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ORIGINAL ARTICLE

Dendrochronological analysis of bowed and plucked instruments from the San Pietro a Majella Conservatory, Naples

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Abstract

The Museo Storico Musicale of the San Pietro a Majella Conservatory of Music in Naples owns a collection of over 200 musical instruments of considerable historical importance. Within the collection, 30 bowed and plucked instruments representative of the Neapolitan violin-making tradition were analysed dendrochronologically to date them, estimate the provenance of the wood and investigate the instruments' construction characteristics. The values of the statistical cross-dating tests were generally high and allowed 26 instruments to be dated. In all but one case, the dates were consistent with those of the catalogue. From the perspective of wood selection, we noted an unusual use of very old spruce wood, well beyond simple seasoning. The construction technique of the soundboard and other characteristics show good similarities with instruments analysed in other Italian collections. Thus, even in Neapolitan instruments, the growth rings are smaller in small instruments and larger in cellos or double basses. In conclusion, the Neapolitan violin-making school has shown great care in the choice of wood, most coming from regions as far away as Germany or Switzerland, thus confirming the existence of an active large-scale trade in wood for the production of musical instruments.

KEYWORDS

Conservatorio di San Pietro a Majella, dendrochronology, dendroprovenancing, musical instruments, Naples, Neapolitan lutherie, violin

INTRODUCTION

Towards the end of the 16th century, many luthiers migrated from Füssen in Bavaria to Italian cities, including Naples, Venice, Florence and Rome (Sisto, 2010a). Füssen was an important centre for the production of musical instruments and home to Europe's oldest luthiers' guild with strict rules dating back to 1562. The migration of German craftsmen to Italy was a consequence of these oppressive statutory constraints. Naples, which together with Venice was one of the musical capitals of the time, attracted a large number of foreign luthiers, mainly lute- and guitar-makers, who helped the local craftsmen satisfy the great demand for musical instruments at the court of the Spanish viceroy. Many German luthiers were working in Naples at the beginning of the 17th century, including Magnus Lang I (Bernabei et al., 2018), Matthäus Selloß, Jacob Stadler and Georg Kayser, as shown by the many archived documents and museum objects (Sisto, 2010b). The coexistence of German and Neapolitan violin-makers produced a flourishing reciprocal exchange, which resulted in a characteristic style that retained a distinctive imprint (Sisto, 2010b).

With regard to stringed instruments, Alessandro Gagliano (1660–1728) can be considered the founder of the Neapolitan school. He was certainly influenced by the Füssen school and started a veritable dynasty that dominated the Neapolitan scene for more than a century and a half (Eckstein, 2020). Late nineteenth-century historiography described Alessandro's stay in Cremona as an apprentice in Antonio Stradivari's workshop (Farga, 1942) or in that of Nicola Amati (Della Corte & Gatti, 1956). However, recent archival research confirms that this luthier never left Naples, rather training in music as well as lutherie in the viceroyal capital (Olivieri, 2012; Sisto, 2020). In addition to the Gagliano family, the Vinaccia, Fabricatore and Ventapane families were active in Naples. After the unification of Italy, the violin-maker Vincenzo Postiglione (Sisto, 2021) and the Calace family—a dynasty from the viceroyal territories and already active in Naples since the end of the 18th century—played a very important role.

Woods for soundboards

Nothing is known about the origin of the wood used in the Neapolitan classical school. Many modern-day scholars and luthiers believe that the wood used to make musical instruments in the past was found locally, although there are no written references to this. However, Norway spruce (*Picea abies* Karst.) does not grow wild in the Neapolitan area. This species is definitely prevalent in the construction of soundboards and its natural range of distribution is limited to the Alps extending southwards only in two small nuclei in the northern Apennines. Consequently, spruce for the soundboard had to come from the Alps or even further north; otherwise, if local, the wood for the soundboard had to be silver fir (*Abies alba* Mill.), similar to spruce but much less frequently used in violin-making.

Here, instruments from the Conservatorio di San Pietro a Majella were analysed using dendrochronology (the science of tree ring growth analysis over time) to date the soundboard and shed light on the various constructive aspects. The date obtained by dendrochronology is called *terminus post quem* (TPQ) and refers to the last (i.e., the most recent) visible ring on the soundboard produced when the tree was still alive. The TPQ therefore does not coincide with the year that the instrument was made, but rather represents a chronological hinge before which the soundboard cannot have been made. The number of years that separates the dendrochronological dating from the date of construction of the instrument, called Δt, includes the time that goes from the felling the tree, harvesting wood, seasoning plus a number of years corresponding to the rings removed when the board was trimmed. Traditionally, only a few rings near the bark were removed during the manufacture of an instrument and, if a piece of timber was larger than necessary, the inner (older) part was removed, not the outer one (Bernabei et al., 2010). The Δt therefore can estimate the seasoning time, which is of crucial importance when studying prior construction techniques.

Dendrochronology can estimate the origin of the timber comparing the growth rings of an instrument with reference chronologies from different geographical areas (Bonde et al., 1997). The dendroprovenance theory is based on the following concepts. When comparing a dated time-series of unknown provenance with a suitable number of reference chronologies, the correlation value will be highest with that chronology whose tree-ring growth was influenced by environmental factors most similar to the single time-series. In theory, therefore, and other conditions being equal, the higher the correlation value between dendrochronological curves, the closer the distance between the sites where the trees grew (Bernabei & Bontadi, 2011).

The ecological conditions under which trees grow are important. These may, however, vary considerably even in neighbouring sites. Altitude, for example, markedly impacts correlations between tree ring series. However, with an adequate number of geographically and spatially distributed reference chronologies that represent many different ecological criteria, high correlations can be identified and can identify the wood's provenance. Today, numerous reference chronologies are available from the traditional sites of resonance wood production. Some of them are freely available from the website of the International Tree Ring Data Bank (ITRDB) (http://www.ncdc.noaa.gov/paleo/treering.html).

Dendrochronology can also help identify musical instruments and link them to a particular violin-maker (Bernabei, 2021). The logic behind this is that luthiers, today as in the past, carefully consider the characteristics of the wood they use for making their instruments. When choosing wood for the soundboard, they pay close attention to its acoustic properties, possible defects and aesthetics. Once they have found the right piece, they will continue to use timber from the same source, if possible sometimes even from the same tree. This is common in the instruments made by many famous violin-makers. One of them was Stradivari (Topham & McCormick, 2000). Even though it is difficult to date his instruments against already published reference chronologies—mainly because, as yet, we do not know with certainty where the wood for Stradivari's instruments came from—the relative dating of his instruments when compared one against another is often highly significant.

Lastly, dendrochronological analysis can also provide information about the construction technique used in the soundboard (Bernabei & Čufar, 2018). First, the number of elements that make up the soundboard is determined and the direction of tree ring growths is identified for each side. The mean tree-ring width and the relative standard deviation (RSD) are then determined: these parameters characterize the instruments from both a technical and an acoustic point of view. With the same dimensions, spruce wood with smaller growth rings vibrates longer and with sharper tones than wood with larger growth rings (Ille, 1976), while wood with large growth rings has lower and deeper sounds (Bariska, 1996; Blossfeld et al., 1962). The standard deviation (SD), which expresses the dispersion of the data around the mean, is an index of the regularity of ring growth. In general, spruce wood with irregular tree rings is less suitable for the manufacture of soundboards because it is believed to lead to inferior acoustic properties (Buksnowitz et al., 2007). Indeed, it has been observed that wood with sudden variations in the ring pattern has less homogeneous and predictable acoustic properties (cf. Zieger, 1960). The higher the SD of instruments such as the cello and double bass may simply be due to the larger amount of wood required for their manufacture (Bernabei et al., 2010).

This work aims to shed light on the Neapolitan violin-making school. The objectives of this work are multifold: (1) to date the instruments via the identification of the TPQ; (2) to identify the number of years that separate the dendrochronological dating from the date of construction of the instruments (Δt); (3) to estimate the origin of the wood used for the soundboards; and (4) to identify the main technical characteristics of the instruments. The resulting data will make it possible to characterize Neapolitan violin-making production and compare it with that of other schools, such as those of Central and Northern Italy, thus identifying differences or affinities.

MATERIALS AND METHODS

Materials

The collection of the Conservatorio di San Pietro a Majella includes over 200 musical instruments of historical importance, many of them exemplary of the Neapolitan construction tradition. The collection includes the “vis-à-vis”, a piano and a harpsichord mounted in the same cabinet with the keyboards facing each other made by Johann Andreas Stein, and the harp by Stradivari; instruments by Cimarosa, Paisiello, Mercadante, Martucci and Rossomandi; plucked instruments that belonged to Queen Margherita of Savoy, the dancer Amina Boschetti and the singer Barbara Marchisio; and fine harps and psalteries and woodwinds that demonstrate the achievements and refinements of the many Neapolitan craftsmen of the 19th century (Sisto, 2010a). The musical instruments analysed here were selected on the basis of their representativeness and historical relevance for the Neapolitan violin-making school. The luthiers considered were the Gagliano family (10 instruments), Vincenzo Postiglione (10), the Calace family (two), as well as Ventapane, Vinaccia, De Blosji and De Falco (one each). In addition to the Neapolitans, instruments by Italian violin-makers from other regions (Mariani, Zanti, Klotz and Goffriller) were also analysed. Thus, seven violins, six violas, two violas da gamba, two violas d’amore, nine cellos, three mandolins and one double bass were analysed for a total of 30 instruments (Table 1).

Methods

The growth rings on the soundboards were measured with different techniques and devices depending on the size of the instruments (Blossfeld et al., 1962). Smaller hand instruments were studied with a portable dendrochronograph equipped with a stereomicroscope and a micrometer table (LINTAB, RinnTech, Germany). The data were collected with the TSAPWin program and processed and analysed with the TSAPWin, PAST4 and PAST5 programs. Larger instruments such as cellos and double basses were analysed with the video time table (VTT) (Vienna Institute of Archaeological Science) (Bernabei et al., 2010); this device integrates a portable dendrochronograph with a high-resolution digital camera all connected to a computer that displays the data using the PAST4 program (Figure 1). Both devices can measure wood rings *in situ* in a completely non-invasive way and can immediately verify the quality of the sampling.

Sampling scheme

On average, four dendrochronological series were constructed for each musical instrument: two on each side of the soundboard repeated at different heights in order to measure the greatest number of rings (Bernabei et al., 2010). This approach also avoids errors due to possible deformation of the grain. If anomalies were detected, then the measurements were repeated. Thus, up to nine measurements were taken for some instruments. The sampling scheme was adapted to the characteristics of the instruments. The number of elements making up the soundboard was considered, that is, one, two or more elements. The number of measurements increased or decreased accordingly. Sampling with devices for direct microscopic observation (LINTAB and

TABLE 1 Stringed instruments of the Conservatorio di Musica San Pietro a Majella in Naples analysed through dendrochronology

No.	*Cat. no.*	*Musical instrument*	*Label date*	*Origin*	*Violin-maker*
1	3.57	Violin		Mantua	Alessandro Zanti
2	5.47	Mandolin	1889	Naples	Gennaro and Achille Vinaccia
3	5.49	Mandolin	1901	Naples	Fratelli Calace
4	5.50	Mandolin	1906	Naples	Fratelli De Falco
5	5.61	Violin	1768	Naples	Ferdinando Gagliano
6	5.62	Violin	18..	Naples	Raffaele and Antonio Gagliano
7	5.63	Violin piccolo	1845	Naples	Raffaele and Antonio Gagliano
8	5.64	Violin	1890	Naples	Vincenzo Postiglione
9	5.65	Violin	1916	Naples	Raffaele Calace
10	5.66	Violin	Late 18th century	Mittenwald (Germany)	Fam. Klotz
11	5.77	Viola	1772	Naples	Giuseppe Gagliano
12	5.78	Viola	1806	Naples	Giovanni Gagliano
13	5.79	Viola	1881	Naples	Vincenzo Postiglione
14	5.80	Viola	1882	Naples	Vincenzo Postiglione
15	5.81	Viola	1890	Naples	Vincenzo Postiglione
16	5.82	Viola	1886	Naples	Nicolaus De Blosji
17	5.84	Viola d'amore	1888	Naples	Vincenzo Postiglione
18	5.85	Viola d'amore	1890	Naples	Vincenzo Postiglione
19	5.86	Viola da Gamba	1646	Pesaro	Antonio Mariani
20	5.87	Viola da Gamba	1874	Naples	Vincenzo Postiglione
21	5.89	Cello	1898	Naples	Vincenzo Postiglione
22	5.90	Cello	1856	Naples	Raffaele and Antonio Gagliano
23	5.91	Cello	1857	Naples	Raffaele and Antonio Gagliano
24	5.92	Cello	1857	Naples	Raffaele and Antonio Gagliano
25	5.93	Cello	1866	Naples	Raffaele and Antonio Gagliano
26	5.95	Cello	1873	Naples	Vincenzo Gagliano
27	5.96	Cello piccolo	1871	Naples	Vincenzo Gagliano
28	5.100	Cello piccolo		Naples	Lorenzo Ventapane
29	5.102	Cello		Naples	Vincenzo Postiglione
30	5.117	Double bass	1895	Naples	Vincenzo Postiglione

'No.' is the progressive number; 'Cat. no.' is the repertory number as given in the catalogue of musical instruments (Sisto, 2010a). 'Label date' is the date given on the label or deduced from documents.

VTT) was always accompanied by a photographic survey of the soundboards. The digital photographic image facilitated a constant comparison of the tree-ring series on the soundboard surfaces.

FIGURE 1 Sampling practices: (top left) portable dendrochronograph with stereomicroscope. The other images refer to the video time table (VTT) during the measurement of the tree-rings on a cello without removing the instrument from its case.

Cross-dating

Each series was compared visually and statistically with different reference chronologies. The reference chronologies are already published (Bernabei & Bontadi, 2011) and valid for conifers from the Alps and Central Europe. In addition, mean series based on musical instruments (MMS), tree ring series of individual musical instruments including those from the Cherubini collection in Florence (AMC01) (Bernabei et al., 2010) and the Carlo Schmidl Museum in Trieste (TMC) (Bernabei et al., 2017) were used for comparison. Dating was only considered reliable when the same year was confirmed with multiple reference chronologies.

The tests considered in the statistical cross-dating were:

- T_{BP} and T_{HO}: Student's *t*-test adapted to time-series analysis from Baillie and Pilcher (1973) and Hollstein (1980), respectively.
- Glk: Gleichläufigkeit and its value Gleichläufigkweitswert discussed by Eckstein and Bauch (1969). In comparing two chronologies in a given time interval, Glk represents the percentage of the agreement between the sign of the growth from one year to another.
- Statistical significance of Glk at 95.0%, 99.0% and 99.9% confidence were indicated by *, ** and ***, respectively.
- Overlap: number of growth rings compared. Dendrochronology is based on statistical correlations and thus there is more reliability with more data. Although there is no universally accepted minimum threshold, it is not wise to go below at least 40 rings.

Three categories of dating reliability were created based on the above-mentioned statistical considerations to facilitate the data interpretation. Thus, the following were considered for each instrument: (1) the length of the tree-ring series (overlap); (2) the value of the statistical tests; and (3) the number of reference series confirming the same year. Consequently, the instrument series were divided into: (1) undated (< 50 rings; *t*-tests < 4; ≤ 1 reference chronology); (2) moderately reliable dating (50 > rings < 70; 4 > *t*-tests < 5; 2 reference chronologies); and (3) certainty dated (> 70 rings; > 6 *t*-tests; > 2 chronologies).

RESULTS

A total of 30 musical instruments were analysed, 103 dendrochronological series were constructed and 9644 rings were measured (Table 2). Four instruments were not datable: the mandolin of the Calace brothers, catalogue number CN 5.49 (Sisto, 2010a), where the tree rings are not sufficiently visible and measurable; and the violin of Raffaele Calace (5.65), on which only 51 rings are visible (Table 2). For the other two undatable instruments, Raffaele and Antonio Gagliano's violin (5.62) and Giuseppe Gagliano's viola (5.77), the statistical correlations were not high enough (*t*-values < 4). In general, statistical test values were in line with those found in other collections (Bernabei et al., 2010, 2017). The means of cross-dating are: $T_{BP} = 5.53$, $T_{HO} = 5.75$ and Glk = 67.71, with a Glk significance of ≥ 95%, in 20 cases 99.9%. The highest correlations (Table 2) were found when comparing the average tree-ring series derived from musical instruments (MMS or AMC01) rather than non-instruments reference chronologies. Data useful for technical/acoustic characterization were collected for each instrument (Tables 2 and 3). The number and arrangement of the parts of each individual soundboard were determined. The mean Δt—the distance in number of years between the date on the label and that identified by dendrochronology—is 37.

DISCUSSION

The dendrochronological analysis of Neapolitan musical instruments was fairly successful, allowing the dating of 26 instruments out of 30. Apart from the four undated instruments, eight showed dates of intermediate reliability and 18 were dated with certainty (shown in bold in Table 2). Violin CN 5.61, attributed to Ferdinando Gagliano according to the instrument label, was dated by dendrochronology to 1883 (TPQ), over 115 years after the label date (1768). This result confirms the hypothesis of Claude Lebet, who questioned the authorship of this instrument in 2001, attributing it to a Bohemian manufacturer of the late 19th century. The dendrochronological dates of the other instruments are always compatible with those on the label or in the catalogue.

TABLE 2 Dendrochronological results

No.	*Cat. no.*	*Species*	*Tree rings*	*Dendrochronological dating*	T_{BP}	T_{HO}	*Glk*	Δt	*Reference chronology*
1	**3.57**	**Spruce**	**124**	**1693**	**5.91**	**6.21**	**70.5*** **		**Kerner**
2	**5.47**	**Spruce**	**66**	**1819**	**5.47**	**4.85**	**69.7*** **	**70**	**Kerner**
3	5.49		0						
4	5.50	Spruce	80	1701	4.44	5.48	63.1**	205	AMC01
5	**5.61**	**Spruce**	**82**	**1883**	**5.09**	**5.80**	**67.1*** **	**−115**	**MMS**
6	5.62		71						
7	5.63	Spruce	143	1831	4.47	4.91	65.3***	14	AMC01
8	5.64	Spruce	73	1876	4.19	4.63	71.4***	14	MMS
9	5.65		51						
10	**5.66**	**Spruce**	**226**	**1799**	**5.44**	**5.75**	**64.5** **		**MMS**
11	5.77		68						
12	5.78	Spruce	121	1768	4.99	6.04	70.2***	38	PIABms
13	**5.79**	**Spruce**	**92**	**1849**	**8.51**	**9.27**	**76.6*** **	**32**	**germ040**
14	**5.80**	**Spruce**	**124**	**1850**	**7.24**	**5.72**	**65.8*** **	**32**	**germ040**
15	**5.81**	**Spruce**	**99**	**1880**	**6.89**	**7.01**	**68.0*** **	**10**	**germ040**
16	**5.82**	**Spruce**	**98**	**1780**	**5.24**	**6.18**	**67.3*** **	**106**	**AMC01**
17	5.84	Spruce	117	1843	4.37	4.42	68.3**	45	germ4
18	**5.85**	**Spruce**	**94**	**1886**	**7.33**	**7.46**	**70.8*** **	**4**	**germ12**
19	**5.86**	**Spruce**	**174**	**1641**	**6.45**	**6.57**	**60.6** **	**5**	**MMS**
20	**5.87**	**Spruce**	**79**	**1833**	**6.05**	**6.43**	**71.2*** **	**41**	**AMC01**
21	**5.89**	**Spruce**	**145**	**1888**	**5.94**	**6.19**	**62.1** **	**10**	**germ14**
22	5.90	Spruce	118	1851	4.02	4.28	62.8**	5	MMS

TABLE 2 (Continued)

No.	*Cat. no.*	*Species*	*Tree rings*	*Dendrochronological dating*	T_{BP}	T_{HO}	*Glk*	Δt	*Reference chronology*
23	5.91	Silver fir	82	1848	4.70	4.42	74.4***	9	aust023
24	**5.92**	**Silver fir**	**105**	**1840**	**5.86**	**5.33**	**70.2*** **	**17**	**aust023**
25	**5.93**	**Silver fir**	**182**	**1843**	**5.12**	**5.36**	**66.0*** **	**23**	**aust023**
26	**5.95**	**Silver fir**	**101/169**	**A1852/B1828**	**6.48/5.06**	**7.34/5.46**	**65.40/60.40***/* **		**aust023**
27	**5.96**	**Spruce**	**168**	**1852**	**5.92**	**5.66**	**63.30*** **	**19**	**germ040**
28	**5.100**	**Silver fir**	**83/109**	**A1820/B1628**	**5.89/6.57**	**7.41/7.29**	**69.90/68.10***/*** **		**aust023**
29	5.102	Silver fir	93	1878	4.53	5.08	68.7***		swit123
30	**5.117**	**Spruce**	**155**	**1857**	**5.69**	**5.31**	**60.0** **	**38**	**swit173**

Entries shown in bold are instruments dated with certainty. Duplicate results refer to instruments whose soundboard parts do not correlate and have different dates. The species was attributed through analysis of anatomical features and correlation with reference chronologies. The column ‘Reference chronology’ shows the reference chronologies listed in Table 4 to which the statistical tests (T_{BP}, T_{HO} and Glk) refer.

TABLE 3 Dendrochronological parameters of the violins and violas time-series grouped according to their geographical origin

	Naples Conservatory	*Florence Cherubini Collection*	*Trieste Carlo Schmidl Museum*	*Europe non-instrument chronologies*
Mean tree-ring width (0.01 mm)	127.4	127	120.	149.0
SD (0.01 mm)	39.5	27.24	19.3	44.4
Autocorrelation (first order)	0.72	0.85	0.68	0.70
Mean sensitivity	0.14	0.10	0.12	014

The first-order autocorrelation coefficient calculates the correlation between a time series and the same time series lagged by one year. Mean sensitivity is the mean percentage change from each measured yearly ring value to the next and describes the variability in a tree ring series (Kaennel & Schweingruber, 1995).

The De Falco brothers' mandolin (5.50), dated 1906, was made from a much older wood, dated with certainty to 1701. The same was found, although less pronounced, for Nicolaus De Blosji's viola (5.82) and Gennaro and Achille Vinaccia's mandolin (5.47) (Table 2). These results demonstrate the luthiers' intention to make soundboards with very old wood, far beyond simple seasoning. This technical choice lies in the belief that the use of very old wood can give the instrument superior characteristics in terms of sound quality and dimensional stability (Obataya et al., 2020). It was already known that some luthiers in the past had experimented with the use of very old wood. For example, the French luthier Jean-Baptiste Vuillaume (1798–1875) often used wood from old beams or old furniture for the construction of his instruments (Millant, 1972) and it is still widely believed that the wood most suitable for making musical instruments should have a very long, preferably old, seasoning period (Obataya et al., 2020). However, this belief is not confirmed by scientific analyses of classical instruments: makers, for example, Giuseppe Guarneri, often used wood with only two or three years of seasoning (Bernabei, 2021). If we exclude the three instruments mentioned above, then the mean Δt ranges from 37 to 21 years (Table 2, which is perfectly consistent with other Italian collections (Bernabei et al., 2010, 2017).

In three instruments (the cellos of Vincenzo Gagliano (5.95) and Lorenzo Ventapane (5.100) as well as Giuseppe Gagliano's viola), the two sides of the soundboard are made of wood that does not belong to the same tree trunk. In Ventapane's case, the dates of the two sides are quite far apart. In 20 instruments out of 30, the direction of growth of the annual rings in the two parts of the soundboard is towards the centre of the instrument according to traditional construction procedures. Three instruments have the soundboard made of a single element: the small violin of Raffaele and Antonio Gagliano (5.63), the viola da gamba of Antonio Mariani (5.86) and the violin from the Klotz family (5.66). Finally, three cellos (5.91, 5.95 and 5.100) and a mandolin (5.50) both had parts facing the same direction: in two cases it is towards the bass and in two cases it is towards the treble side.

If we consider only violins and violas, the mean tree ring width is 1.27 mm and agrees exactly with instruments from the Cherubini Collection (instruments from Central Italy) (Table 3). This similarity is certainly not accidental and highlights the importance of tree ring width as a decisive factor in the choice of wood for soundboard construction. The SD is slightly higher in Neapolitan instruments, which indicates a greater variability in tree ring width in the timber used by Neapolitans violin-makers. Similar results are also seen in comparison with instruments from the Carlo Schmidl Museum in Trieste, Italy, which includes instruments made by violin-makers from North-eastern Italy (Table 3). Lastly, even in Neapolitan instruments, the growth ring widths are smaller in small instruments and larger in cellos or double basses, thus confirming the relationship between large rings and low tones (Bucur, 2006).

Nine instruments show higher correlations with the mean tree-ring series derived from musical instruments than with the non-instruments' reference chronologies (Table 4 and Figure 2).

This confirms that, in general, the wood used for making soundboards has very similar growth characteristics. Indeed, most samples are made from the same tree species (Norway spruce), which comes from a limited geographical region (the Alps and a few other areas in Central Europe). Wood with excessively large or small rings is avoided, as is wood with widely varying ring sizes. Finally, defects such as grain deviations and pronounced knots as well as reaction wood are carefully avoided, while wood with a slightly lower density than usual is generally preferred (Buksnowitz, 2006). These characteristics are typically found in the wood of trees grown in high elevation sites and characterize what is known as 'resonance wood' (Buksnowitz, 2006). As a consequence, dendrochronological analysis of resonance wood usually shows a higher reliability in cross-dating (Figure 2), compared with other applications of dendrochronology such as dating the wooden structure of historical buildings, wooden sculptures or panel paintings (Bernabei, 2021).

In at least six instruments, particularly the cellos (Table 2), the highest correlations were with reference chronologies of silver fir (*Abies alba* Mill.), thus suggesting the probable use of

TABLE 4 Comparison of the mean tree ring series of Neapolitan instruments (NMC) with the most effective reference chronologies

Reference chronology	*Region*	*Species*	*Period*	*Length (years)*	T_{BP}	T_{HO}	*Glk*
MMS	Europe	Spruce plus silver fir	1339–2009	621	**13.8**	**14.4**	**73.1*** **
AMC01	Central Italy	Spruce plus silver fir	1359–1953	595	**11.4**	**11.8**	**70.6*** **
germ5	Bayerischer Wald (Germany)	Silver fir	1541–1963	314	8.7	9.3	63.8***
germ4	Bayerischer Wald (Germany)	Silver fir	1541–1963	314	8.4	9.1	65.7***
MST	Trieste (Italy)	Spruce	1600–1994	395	**7.8**	**8.2**	**64.6*** **
aust023	Central Europe	Silver fir	820–1961	1142	6.9	7.7	65.4***
Kerner	Ötztal (Tyrol, Austria)	Spruce	1276–1974	699	6.7	7.4	60.6***
Czec	Beskid Mountains (Czech Republic)	Silver fir	1701–1943	243	6.5	6.6	65.6***
swit177	Lauen (Switzerland)	Spruce	982–1875	894	6.3	6.7	64.4***
PIABms	Trentino (Italy)	Spruce	-984–2019	3003	6.1	6.6	58.3***
swit180	Brigels GR Scatlé (Switzerland)	Spruce	1750–1999	250	5.7	5.9	63.9***
Paneveggio	Trentino (Italy)	Spruce	1583–2009	427	5.6	5.8	57.9***
germ14	Bayerischer Wald (Germany)	Spruce	1622–1953	332	5.3	5.6	60.8***
swit166	Simmenthal (Switzerland)	Spruce	1690–1986	297	5.3	4.9	62.2***
germ039	Hochzell (Germany)	Spruce	1812–1996	185	5.2	5.5	68.0***
germ12	Kreuth (Germany)	Silver fir	1586–1961	376	4.9	4.9	60.3***
swit173	Obersaxen (Switzerland)	Spruce	1537–1995	459	4.9	4.9	66.0***
ital025	Fodara Vedla Alm (Italy)	Spruce	1598–1990	393	4.7	4.6	55.4*
Ital 007	Cortina d'Ampezzo (Italy)	Spruce	1660–1975	316	4.4	4.5	56.6*
germ040	Falkenstein (Germany)	Spruce	1540–1995	456	4.2	4.3	62.2***
swit181	Davos (Switzerland)	Spruce	1668–1999	332	4.2	4.1	53.9

All instruments of non-local origin were excluded from the NMC such as the violins Zanti (Mantua) and Klotz (Tyrol) as well as the viola da Gamba by Mariani (Pesaro). Reference chronologies based solely on musical instruments are in bold. Most of the reference chronologies are freely downloadable from the ITRDB site (international tree ring Data Base, https://www.ncei.noaa.gov/products/paleoclimatology/tree-ring). Non-ITRDB chronologies: MMS, based on 142 musical instruments, unpublished; Sieb.-Kerner, Siebenlist-Kerner (1984); PIABms, Trentino spruce chronology (Bernabei, Bontadi, & Nicolussi, 2018), AMC01 (Bernabei et al., 2010), Paneveggio (Bernabei & Bontadi, 2011) and MST (Bernabei et al., 2017)

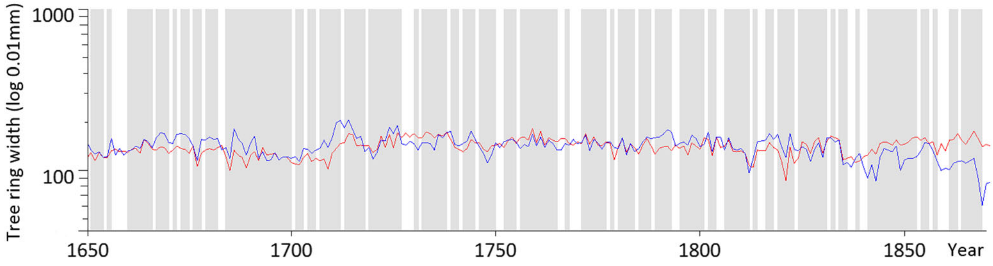

FIGURE 2 Visual cross-matching of the mean tree ring series of a Neapolitan musical instrument (in red) and the musical instruments reference chronology (mean series based on musical instruments—MMS) from 1650 to 1850. $T_{BP} = 13.8$, $T_{HO} = 14.4$ and Glk = 73.1***. The grey areas show where the time-series have the same sign of growth (Gleichläufigkeit significant).

fir rather than spruce. The two wood species are difficult to distinguish visually in artefacts such as the musical instruments, which have been varnished and subjected to the action of time. Furthermore, it is difficult to make correct microscopic identification on musical instruments without damaging the soundboards (Fioravanti et al., 2017). This left some uncertainty in identification even if the use of silver fir instead of spruce for soundboards construction has been already reported (Bernabei & Bontadi, 2011). In any case, even if silver fir were used, it was from the Alps and not from the Apennines, as shown by the statistical comparison (germ4, germ5 and others; Table 4).

Finally, seven of the nine instruments made by Vincenzo Postiglione have soundboards made of wood from beyond the Italian Alps including five (cod. 5.81, 5.79, 5.80, 5.84 and 5.85) with spruce from Germany and two (cod. 5.102, 5.117) with spruce from Switzerland (Table 2). Considering the large distances involved, our findings confirm the existence of a trade dedicated to the production of musical instruments, active on a European scale, able of supplying violin-makers all over Europe with the best quality resonance wood.

CONCLUSIONS

The bowed and plucked stringed instruments of the Conservatorio di San Pietro a Majella represent an unrepeatable opportunity to deepen research into the Naples violin-making school of the 'classical' period, that is, the second half of the 18th to the early 20th centuries. Dendrochronological analysis dated 26 instruments out of 30 and deepened our knowledge of some technical–constructive characteristics of the soundboards including the most probable origins of the resonance woods. From the dating perspective, all instruments except one were compatible with dates reported on the label or in the catalogue. Some examples were found in which violin-makers used very old wood beyond the normal practice of seasoning. The arrangement and number of elements of the soundboards, the mean tree-ring widths and the RSD are consistent with other studies on Italian musical instruments. Many of the instruments are made of wood from abroad, thus confirming the existence of an active large-scale trade for the production of musical instruments. In summary, the Neapolitan school was very lively and used wood from various geographical regions. This does not exclude the use of silver fir rather than spruce while maintaining great attention to wood quality.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Baillie, M. G. L., & Pilcher, J. R. (1973). A simple cross-dating program for tree-ring research. *Tree-Ring Bulletin*, *33*, 7–14.

Bariska, M. (1996). Zur Geschichte der Holzverwendung beim Musikinstrumentenbau. *Schweizerische Zeitschrift für Forstwesen*, *147*(9), 683–693.

Bernabei, M. (2021). A Guarneri violin in the attic: The power of dendrochronology for analysing musical instruments. *Heritage Science*, *9*, 47. https://doi.org/10.1186/s40494-021-00521-4

Bernabei, M., & Bontadi, J. (2011). Determining the resonance wood provenance of stringed instruments from the Cherubini conservatory collection in Florence, Italy. *Journal of Cultural Heritage*, *12*(2), 196–204. https://doi.org/10.1016/j.culher.2010.12.001

Bernabei, M., Bontadi, J., Čufar, K., & Baici, A. (2017). Dendrochronological investigation of the bowed string instruments at the theatre museum Carlo Schmidl in Trieste. *Journal of Cultural Heritage*, *27S*, S55–S62. https://doi.org/10.1016/j.culher.2016.11.010

Bernabei, M., Bontadi, J., & Nicolussi, K. (2018). Observations on Holocene subfossil tree remains from high-elevation sites in the Italian Alps. *The Holocene*, *28*(12), 2017–2027. https://doi.org/10.1177/0959683618798149

Bernabei, M., Bontadi, J., & Rossi Rognoni, G. (2010). A dendrochronological investigation of stringed instruments from the collection of the Cherubini conservatory in Florence, Italy. *Journal of Archaeological Science*, *37*, 192–200. https://doi.org/10.1016/j.jas.2009.09.031

Bernabei, M., & Čufar, K. (2018). Methods of Dendrochronology for Musical Instruments. In A. Pérez M & E. Marconi (Eds.), *Wooden musical instruments. Different forms of knowledge. Book of end of WoodMusICK COST action FP1302* (pp. 67–80). Cité de la Musique.

Bernabei, M., Macchioni, N., Ricetti, V. M., & Sisto, L. (2018). A multi-analytical study on the mango Longo guitar, a baroque masterpiece from the Castello Sforzesco, Milan, Italy. *Journal of Cultural Heritage*, *34*, 69–73. https://doi.org/10.1016/j.culher.2018.04.005

Blossfeld, O., Haasemann, W., & Haller, K. (1962). Klangholz und Klangholzsortierung. *Deutsche Sozialistische Forstwirtschaft*, *12*, 140–145.

Bonde, N., Tyers, I., & Wazny, T. (1997). Where does the timber come from? Dendrochronological evidence of the timber trade in Northern Europe. In A. Sinclair, E. Slater, & J. Gowlett (Eds.), *Archaeological sciences 1995* (pp. 201–204). Oxbow Books.

Bucur, V. (2006). *Acoustics of wood* (Second ed.). Springer Series in Wood Sciences. (p. 393). Springer-Verlag. https://doi.org/10.1007/3-540-30594-7

Buksnowitz, C. (2006). *Resonance wood of Picea abies*. Doctoral thesis, Institute of Wood Science and Technology, BOKU, Vienna.

Buksnowitz, C., Teischinger, A., Müller, U., Pahler, A., & Evans, R. (2007). Resonance wood [Picea abies (L.) karst.]-evaluation and prediction of violin makers quality-grading. *The Journal of the Acoustical Society of America*, *121*(4), 2384–2395. https://doi.org/10.1121/1.2434756

Della Corte, A., & Gatti, G. M. (1956). *Dizionario di musica* (p. 243). Torino, Paravia.

Eckstein, D., & Bauch, J. (1969). Beitrag zur Rationalisierung eines dendrochronologischenVerfahrens und zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt*, *88*, 230–250. https://doi.org/10.1007/BF02741777

Eckstein, R. (2020). Alessandro Gagliano. *The Strad*, *131*(1564), 55–57.

Farga, F. (1942). *Storia del violino* (p. 336). Corbaccio.

Fioravanti, M., Di Giulio, G., & Signorini, G. (2017). A non-invasive approach to identifying wood species in historical musical instruments. *Journal of Cultural Heritage*, *27*, S70–S77. https://doi.org/10.1016/j.culher.2016.05.012

Hollstein, E. (1980). *Mitteleuropäische Eichenchronologie. Trierer dendrochronologische Forschungen zur Archäologie und Kunstgeschichte* (p. 273). Trierer Grabungen u. Forsch.

Ille, R. (1976). Eigenschaften und Verarbeitung von Fichtenresonanzholz für Meistergeigen (II). *Holztechnologie*, *17*, 32–35.

Kaennel, M., & Schweingruber, F. H. (1995). *Multilingual glossary of dendrochronology* (p. 467). (WSL/FNP). Berne, Stuttgart, Vienna, Haupt Publishers.

Millant, R. (1972). *J.B. Vuillaume, Sa Vie et son Oeuvre*. English Translation by Desmond Hill (Vol. 58 2) (p. 272). W. E. Hill & Sons. 10.2307/928843

Obataya, E., Zeniya, N., & Endo-Ujiie, K. (2020). Effects of seasoning on the vibrational properties of wood for the soundboards of string instruments. *The Journal of the Acoustical Society of America*, *147*(2), 998–1005. https://doi.org/10.1121/10.0000723

Olivieri, G. (2012). The Gagliano: First documents on the Activity of an Italian Family of Violin-Makers in Sleuting the Muses. In K. K. Forney & J. L. Smith (Eds.), *Essays in honor of William Prizer* (pp. 363–376). Pendragon University Press.

Siebenlist-Kerner, V. (1984). Der Aufbau von Jahrringchronologien fur Zirbelkiefer, Larche, und Fichte eines alpinen Hochgebirgstandortes. *Dendrochronologia*, *2*, 9–29.

Sisto, L. (2010a). *Gli strumenti musicali in Dal Segno al Suono. Il Conservatorio di Musica S. Pietro a Majella. Repertorio del patrimonio storico-artistico e degli strumenti musicali* (pp. 197–295). Arte-m.

Sisto, L. (2010b). *I liutai tedeschi a Napoli tra Cinque e Seicento* (p. 224). IISM Istituto Italiano per la storia della musica.

Sisto, L. (2020). *Da Mathias Popeller ai Gagliano*. La nascita della scuola liutaria di Napoli. In D. Fabris (Ed.), *Gli esordi del violoncello a Napoli e in Europa* (pp. 157–182). Cafagna Editore.

Sisto, L. (2021). Vincenzo Postiglione: Fair copies. *The Strad*, *6*, 46–49.

Topham, J., & McCormick, D. (2000). A dendrochronological investigation of stringed instruments of the Cremonese school (1666–1757) including 'the messiah' violin attributed to Antonio Stradivari. *Journal of Archaeological Science*, *27*(3), 183–192. https://doi.org/10.1006/jasc.1999.0516

Zieger, E. (1960). Untersuchungen über äußere Merkmale, Holzeigenschaften und forstgeographische Vorkommen der Resonanzqualitäten bei Fichte und einigen anderen Holzarten. *Mitteilungen Aus der Staatsforstverwaltung Bayerns*, *31*, 285–298.

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