublished)
82	73	4.9	1.000	I03060801BT006	n.i.	1640-1775	CEF-ISA database (unpublished)
82	74	4.7	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
82	73	4.7	1.000	I02090801T042	n.i.	1643-1744	CEF-ISA database (unpublished)
82	71	4.6	1.000	SWIT169	*Picea abies*	1532-1986	ITRDB
82	71	4.5	1.000	JJAIS	*Picea abies*	1630-1793	ITRDB
70	71	4.4	1.000	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
82	68	4.3	0.999	MITT1	Picea	1490-1803	ITRDB
82	71	4.1	1.000	IM017III	Picea	1474-1820	HOUBRECHTS (2004)
76	69	4.1	1.000	origHK090107B012	n.i.	1675-1786	CEF-ISA database (unpublished)
82	68	4.0	0.999	ITA024	*Larix decidua*	1520-1990	ITRDB

MNM0425002-004-006-007 (1538-1736)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
120	83	16.2	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
138	78	14.0	1.000	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
179	68	11.8	1.000	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
199	70	10.9	1.000	MITT1	Picea	1490-1803	ITRDB

187	65	10.1	1.000	IM023II	Picea	1550-1757	HOUBRECHTS (2004)
107	73	9.2	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
113	71	9.0	1.000	I03090801B022	n.i.	1586-1698	CEF-ISA database (unpublished)
199	69	8.1	1.000	ITA024	*Larix decidua*	1520-1990	ITRDB
74	72	7.9	1.000	I02090801T042	n.i.	1643-1744	CEF-ISA database (unpublished)
132	70	7.6	1.000	MITT2	Picea	1605-1805	ITRDB
110	68	7.6	1.000	IM004I	Picea?	1627-1767	HOUBRECHTS (2004)
199	64	7.5	1.000	SWIT169	*Picea abies*	1532-1986	ITRDB
169	64	7.0	1.000	I03080801B001	n.i.	1567-1735	CEF-ISA database (unpublished)
199	61	6.1	0.999	IM017III	Picea	1474-1820	HOUBRECHTS (2004)
92	70	5.7	1.000	PS06DX	*Larix decidua*	1645-2004	ITRDB
91	67	5.5	0.999	IM020I	Picea	1646-1813	HOUBRECHTS (2004)
66	70	5.4	0.999	IM008I	Picea	1671-1779	HOUBRECHTS (2004)
70	75	5.3	1.000	IM005I	Picea?	1667-1805	HOUBRECHTS (2004)
94	66	5.3	0.999	I02090801BT012	n.i.	1643-1744	CEF-ISA database (unpublished)
160	63	5.2	0.999	TAM062a	*Pinus cembra*	1577-2002	ITRDB
174	63	5.2	1.000	I02170202BT106	n.i.	1535-1711	CEF-ISA database (unpublished)
62	72	5.1	1.000	origHK090107B012	n.i.	1675-1786	CEF-ISA database (unpublished)
118	67	4.5	1.000	HK020407T060	n.i.	1562-1679	CEF-ISA database (unpublished)
148	63	4.0	0.999	GuA23T1	*Picea abies*	1557-1704	ITRDB
199	63	4.0	1.000	IM029I	Picea	1536-1829	HOUBRECHTS (2006)

Table 2. Cross-matching of the dendrochronological sequences obtained in the fortepiano CRMM (Mathias Bostem, Portugal, 1777) against published and unpublished reference chronologies (t_H≥4.0 and P≥0.999) [* – description according to the publication reference; n.i. – not identified].

CRMM001 (1624-1751)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
106	65	6.1	0.999	IM020I	Picea	1646-1813	HOUBRECHTS (2004)
128	69	6.0	1.000	IM015I	Picea	1617-1812	HOUBRECHTS (2004)
128	69	5.6	1.000	IM017III	Picea	1474-1820	HOUBRECHTS (2004)
128	70	5.3	1.000	MITT2	Picea	1605-1805	ITRDB
104	65	5.3	0.999	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
99	73	5.2	1.000	HK033402T037	n.i.	1653-1759	CEF-ISA database (unpublished)
112	68	5.1	1.000	I03080801BT003	n.i.	1567-1735	CEF-ISA database (unpublished)
115	64	5.1	0.999	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
122	66	4.9	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
128	66	4.9	1.000	SWIT173	*Picea abies*	1537-1995	ITRDB
67	71	4.8	1.000	I03111001T066	n.i.	1545-1690	CEF-ISA database (unpublished)
128	67	4.8	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
128	67	4.8	1.000	Tam010b	*Pinus cembra*	1550-1792	ITRDB
75	68	4.7	0.999	I03090801BT024	n.i.	1574-1698	CEF-ISA database (unpublished)
94	66	4.6	0.999	GuA23B1	*Picea abies*	1567-1717	ITRDB
89	66	4.1	0.999	I02070702BT021	n.i.	1663-1762	CEF-ISA database (unpublished)
128	64	4.1	0.999	TAM021a	*Pinus cembra*	1612-2002	ITRDB
112	67	4.0	1.000	I03060801BT006	n.i.	1640-1775	CEF-ISA database (unpublished)
128	67	4.0	1.000	IM007I	Picea?	1584-1788	HOUBRECHTS (2004)
124	66	4.0	1.000	TAM002	*Pinus cembra*	1628-1819	ITRDB

CRMM002 (1615-1728)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
102	73	8.9	1.000	IM004I	Picea?	1627-1767	HOUBRECHTS (2004)
114	68	7.7	1.000	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
114	65	7.7	0.999	SWIT169	*Picea abies*	1532-1986	ITRDB
84	71	7.1	1.000	I03090801BT024	n.i.	1574-1698	CEF-ISA database (unpublished)

113	69	6.8	1.000	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
112	68	6.8	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
114	69	6.2	1.000	MITT1	Picea	1490-1803	ITRDB
99	68	6.1	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
114	71	5.9	1.000	I03080801BT003	n.i.	1567-1735	CEF-ISA database (unpublished)
62	72	5.8	1.000	IM005I	Picea?	1667-1805	HOUBRECHTS (2004)
114	65	5.7	0.999	IM023II	Picea	1550-1757	HOUBRECHTS (2004)
114	70	5.4	1.000	SWIT173	*Picea abies*	1537-1995	ITRDB
114	69	5.3	1.000	MITT2	Picea	1605-1805	ITRDB
99	67	4.5	1.000	JJAIS	*Picea abies*	1630-1793	ITRDB
114	69	4.3	1.000	IM029I	Picea	1536-1829	HOUBRECHTS (2006)

CRMM005 (1673-1732)							
OVERLAP (YEARS)	**Glk (%)**	**t_H**	**P**	**CHRONOLOGY DESCRIPTION**			
				CODE	**WOOD SPECIES***	**SPANNING**	**PUBLICATION REFERENCE**
60	73	6.6	1.000	SWIT169	*Picea abies*	1532-1986	ITRDB
60	74	6.2	1.000	I02090801T042	n.i.	1643-1744	CEF-ISA database (unpublished)
60	71	5.9	0.999	IM004I	Picea?	1627-1767	HOUBRECHTS (2004)
60	70	4.5	0.999	I02070702BT021	n.i.	1663-1762	CEF-ISA database (unpublished)
60	72	4.0	1.000	I02090801BT012	n.i.	1643-1744	CEF-ISA database (unpublished)

CRMM003-004 (1608-1728)							
OVERLAP (YEARS)	**Glk (%)**	**t_H**	**P**	**CHRONOLOGY DESCRIPTION**			
				CODE	**WOOD SPECIES***	**SPANNING**	**PUBLICATION REFERENCE**
112	74	8.1	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
121	70	7.6	1.000	MITT1	*Picea abies*	1490-1803	ITRDB
121	66	7.5	1.000	SWIT169	*Picea abies*	1532-1986	ITRDB
91	68	7.1	1.000	I03090801BT024	n.i.	1574-1698	CEF-ISA database (unpublished)
121	72	7.0	1.000	ITA024	*Larix decidua*	1520-1990	ITRDB
121	73	6.9	1.000	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
79	74	6.6	1.000	HK020102BT042	n.i.	1575-1686	CEF-ISA database (unpublished)
120	65	6.5	0.999	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
87	66	5.9	0.999	HK020407BT028a	n.i.	1637-1723	CEF-ISA database (unpublished)
99	67	5.3	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
121	67	4.9	1.000	IM007I	Picea?	1584-1788	HOUBRECHTS (2004)
121	67	4.9	1.000	TAM003a	*Pinus cembra*	1478-2002	ITRDB
86	68	4.7	1.000	origHK020407B027	n.i.	1638-1723	CEF-ISA database (unpublished)
121	66	4.5	1.000	MITT2	Picea	1605-1805	ITRDB
102	70	4.4	1.000	IM004I	Picea?	1627-1767	HOUBRECHTS (2004)
121	65	4.4	1.000	GRPCS	*Pinus cembra*	1456-2009	ITRDB
121	66	4.3	1.000	SZ22AA	*Larix decidua*	1603-2000	ITRDB
75	69	4.0	1.000	origHK023507B038	n.i.	1654-1736	CEF-ISA database (unpublished)

Table 3. Cross-matching of the dendrochronological sequences obtained in the fortepiano MNM0648 (Mathias Bostem, Portugal, 1786) against published and unpublished reference chronologies (t_H≥4.0 and *P*≥0.999) [[* – description according to the publication reference; n.i. – not identified].

MNM0648001 (1586-1715)							
OVERLAP (YEARS)	**Glk (%)**	**t_H**	**P**	**CHRONOLOGY DESCRIPTION**			
				CODE	**WOOD SPECIES***	**SPANNING**	**PUBLICATION REFERENCE**
113	69	6.0	1.000	I03090801BT024	n.i.	1574-1698	CEF-ISA database (unpublished)
130	65	5.3	1.000	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)

MNM0648002 (1635-1731)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
97	67	7.4	1.000	I03080801BT003	n.i.	1567-1735	CEF-ISA database (unpublished)
97	65	4.2	0.998	IM017III	Picea	1474-1820	HOUBRECHTS (2004)

MNM0648003 (1589-1676)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
88	70	6.0	1.000	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
88	66	4.9	0.999	I03090801BT024	n.i.	1574-1698	CEF-ISA database (unpublished)
72	67	4.5	0.998	MITT2	Picea	1605-1805	ITRDB
88	70	4.2	1.000	pkuxb	*Picea abies*	1560-1682	ITRDB

MNM0648005 (1618-1693)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
76	67	5.2	0.999	IM007I	Picea?	1584-1788	HOUBRECHTS (2004)
73	67	4.6	0.999	I03111001T066	n.i.	1545-1690	CEF-ISA database (unpublished)
76	68	4.0	0.999	I02010202BT109	n.i.	1582-1704	CEF-ISA database (unpublished)

MNM0648007 (1651-1724)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
74	73	5.5	1.000	IM017III	Picea	1474-1820	HOUBRECHTS (2004)
74	69	5.5	0.999	I03080801BT003	n.i.	1567-1735	CEF-ISA database (unpublished)
74	74	5.4	1.000	MITT2	Picea	1605-1805	ITRDB
67	70	5.1	0.999	GuA23B1	*Picea abies*	1567-1717	ITRDB
74	67	4.6	0.999	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
74	69	4.2	0.999	IM023II	Picea	1550-1757	HOUBRECHTS (2004)
74	68	4.1	0.999	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)

Table 4. Cross-matching of the dendrochronological sequences obtained in fortepiano MNM0833 (Mathias Bostem, Portugal, 1789) against published and unpublished reference chronologies ($t_H \geq 4.0$ and $P \geq 0.999$) [* – description according to the publication reference; n.i. – not identified].

MNM0833002 (1628-1720)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
93	74	11.1	1.000	IM009I	Picea	1617-1784	HOUBRECHTS (2004)
71	77	10.0	1.000	I03090801B022	n.i.	1586-1698	CEF-ISA database (unpublished)
93	69	9.5	1.000	IM027I	Picea	1599-1738	HOUBRECHTS (2006)
93	68	8.7	1.000	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
93	71	8.5	1.000	SWIT169	*Picea abies*	1532-1986	ITRDB
93	73	7.6	1.000	IM023II	Picea	1550-1757	HOUBRECHTS (2004)
93	68	6.9	1.000	MITT1	*Picea abies*	1490-1803	ITRDB
93	73	6.8	1.000	ITA024	*Larix decidua*	1520-1990	ITRDB
84	69	6.6	1.000	HK020407BT028a	n.i.	1637-1723	CEF-ISA database (unpublished)

MNM0833002 (1628-1720)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
63	73	6.5	1.000	I03111001T066	n.i.	1545-1690	CEF-ISA database (unpublished)
93	66	6.1	0.999	GRPCS	*Pinus cembra*	1456-2009	ITRDB
93	65	5.9	0.999	GERM021	*Pinus cembra*	1468-1765	ITRDB
93	68	5.4	1.000	TAM062a	*Pinus cembra*	1577-2002	ITRDB
93	65	5.3	0.999	ITA023	*Pinus cembra*	1474-1990	ITRDB
93	69	5.1	1.000	I02010102BT061	n.i.	1578-1762	CEF-ISA database (unpublished)
93	65	5.1	0.999	Tam007a	*Pinus cembra*	1604-2002	ITRDB
63	78	4.6	1.000	origHK024007B050	n.i.	1658-1769	CEF-ISA database (unpublished)
60	69	4.5	0.999	TAM080b	*Pinus cembra*	1661-2002	ITRDB
93	67	4.5	0.999	GERM021	*Pinus cembra*	1475-1760	ITRDB
77	66	4.5	0.999	I02010202BT109	n.i.	1582-1704	CEF-ISA database (unpublished)
93	65	4.5	0.999	TAM003a	*Pinus cembra*	1478-2002	ITRDB
78	71	4.4	1.000	I02090801BT012	n.i.	1643-1744	CEF-ISA database (unpublished)
93	71	4.3	1.000	TAM001a	*Pinus cembra*	1564-1805	ITRDB
65	72	4.2	1.000	HK020407T064	n.i.	1572-1692	CEF-ISA database (unpublished)
93	66	4.1	0.999	GERM021	*Pinus cembra*	1485-1752	ITRDB
91	65	4.0	0.999	origHK030407B029	n.i.	1614-1718	CEF-ISA database (unpublished)

MNM0833005 (1677-1741)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
65	75	7.3	0.999	I02090801T042	n.i.	1643-1744	CEF-ISA database (unpublished)
65	69	6.3	0.999	I02070702BT021	n.i.	1663-1762	CEF-ISA database (unpublished)
60	70	6.1	0.999	origHK023507B038	n.i.	1654-1736	CEF-ISA database (unpublished)
65	76	5.9	0.999	I02090801BT012	n.i.	1643-1744	CEF-ISA database (unpublished)
65	70	5.6	0.999	origHK024007B050	n.i.	1658-1769	CEF-ISA database (unpublished)
65	68	5.5	0.999	HK090107BT014	n.i.	1673-1787	CEF-ISA database (unpublished)
65	68	4.9	0.999	SWIT173	*Picea abies*	1537-1995	ITRDB
65	72	4.3	1.000	I03060801BT006	n.i.	1640-1775	CEF-ISA database (unpublished)
65	71	4.3	1.000	ITA042	*Larix decidua*	1635-1742	ITRDB
65	68	4.3	1.000	ITA024	*Larix decidua*	1520-1990	ITRDB

MNM0833007 (1693-1765)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
73	72	5.5	1.000	I03101001BT064	n.i.	1688-1802	CEF-ISA database (unpublished)
73	73	4.1	1.000	HK020107BT003	n.i.	1669-1782	CEF-ISA database (unpublished)

MNM0833008 (1628-1720)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				Code	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
72	73	6.1	1.000	HK020107BT003	n.i.	1669-1782	CEF-ISA database (unpublished)
72	72	5.6	1.000	I03101001BT064	n.i.	1688-1802	CEF-ISA database (unpublished)

Table 5. Cross-matching of the dendrochronological sequences obtained in the clavichord MNM0419 (unknown attribution, Germany, XVIII century) against published and unpublished reference chronologies (t_H≥4.0 and P≥0.999) [* – description according to the publication reference; n.i. – not identified].

MNM0419001-002-003 (1683-1760)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
78	66	5.0	0.999	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
78	65	4.9	0.999	origHK024007B050	n.i.	1658-1769	CEF-ISA database (unpublished)
78	75	4.2	1.000	I03060801BT006	n.i.	1640-1775	CEF-ISA database (unpublished)
78	66	4.1	0.999	SWIT169	*Picea abies*	1532-1986	ITRDB

Table 6. Cross-matching of the dendrochronological sequences obtained in the harpsichord MNM1096 (Joseph-Pascal Taskin, France, 1782) against published and unpublished reference chronologies (t_H≥4.0 and P≥0.999) [* – description according to the publication reference; n.i. – not identified].

MNM1096w002 (1573-1717)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
74	77	7.2	1.000	IM010II	Abies	1644-1779	HOUBRECHTS (2004)
85	66	5.6	0.999	IM037I	Abies	1605-1689	HOUBRECHTS (2006)
40	81	5.4	1.000	FRAN038	*Abies alba*	1678-1980	ITRDB
140	67	5.1	1.000	I02010102BT061	n.i.	1578-1762	CEF-ISA database (unpublished)
88	71	4.1	1.000	I02130602T091	n.i.	1630-1780	CEF-ISA database (unpublished)
77	67	4.1	0.999	I02160202BT104	n.i.	1641-1789	CEF-ISA database (unpublished)

MNM1096w006 (1637-1709)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
73	72	6.3	1.000	I02010102BT061	n.i.	1578-1762	CEF-ISA database (unpublished)
66	76	5.0	1.000	IM010II	Abies	1644-1779	HOUBRECHTS (2004)
71	74	4.5	1.000	I03090801BT034	n.i.	1581-1707	CEF-ISA database (unpublished)
32	81	4.2	1.000	FRAN038	*Abies alba*	1678-1980	ITRDB

MNM1096w010 (1643-1686)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
44	78	6.6	1.000	I02010102BT061	n.i.	1578-1762	CEF-ISA database (unpublished)
44	74	5.6	0.999	IM037I	Abies	1605-1689	HOUBRECHTS (2006)
43	80	5.5	1.000	IM010II	Abies	1644-1779	HOUBRECHTS (2004)
44	74	4.6	0.999	IM006I	Abies?	1642-1737	ITRDB
44	73	4.1	0.999	origHK020102B040	n.i.	1577-1686	CEF-ISA database (unpublished)

MNM1096w003-004-005-007-009 (1642-1764)							
				CHRONOLOGY DESCRIPTION			
OVERLAP (YEARS)	Glk (%)	t_H	P	CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
121	76	9.5	1.000	IM010II	Abies	1644-1779	HOUBRECHTS (2004)
121	68	8.8	1.000	I02010102BT061	n.i.	1578-1762	CEF-ISA database (unpublished)
96	72	6.6	1.000	IM006I	Abies?	1642-1737	HOUBRECHTS (2004)
123	63	4.8	0.999	I02160202BT104	n.i.	1641-1789	CEF-ISA database (unpublished)

MNM1096w003-004-005-007-009 (1642-1764)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
49	75	4.6	1.000	I03111001T066	n.i.	1545-1690	CEF-ISA database (unpublished)
86	67	4.4	0.999	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)
57	70	4.3	0.999	I03090801BT024	n.i.	1574-1698	CEF-ISA database (unpublished)
123	65	4.3	1.000	I02130602BT092	n.i.	1630-1780	CEF-ISA database (unpublished)
119	65	4.0	0.999	IM020I	Picea	1646-1813	HOUBRECHTS (2004)

MNM1096s005-006-007 (1543-1625)							
OVERLAP (YEARS)	Glk (%)	t_H	P	CHRONOLOGY DESCRIPTION			
				CODE	WOOD SPECIES*	SPANNING	PUBLICATION REFERENCE
83	73	6.3	1.000	I03010802BT058	n.i.	1458-1671	CEF-ISA database (unpublished)
83	68	6.3	0.999	IM017III	Picea	1474-1820	HOUBRECHTS (2004)
69	72	5.9	1.000	GuA23m	*Picea abies*	1557-1717	ITRDB
77	70	5.2	1.000	I03010602BT078	n.i.	1549-1727	CEF-ISA database (unpublished)