High-precision dating the Akko 1 shipwreck, Israel: wiggle-matching the life and death of a ship into the historical record

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ABSTRACT

The Akko 1 shipwreck is the remains of an eastern Mediterranean naval or auxiliary brig, which was found inside the ancient harbor of Akko, Israel. The shipwreck and finds were recorded underwater, and some of the ship components, along with the majority of the finds, were retrieved and analyzed. A Bayesian dating model, incorporating 14C wiggle-matching of the ship timbers, tree-ring analysis, and 14C dates from short-lived finds, is used to model the ship’s construction and wrecking dates. These new data, combined with the results of archaeological research and available historical records, suggest that the ship was built during the first third of the 19th century as part of Muhammad Ali’s fleet. Akko 1 then possibly plied the eastern Mediterranean under the Egyptian flag during the First Egyptian–Ottoman War in 1831–1833. The wrecking event apparently occurred during the 1840 naval bombardment of Akko. This is the first time that 14C wiggle-matching and Bayesian analyses have been used to date the construction and wrecking of a shipwreck in the southeastern Mediterranean. The results show that Bayesian analysis and 14C wiggle-matching techniques are valuable tools for analyzing the region’s shipwrecks, including those from recent historical periods.

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1. Introduction

1.1. Historical setting

The historic walled port city of Akko (Acre, St. Jean d’Acre, Akka) is located at the northern extremity of Haifa Bay in northern Israel. It has a continuous settlement history from the Early Bronze Age to the modern era, serving as an important naval and trading port (Dothan, 1993; Makhouly and Johns, 1941; Negev and Gibson, 2005, pp. 27–28).

The town and its harbor were conquered by the Ottomans in 1516 (Masters, 2009, p. 9), and were the scene of several naval campaigns during the Late Ottoman Period. In 1799, British control of the sea and the Akko harbor prevented Napoleon Bonaparte from taking the town, and stopped his advance northwards (Alderson, 1843, p. 28; Anderson, 1952, pp. 372–373; La Jonquière, 1900, IV). Muhammad Ali’s Egyptian flotilla was severely damaged during a heavy bombardment of Akko in December 1831, and the Egyptians took the town by land on 27 May 1832, after a 6-month siege. The period of Egyptian rule over Akko lasted until 3 November 1840, when a British-Austrian-Ottoman fleet bombarded the town. During this event, the main powder magazine of Akko exploded, causing enormous damage to the town, which was taken the following day (Alderson, 1843, pp. 39–48; Anderson, 1952, pp. 561–564; Kutluoğlu, 1998, pp. 62–73, 173; Rustum, 1926). Analysis of the hull timbers and finds from the Akko 1 shipwreck indicated that the ship was built, sailed, and sank during this same dynamic time period (Cvikel and Kahanov, 2009, 2013).

1.2. The Akko 1 shipwreck

The Akko 1 shipwreck was found in 4 m of water and under a thin layer of sand inside the ancient Akko harbor (see Fig. 1). It was excavated over three seasons in 2006–2008 by the Leon Recanati Institute for Maritime Studies at the University of Haifa. The shipwreck remains, lying northwest to southeast, were 23 m long from the bow to aft extremity, and a maximum 4.66 m wide from the line of the false keel to the uppermost remains of the port side. It is suggested that the original ship was a small Egyptian armed vessel, or auxiliary brig, about 26 m long, built in the eastern
Mediterranean. A complete description of the ship components and finds is given by Cvikel and Kahanov elsewhere (2009, 2013). Our work here is part of an ongoing series of studies about the Akko 1 shipwreck (e.g., Ashkenazi et al., 2011; Cvikel and Kahanov, 2009, 2013; Kahanov et al., 2012; Mentovich et al., 2010).

Given the large amount of political upheaval and frequent naval campaigns that occurred in Akko during this relatively short time, high-precision absolute dates are required to place Akko 1's construction and wrecking within their appropriate historical context. Dendrochronology (tree-ring dating) can provide extremely precise dates or a terminus post quem for when ship timbers and wooden elements were cut. However, it is not always possible to obtain a dendrochronological date from sampled wood. Even when dendrochronological dates are available, it may be necessary to relate tree-ring data to dates from other materials from the shipwreck site, in order to date events post-dating the ship's construction. Typological dates derived from the ship's hull and small finds do not provide the level of dating precision required, nor do single AMS $^{14}$C dates, because the history of past radiocarbon levels in the atmosphere is such that for radiocarbon ages in the last 300 years, there will always be several wide ranges of possible calibrated calendar ages if the $^{14}$C data are considered in isolation. This problem has been encountered in dating several other historical shipwrecks (Cvikel et al., 2008; Cvikel and Kahanov, 2006) and buildings (Biger and Liphschitz, 1991) in the region.

1.3. Bayesian modeling and $^{14}$C wiggle-matching

In order to obtain useful, high-precision $^{14}$C dates for historical sites, buildings, or shipwrecks, $^{14}$C data can be analyzed together within a Bayesian chronological model (Bayliss, 2007; Bronk Ramsey, 2009a). A more detailed description of Bayesian principles and its applications in dating archaeological sites for non-specialists is given by Bayliss (2007), so only a short summary of these methods is given here. Within the Bayesian framework, a site's scientific dates, such as $^{14}$C and dendrochronological dates...
(known as the ‘standardized likelihoods’), are analyzed in the context of one’s additional knowledge about the dates and site (‘priors’) (Bayliss, 2007). For a shipwreck, this additional data may include information relating ship materials and finds to relative chronological sequences (e.g., whether materials belong to the ship’s construction or its later period of use), typical use periods of materials onboard, or documentary evidence about the ship or shipbuilding practices during a particular time period. The Bayesian model combines the raw scientific dates with the other prior information in a quantitative manner to produce formal statistical date estimates (‘posterior density estimates’) for a given event, such as a ship’s construction or wrecking date (Bayliss, 2007; Bronk Ramsey, 2009a).

Radiocarbon wiggle-matching is a specific application of Bayesian analysis, which combines tree-ring analysis and radiocarbon data (Bayliss, 2007; Bayliss and Tyers, 2004; Bronk Ramsey et al., 2001; Galimberti et al., 2004). $^{14}$C dates are obtained from multiple tree-ring samples, whose relative order is known by an exact number of years. This sequence of $^{14}$C dates can then be fitted to the fluctuations of past atmospheric radiocarbon levels recorded in the radiocarbon calibration curve, in order to provide high-precision dating estimates for a given year in the tree-ring sequence. Wiggle-matched data can in turn be incorporated with other dates and prior information into a larger Bayesian model, which can increase the precision of a model’s dating estimates, including for relatively recent historical events (e.g., Turetsky et al., 2004).

In this study, we present a comprehensive Bayesian analytical model for Akko 1 to determine high-precision absolute dates for the ship’s construction and last voyage/wrecking event. We use $^{14}$C wiggle-match dating of tree-ring sequences from the ship’s timbers and additional $^{14}$C dates from the ship’s wooden elements to provide a terminus post quem for the ship’s construction, and a series of $^{14}$C dates on short/shorter-lived samples found on the shipwreck, as well as a terminus post quem dating estimate from an earlier analysis of the ship’s cannonballs (Mentovich et al., 2010), in order to determine the most likely date of the ship’s last voyage or wrecking.

Our study is, to our knowledge, the first time that Bayesian analysis and wiggle-matching have been used to date the construction and wrecking of a shipwreck in the southeastern Mediterranean. Our results show that these techniques are extremely valuable tools for the analysis of shipwrecks, particularly from the historical period, when there can be rich, detailed historical documentation available, but the traditional dating of undocumented physical remains is not always precise enough to link the archaeological and textual records. Bayesian chronological models, like the one we employ for Akko 1, can narrow possible shipwreck dates to a range that allows the physical ship remains to tie into, and greatly enhance, the period’s historical documents, and may — and should — be used in the future to date and interpret other shipwrecks that have been found in the region.

2. Material and methods

2.1. Tree-ring analysis and radiocarbon wiggle-matching of the ship timbers

The Akko 1 ship timbers were first analyzed for potential dendrochronological dating. Cross-sections were cut from twelve of the ship timbers, which appeared upon initial examination to be suitable for dendrochronological analysis. The surface of each sample was prepared with a razor blade, and the tree-ring widths measured along two to three radii for each sample using the Tellervo (Brewer et al., 2010) dendrochronological analysis package. Sample metadata, including presence of injuries and species, were
also recorded. Since many of the sampled timbers are oak (Quercus sp.), samples were also examined to determine if any sapwood (the anatomically distinct area of the tree containing the outermost tree-rings) was present, since accurate estimation of the tree's felling date is often possible when sapwood is preserved (Hillam et al., 1987; Hughes et al., 1981; Wazny, 1990).

Since the samples do not cross-match against one another or against any of the available Aegean or European reference tree-ring chronologies, three samples — all oak (Quercus sp.) — labeled AKO-1, AKO-11, and AKO-12) were selected for 14C wiggle-matching (see Fig. 2). Twelve 10-year segments of tree-rings (three each from AKO-1 and AKO-11, and six from AKO-12), whose relative position to one another on each sample was known from exact ring counts, were dissected and sent to the Heidelberg and Oxford Radiocarbon Laboratories for analysis. Ten-year increments were selected for wiggle-matching, because most of the samples include periods of extremely narrow ring growth with a limited amount of material to sample. Thus taking decadal sections allowed sufficient material to be sampled for both routine high-precision 14C dating at Heidelberg on two larger timbers, and AMS 14C dating at Oxford on the smaller sample, while gaining adequate dating precision against the radiocarbon calibration curve.

Following sequences were selected for both wiggle-matching and conventional 14C dating (e.g., the date for rings 1001–1010 was treated as ring 1005.5). Since the Akko 1 tree-ring sequences do not dendrochronologically crossdate one another, they were treated as independent series in a single model, in which there was no prior assumption about which sample was older/younger.

None of the samples contain sapwood. The average number of sapwood rings in oak species varies depending on the tree's growing location (e.g., northern Europe versus Anatolia) and age (Griggs et al., 2009; Hillam et al., 1987; Hughes et al., 1981; Wazny, 1990). Thus, a minimum number of additional rings was added to the wiggle-matched date of each sample's last extant ring, in order to determine a minimum felling date for the trees. This number was based on the average number of sapwood rings for oaks from the ship timbers' likely area(s) of origin. This simpler method was used instead of Millard's (2002) proposed model for estimating sapwood, which has been developed for British oaks in the research of Miles (2005, 2006) and is implemented in OxCal 4 (Bronk Ramsey, 1995, 2009a; Bronk Ramsey et al., 2001) and compared against the IntCal09 radiocarbon calibration curve (Reimer et al., 2009) with curve resolution set at 1 year and no allowance made for possible regional 14C variation (±1σ). Each radiocarbon date was treated as the center-point of the dated rings (e.g., the date for rings 1001–1010 was treated as ring 1005.5). Since the Akko 1 tree-ring sequences do not dendrochronologically crossdate one another, they were treated as independent series in a single model, in which there was no prior assumption about which sample was older/younger.

The Akko 1 ship finds (Cvikel and Kahanov, 2009; 2013); the modern distributions of the tree species from which the ship timbers were cut (Akkenik and Yaman, 2012, pp. 166–170; Ducouso and Bordacs, 2003; Schweingruber, 1993, pp. 188–201); and historical evidence (McNeill, 1992; Mikhal, 2011) indicate that the ship timbers likely came from Anatolia/the Aegean, and possibly Italy. We therefore first employed a sapwood estimate based on data from a group of mixed north Aegean oak species (Griggs et al., 2007, 2009, pers. comm., 2012), and then a second alternative estimate from a group of oaks in northwest Turkey with higher sapwood counts that were reported as either Quercus robur L. or Quercus petrea (Mattuschka) Liebl., but which may in fact be a similar Turkish endemic species (Quercus vulcanica Boiss. ex Kot-sch). We then made a third sapwood estimate based on sapwood counts for Italian oaks reported in Haneca et al. (2009, Table 1).

It is assumed that more or less all of the outer heartwood (the resin-filled inner part of the tree preceding the sapwood) is present in the samples, and that it is largely the sapwood rings (which are less resistant to decay) that have been removed from the outer part of the timbers. We then added a minimum estimate of 2 ± 1 years in which the oak was seasoned—which we based on 19th century statements that two years of seasoning is a minimum for oak (although it should be noted that in some cases, seasoning could take up to about a decade) (Tredgold, 1875).

The estimated minimum felling dates for the wiggle-matched samples were then incorporated into a dating model with four additional AMS 14C dates from wooden elements analyzed by the Radiocarbon Dating Laboratory in the Institute of Particle Physics in Zurich, in order to calculate a terminus post quem date for the ship's construction (the minimum construction date, or 'MCD' in the OxCal model). The fifth dated timber fragment (ETH-32620) from the ship has a 'modern' (post-AD 1950) radiocarbon age of ~890 ± 40 BP (see Table 1). Whether this date reflects a laboratory error or contamination is not known. This sample is the only extreme outlier in the overall set (see Table 1) and was excluded from analysis.

The non-wiggle-matched timber fragments were modeled using Bronk Ramsey's (2009b) charcoal outlier model in OxCal, which models the 14C dataset as an exponential distribution. This model was used, since many of the wooden fragments were taken from the outer edges of the timbers, which include younger (more recent) tree-rings. Therefore the 14C dates on the wooden fragment dataset will likely have an exponential distribution toward the timber felling date. However, the charcoal outlier model also allows for the fact that some of the timber fragments may include older (less recent) tree-rings toward the center of the tree, whose dates are substantially older than the general felling period for the ship's timbers.

The calculated MCD for Akko 1 was constrained to a very conservative uniform date range (in which there are no prior dating preferences within the specified interval) between AD 1600 and 1950 (which marks the end of the "pre-bomb" 14C period, after which nuclear bomb testing altered atmospheric 14C levels and the shape of the radiocarbon calibration curve) (Randerson et al., 2002). After an initial run of the models using the three different sapwood estimates, a second iteration of the model using the north Aegean sapwood estimate was run, which excluded two dates (ETH-32621 and ETH-32623) identified as outliers.

2.2. Dating the ship's final voyage/wrecking

The date of Akko 1's last voyage was estimated using a set of five AMS 14C dates, measured by the Radiocarbon Dating Laboratory in the Institute of Particle Physics in Zurich, on short or shorter-lived samples found in the shipwreck (see Table 1). It is likely that the dates on the short or shorter-lived samples are distributed toward the last few years or voyages of the ship (e.g., the two rope samples, and the leather flax), or — in the case of the dated food remains — likely the literal last voyage or season of sailing, and give a close terminus post quem for the ship's wrecking date. The 14C dates on the short/shorter-lived samples are therefore grouped in the same Phase in OxCal (see Fig. 4) and modeled as an exponential distribution ('Tau_Boundary' in OxCal) (Bronk Ramsey, 2009a) toward the end of this Phase.
It is assumed that the estimated cutting dates for samples AKO-1, 11, and 12, and the dates for the non-wiggle-matched ship timber fragments (e.g., materials relating to the ship’s construction) precede the dates for the shorter-lived samples onboard the ship. Therefore the initial boundary of the ‘Last Voyage Phase’ was modeled as the ship MCD, while this Phase’s end boundary is considered the best estimate for Akko 1’s last voyage or wrecking date (1839, which suggests a post-1839 date for the ship manufacturing technique used in cannonballs produced only after 1839 for the date of the last voyage was added. This constraint defines (Cvikel and Kahanov, 2013) suggests that Akko 1 was a ship friendly to Egypt and was possibly even built there. If, then, the short/shorter-lived samples are from Egypt, there may be a small but significant growing season-related offset of about 19 ± 5 14C years like that which Dee et al. (2010) found in samples from the Nile Valley in periods prior to the Aswan dam construction. However, it should be noted that sample material from Egypt’s Mediterranean coast would have a smaller offset, while the offset in material from the Levant would be smaller still. To consider the relevance of such an offset to our dating models, we compared the modeled minimum construction dates against the calibration curve in OxCal first with a general ΔR allowance of 0 ± 10. Then, in a second test, we added a 19 ± 5 14C years adjustment only to the modeled date for the short/shorter-lived samples to determine the effect on the modeled date for the ship’s final voyage/wrecking.

3. Results

3.1. Tree-ring analysis and wiggle-matching the ship timbers

Of the twelve ship timbers sampled, only six – all deciduous oaks – had sufficient rings (>50) for dendrochronological analysis. Reliably identifying European and Mediterranean oak wood at the species level is not possible; thus we give wood identifications only at section level, following the recommendations of Akkemik and Yaman (2012, p. 178), Schweingruber (1990, pp. 401–403), and Ważny (pers. comm., 2012). Five samples were cut from oaks belonging to the section Quercus (white oaks), which in Europe and the Mediterranean includes the common species Q. petraea (Mattheschka) Liebl., Q. pubescens Willdl., Q. vulcanica Boiss. ex Kotschy, and Q. robur L. One sample was cut from an oak belonging to the section Cerris (red oaks), which in Europe and the Mediterranean includes the common species Quercus cerris L. All of the samples have relatively short tree-ring sequences of less than 100 rings, and nine of the twelve include the innermost, juvenile tree-rings at or near the tree’s pith. The bark, vascular cambium, and sapwood are absent from all of the timbers sampled. Most of the samples have scarring and abrupt growth suppression and releases in their tree-rings (see Fig. 3), which altered tree-ring growth. None of the
samples yielded significant dendrochronological crossdates with one another or with existing European and Mediterranean oak reference chronologies.

The three samples selected for 14C wiggle-matching, AKO-1 and 12, and AKO-11, were sampled from hull timbers: two frame timbers and a hull plank, respectively (see Table 2). AKO-1 has 74 rings (plus one unmeasured, partial ring); AKO-11 has 65 rings (plus one unmeasured, partial ring); and AKO-12 has 93 rings. The 10-year sections taken from each sample and used in the wiggle-match are given in Table 2, and their calculated placements from the model (Fig. 4) are shown in terms of their fit on the IntCal09 radiocarbon calibration curve (Reimer et al., 2009) in Fig. 5. All the 14C data from the wiggle-matched wood samples lie in the 18th century AD on the upward 1715\textendash 1790 slope. When the OxCal charcoal outlier model is used, the non-wiggle-matched wood samples lie in the late 18th through early 19th century AD. The data from the subsequent short/shorter-lived samples fit best around the wiggle in the calibration curve between approximately 1820 and 1840.

All three samples were cut from Quercus section Quercus. Species in this section have a wide distribution stretching from the Black Sea and southwest coasts of Anatolia westward throughout most of Europe (Akkemik and Yaman, 2012, pp. 166\textendash 170; Ducousso and Bordacs, 2003; Schweingruber, 1993, pp. 188\textendash 201). For reasons discussed above (also: see discussion below), the ship timbers were most likely culled from forests in Anatolia/the Aegean, and also possibly northern Italy, so average sapwood estimates from these regions are employed. According to Griggs’ research (pers. comm., 2012; modified from data in Griggs et al., 2007, 2009) on a multi-species group of 167 oaks growing in northern Turkey and Greece, oaks ages < 100 years generally have an average of

<table>
<thead>
<tr>
<th>Lab ID</th>
<th>Relative rings (each sample)</th>
<th>δ13C %o</th>
<th>14C age (BP)</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>AKO-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hd-27447</td>
<td>1008\textendash 1017</td>
<td>-24.52</td>
<td>117</td>
<td>22</td>
</tr>
<tr>
<td>Hd-27465</td>
<td>1028\textendash 1037</td>
<td>-26.6</td>
<td>150</td>
<td>19</td>
</tr>
<tr>
<td>Hd-27487</td>
<td>1048\textendash 1057</td>
<td>-25.92</td>
<td>142</td>
<td>20</td>
</tr>
<tr>
<td>AKO-11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hd-30362</td>
<td>1006\textendash 1015</td>
<td>-26.2</td>
<td>140</td>
<td>12</td>
</tr>
<tr>
<td>Hd-30391</td>
<td>1036\textendash 1045</td>
<td>-26.3</td>
<td>185</td>
<td>26</td>
</tr>
<tr>
<td>Hd-30392</td>
<td>1046\textendash 1055</td>
<td>-25.7</td>
<td>152</td>
<td>19</td>
</tr>
<tr>
<td>AKO-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OxA-19432</td>
<td>1001\textendash 1010</td>
<td>-25.0</td>
<td>119</td>
<td>25</td>
</tr>
<tr>
<td>OxA-19466</td>
<td>1011\textendash 1020</td>
<td>-24.0</td>
<td>128</td>
<td>21</td>
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<tr>
<td>OxA-19433</td>
<td>1031\textendash 1040</td>
<td>-24.5</td>
<td>202</td>
<td>25</td>
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<tr>
<td>OxA-19467</td>
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<td>-23.7</td>
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<tr>
<td>OxA-19434</td>
<td>1061\textendash 1070</td>
<td>-23.9</td>
<td>191</td>
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<tr>
<td>OxA-19468</td>
<td>1071\textendash 1080</td>
<td>-24.2</td>
<td>191</td>
<td>22</td>
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</table>

Fig. 3. Photos of sample AKO-1, and graph showing the AKO-1 ring-width measurement sequence (relative years beginning at 1001 from the center of the tree outwards are shown), which features abrupt growth releases due to an injury (A), and abrupt growth declines in both the section’s middle (B) and center (C). The lighter color around the sample’s outer edges gives the appearance of sapwood, but closer inspection revealed it to be only discoloration (photos: B. Lorentzen).
19 ± 4.33 sapwood rings, while oaks ages 101–150 years have an average of 21.19 ± 4.61 sapwood rings. If we use Griggs’ (pers. comm., 2012) sapwood estimates from the smaller dataset of oaks (possibly Quercus vulcanica Boiss. ex Kotschy) from northwest Turkey, then the average for oaks < 100 years old is 27.2 ± 7.19 sapwood rings, and 27.81 ± 7.78 for oaks 101–150 years old. According to the data from Martinelli reported in Haneca et al. (2009, Table 1), Italian oaks have an average of 13.23 ± 6.06 sapwood rings.

Sample AKO-1 was cut from a tree that was at least 75 years old, and the pith and innermost rings of the tree are present. Sample AKO-11 was cut from a tree at least 66 years old; the pith is not present, although based on the sample’s ring curvature, its innermost rings are likely from very close to the tree’s center (within approximately 10 rings). Sample AKO-12 was cut from a tree at least 93 years old, although the pith is not present, nor is there clear indication that the sampled timber was cut close to the center of the tree (thereby placing AKO-12 in the older sapwood estimate age class). Thus the sapwood estimate for trees in the <100-years age class is used for samples AKO-1 and AKO-11, while the older 101-to-125 years age class estimate is used for AKO-12.

The minimum felling dates for the three wiggle-matched timbers using the different sapwood estimates are given in Table 3. The north Aegean oak sapwood model is shown in Fig. 4.
across the different sapwood models between samples AKO-1 and 11 versus AKO-12, which may reflect very small differences between the Heidelberg (which measured AKO-1 and 11) and Oxford (which measured AKO-12) radiocarbon laboratories, or a slight difference in the actual timber ages. However, the date ranges for all three samples comfortably overlap one another at both 68.2% and 95.4% probability. This indicates that the timbers were cut at roughly the same time; our assumption that the timbers had only their sapwood rings removed (plus possibly a few heartwood rings) is likely correct; and the calculated minimum timber felling date and subsequent minimum construction date is robust.

3.2. Dating the ship’s construction

The calculated minimum construction dates for Akko 1 using the different sapwood estimates are given in Table 3, and their probability distributions are shown in Fig. 6. If we calculate a minimum construction date using the north Aegean oak sapwood estimate (since it is the most likely origin for the timber), the most likely period for the ship’s construction is between AD 1817 and 1834 at 68.2% probability (AD 1810–1856 at 94.3% probability and 1889–1897 at 1.1% probability) (see Fig. 6A). If we use the other two sapwood estimates instead, the likely ship construction dates vary by less than 10 years at 68.2% probability (see Fig. 6B, C, Table 3). If we rule out the very small probability of a minimum construction date in ca. 1880–1900 in two of the models, the likely minimum construction dates produced from using different sapwood estimates vary by less than 20 years at 95.4% probability.

The different models give a possible (but very unlikely) minimum construction date range from ca. AD 1880–1890. However, none of the finds from Akko 1 indicate that the ship was constructed any later than the mid-19th century (Cvikel and Kahanov, 2013). Our models likely produce these date ranges because of changes to the shape of the radiocarbon calibration curve around the early 20th century, when burning of fossil fuels started altering radiocarbon levels in the atmosphere (the ‘Suess Effect’) (Suess, 1955). Thus, while these post-1880 construction (and also wrecking) date ranges are included in our results and shown in Figs. 6 and 7, they may be excluded from our analysis of both the ship’s likely construction and wrecking dates.

3.3. Dating the ship’s final voyage/wrecking

The overall model produces slightly different estimates for the calendar date of the ship’s final voyage/wrecking depending on the sapwood estimate employed (see Fig. 7A, C, and D). The most likely probability ranges are all very similar at AD 1822–1842 (north Aegean oaks); AD 1825–1848 (the northwest Turkey oak subset, ‘DEV’); and AD 1821–1837 (Italian oaks) at 68.2% probability (see Table 3). If an additional terminus post quem of 1839 for the ship’s last voyage, based on Mentovich et al.’s analysis (2010), is added to the model using the north Aegean sapwood estimate, OxCal produces a most likely date range of AD 1839–1852 at 68.2% probability, with probability strongly skewed toward the earlier part of the date range (see Fig. 7B).

3.4. Testing model robustness and possible regional 14C offsets

The overall dataset employed in our model (see Fig. 4)–comprising the 14C wiggle-matched timbers, additional wood samples, and short/shorter-lived sample set–fits nicely to the variations in the atmospheric radiocarbon record (see Fig. 5). The overall model using the north Aegean sapwood estimates produces an analysis with a good OxCal agreement index (Amodel 69.7 > 60), and the alternative northwest Turkish subset and Italian sapwood estimate models also offer Amodel values >60 at 69.8 and 67.5, respectively. There are only two minor outliers produced using Bronk Ramsey’s General Outlier model (2009b) (see Figs. 4 and 5). If the model using north Aegean sapwood estimates is re-run without
these two outliers, the resulting date ranges are almost the same (see Table 3).

The ΔR test of 0 ± 10 years for calculations using the north Aegean oak sapwood model returns little evidence of any significant offset. The mean offset for the minimum timber use date is just −3.3 ± 7.7 years (±1 standard deviation), which indicates that there is no substantial offset. This modifies the last voyage/wrecking date range by only a few years, so that it is AD 1823—1847 at 68.2% probability (AD 1815—1874 at 94% probability and AD 1897—1905 at 1.4% probability). If the last pre-Aswan siege (1828) was extended by a few years, so that it is AD 1821—1847 at 68.2% probability (AD 1815—1874 at 94% probability and AD 1897—1905 at 1.4% probability), the overall agreement of the model also goes up (Anmod = 81), which may suggest that this consideration is relevant. Nevertheless, even if a small ΔC offset applies to the short/shorter-lived materials, its overall effect on our dating results is quite small and does not affect our overall interpretation of the dates (see discussion below), but may create a slightly more compatible model.

4. Discussion

According to the dating models calculated above, the minimum construction dates for the Akko 1 ship timbers lie somewhere between AD 1813 and 1843 at the extremes of the 68.2% probability ranges (see Table 3). The ship’s final voyage most likely occurred between AD 1821 and 1852 at 68.2% probability when no other additional information is included in the model. If the terminus post quem indicated by Mentovich et al. (2010) analysis of the cannonballs is incorporated and the north Aegean sapwood estimate used, then the most likely final voyage/wrecking date can be narrowed to AD 1839—1852 at 68.2% probability. The model and calculated dates fit well with the approximate date ranges given to the Akko 1 finds, arms, and rigging elements (Cvikel and Kahanov, 2009, 2013; Shalev, pers. comm., 2007, 2010).

Our model indicates that the ship was constructed after Napoleon Bonaparte’s 1799 siege of Akko (see Table 3). Even if the Italian sapwood model (which provides the earliest possible construction date) is used, the earliest likely construction date at 95.4% probability still post-dates the siege of Akko by 9 years. It is instead most likely that the Akko 1’s timbers were cut, and building of the ship initiated, during the political ascendency of the Egyptian vali Muhammad Ali Pasha.

Muhammad Ali invested considerable resources in obtaining timber, which he deemed critical for building up the Egyptian navy, and even personally oversaw timber importation to Egypt (Mikhail, 2011). The most easily accessible and largest quantities of available timber came from the Black Sea and south Mediterranean coasts of Anatolia, which traded heavily with Egypt during the early 19th century (McNeill, 1992, pp. 246—247; Mikhail, 2011). However it is documented that Muhammad Ali also imported timbers from Italy (McNeill, 1992, pp. 246—247). Muhammad Ali was apparently unhappy with both the quantity and quality of wood from these locations (Marsot Al-Sayid, 1984, p. 221; McNeill, 1992, p. 247). His desire for high-quality, accessible timber resources free from Ottoman control – which he had unsuccessfully attempted to acquire within Egypt – was, in fact, his primary motivation for invading the Levant (including Akko) and southeast Anatolia in 1831 (Kutluoğlu, 1998, p. 51; Marsot Al-Sayid, 1984, p. 228; Mikhail, 2011, pp. 160—169; Rustum, 1936, pp. 63—64).

Akko 1’s wrecking site and hull construction indication that it was friendly to, and was likely even built, in Egypt (Cvikel and Kahanov, 2013). Like the Turkish and Italian timbers that Muhammad Ali reportedly found unsatisfactory for his navy, the timber used to build Akko 1 was generally poor quality, cut from juvenile trees, and (based on the abrupt tree-ring growth suppression and releases in many of the samples) culled from a forest/forests that experienced frequent anthropogenic disturbance (possibly from coppicing and pollarding). If the timbers were in fact culled from multiple areas in the Turkish and Italian forests, this may explain why the ship timbers do not dendrochronologically crossdate.

Even if the Akko 1 timbers were taken entirely from Turkish forests, it is still likely that the ship’s timbers were culled from several different forest stands. Mikhail’s (2011) analysis of the Ottoman and Egyptian archives demonstrated that the standard procedure for timber exportation between Anatolia and Egypt was that: i) the Ottoman sultan agreed to grant an Egyptian request for timber; ii) Anatolian timbers were cut, and building of the ship initiated, during the political ascendency of the Egyptian vali Muhammad Ali Pasha.
Anatolia and then sent in bulk to the Imperial Dockyards in Istanbul, or ports like Antalya and Alanya in southern Anatolia, which served as timber repositories; iii) the wood was then shipped to the dockyards in Alexandria; and iv) timbers were distributed throughout Egypt as needed. Thus, wood used to make an entire fleet of Egyptian vessels might come from several locations within Anatolia.

If ship construction concluded by 1830 (which our dating models indicate is entirely possible), Akko 1 might have even been one of the six Egyptian armed brigs that sailed to Akko and participated in Ibrahim Pasha’s 1831 siege of the town (Cvikel and Kahanov, 2013). Considering that the ship was armed and suffered considerable damage during its wrecking (Cvikel and Kahanov, 2013), it is likely that it was wrecked during a naval battle. The fact that no other naval campaign took place in the vicinity of Akko after 1840, combined with our dating model and analysis of the finds, suggests that the Akko 1 was sunk as a direct result of the 1840 bombardment of Akko by the Allied fleet, or by the explosion of the town’s main powder magazine.

If Akko 1 was a naval vessel in Akko on guarding and patrolling duties, she could have taken part and been sunk during the battle. She might also have been an auxiliary vessel friendly to Egyptian forces, like that which Captain Henry Codrington (commander of the British frigate HMS *Talbot*) observed anchoring in Akko harbor on the eve of the bombardment in 1840 (Codrington, 1880, p. 182). If Akko 1 was the brig that Codrington observed, then she was an auxiliary vessel shipping arms and ammunition to the Egyptians defending Akko when she sank.

5. Conclusions

The Bayesian analysis model used in our study gives a much narrower possible range of dates for when Akko 1’s ship timbers were felled, for when the vessel was built, and for when the vessel was wrecked than either single 14C dates or typological dates derived from the ship’s equipment or finds. This study is, to our knowledge, the first time that such techniques have been used to provide high-precision dates for a shipwreck found in the southeastern Mediterranean. Our results show clear advantages for implementing this type of analysis, particularly for dating historical shipwrecks, and even buildings or archaeological sites, when their specific histories are not documented and direct dendrochronological dating is not possible.

Previously, the broad range of dates from the 17th through 19th centuries AD for the ship’s construction and wrecking available from single-sample radiocarbon dates limited the ability to interpret the physical ship remains in the context of historical events during a time period in which there were multiple political upheavals, naval and military campaigns, and changing and expanding trade networks. However, with our dating model (and as seems most likely—assuming that the timbers are from Anatolia/ the Aegean and citing the model excluding the two outliers), we are able to determine that the ship was constructed no earlier than AD 1815–1837 at 68.2% probability (AD 1808–1856 at 95.4% probability) and likely wrecked between AD 1823 and 1849 at 95.4% probability (AD 1814–1868 at 95.4% probability), or, allowing for the level of manganese in the cannonballs, likely AD 1839–1855 at 95.4% probability (AD 1839–1874 at 95.4% probability). If the analyzed ship timbers came from either of the other two proposed regional oak populations, these dates vary by at most only a few years.

Combined with evidence from the small finds and botanical analysis of the timbers, we can then fit this information with the historical record to suggest that Akko 1 was an Egyptian brig built for Muhammad Ali’s navy during his political ascendency; possibly plied the eastern Mediterranean during the First Egyptian–Ottoman War in 1831–1833; and sank during the Allied bombardment of Akko in 1840.

These data aid in further analysis of the Akko 1 shipwreck as an Egyptian naval brig. Even more critically, our study demonstrates the advantages of using Bayesian analysis techniques combining tree-ring analysis and 14C data, in interpreting and identifying other historical-era shipwrecks (and shipwrecks from earlier periods) from the southeast Mediterranean. These methods provide the high-precision dates that are required to insert such important and rich ship finds into the region’s historical narrative.
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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2013.10.013.

References


Fig. 7. Probability distributions for dating the ship’s final voyage/wrecking from the dating model shown in Fig. 4: (A) uses the north Aegean oak sapwood estimate; (B) the north Aegean oak sapwood estimate including the AD 1839 terminus post quem from Mentovich et al.’s (2010) cannonball analysis; (C) the alternative northwest Turkish sapwood estimate; and (D) Italian oak sapwood estimate.