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To put a cedar ship in a bottle: Dendroprovenancing three ancient East Mediterranean watercraft with the $^{87}Sr/^{86}Sr$ isotope ratio

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ABSTRACT

This paper presents the latest provenance results of cedar wood (*Cedrus* sp.) from three ancient watercraft: the Carnegie boat (Middle Kingdom Egypt), the wrecked merchant ship at Uluburun (Bronze Age Mediterranean), and the galley comprising the Athlit Ram (Hellenistic Mediterranean). Comparing the ratios of $^{87}Sr/^{86}Sr$ of the archaeological wood and cedar from modern forests has helped augment the existing hypotheses pertaining to where the wood used in the construction of these vessels originated. The results demonstrate that strontium isotopic analysis can provide valuable information to assist wood provenance research in ancient and maritime contexts, which in turn may elucidate ancient forestry and shipbuilding practices.

1. Introduction: The need for cedar ship timber provenance

The use of cedar (*Cedrus* sp.) for shipbuilding in the East Mediterranean is known from archaeological and historical records. Since the Predynastic, Egypt imported cedar wood because it was valued by shipwrights (among other artisans and technicians) for its water, rot, and parasite resistance (Meiggs, 1982; Ward, 2000; Pulak, 2001). Cedar is also present in ancient Near Eastern texts related to shipbuilding: e.g., the barge of Nanna-Suen, the Mesopotamian moon god, had cedar ($^{\text{giš}}$erin) beams (Black et al., 2006: *ETCSL* 1.5.1.39-82); Gilgamesh made a raft of timber accrued in the Cedar Forest to float wood down the Euphrates (George, 2003: 613–615, Tablet V.292-302); and the Canaanites and Phoenicians are also said to have used cedar in shipbuilding (Ezekial 27:5; Theophrastus, *Enquiry into Plants* 5.7.1-3). From the archaeological record, Khufu's and Senwosret's buried ships, and the Gelidonya, Uluburun, Athlit Ram, and Kinneret shipwrecks (a.o.) are known to have been constructed with cedar (Pulak, 2001; Liphschitz, 2012c; Rich, 2013). Largely due to biblical and other literary references to the Cedar of Lebanon, scholars commonly assume that raw cedar timber was shipped exclusively from forests of the Lebanon (Meiggs, 1982: 50, 418; Kuniholm et al. 2007); however, there were at least two other cedar-rich areas that were sought out as timber sources in the East Mediterranean: the Taurus and Amanus Mountains (*C. libani* A. Rich, considered by some as *C. libani* var. *stenocoma* (O. Schwarz) – there are a few scattered cedar stands elsewhere in Anatolia: Akkemik, 2003: 63; Boydak, 2003: 232 and refs., Fig. 2) and the Troodos Massif in Cyprus (*C. brevifolia* (Hook f.) A. Henry) (Dagher-Kharrat et al., 2007; Hajar et al., 2010). The Syrian Coastal Range also provided cedar in antiquity (Fig. 1). Employing strontium (Sr) isotope ratios, we can demonstrate likely sources of cedar beyond Lebanon and indicate a range of plausible wood provenance hypotheses. Previous papers have highlighted the application of strontium isotope analysis for dendroprovenancing and a preliminary database of regional cedar forest signatures in the East Mediterranean for this purpose (Rich et al., 2012, 2015). This paper presents the first ancient cedar provenance results on archaeological material using this method (updated since Rich, 2013). This work can establish a more complete picture of the use and mobility of cedar forest products in the ancient East Mediterranean, particularly in relation to shipbuilding. It also emphasizes the often-neglected roles of extra-Lebanon forests in overseas trade and commerce.

Ironically, we often know more about the multitudes of amphorae, anchors, weights, metal and glass ingots carried onboard than we do about the ancient wooden ships themselves (Adams, 2001). It is true that the majority of Mediterranean shipwrecks yield little to no wood, but as

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Fig. 1. Map of the study area with cedar forest site locations (circles), findspots of relevant cedar ships (squares), and city names mentioned in the text (diamonds).

this pilot study hopefully demonstrates, even unassuming, splintery bits can produce valuable information on resource acquisition and the shipbuilding industry. However, problematic for dendroprovenance studies are the nuances of long-distance timber trade. Even if a piece of wood is provenanced back to its original forest, that does not necessarily mean that the entire boat was built at the nearest shipyard; it only indicates the origin of that piece of wood. In theory, the timber could have been transported to any number of distant shipyards and the vessel constructed there. However, other provenance studies performed on ancient ship timbers determined that Northern European shipyards relied most heavily on nearby oak forests, so the provenance of ship timbers was indicative of the approximate provenance of the ship (Daly, 2007a: 229, 236–237; Daly, 2007b; Haneca and Daly, 2014; *contra* later reliance on Baltic timber exports: e.g., Daly, 2008). Furthermore, knowing the origin of even one piece of wood can be important, if not for rewriting history, at least as a step toward understanding why certain forests may have been preferred over others as sources for timber.

2. Material and methods: Using $^{87}Sr/^{86}Sr$ to provenance timbers from three ancient cedar ships

Using strontium isotope determination (ratios of $^{87}Sr/^{86}Sr$), we analyzed cedar wood from three well-known ancient vessels to help determine a plausible timber provenance hypothesis: Senwosret (also Senusret or Sesostris) III's Carnegie boat (Egyptian boat-burial, earlier-mid nineteenth century BC), the Uluburun (shipwrecked merchant vessel, presumably Syro-Palestinian, mid-late fourteenth century BC), and the Athlit Ram (wrecked Ptolemaic warship, late third or early second century BC) (Fig. 1). These remains make ideal comparisons because of their varying proposed origins and dates, and because each represents a different type of ship (mortuary, mercantile, or military, respectively). In all three cases, the provenance of the ship and/or its timber is either unknown or surmised based on historical, iconographical, or associative premises: wood from the Athlit Ram is tentatively provenanced to Ptolemaic Cyprus, as an iconographical study parallels the symbols cast on the bronze ram with those found on coins (Murray, 1991); timber for Senwosret III's Carnegie boat, like other cedar wood from an Egyptian context, is presumed to have originated from a forest near Byblos, as later historical documentation refers to timber trade with that port city (Fig. 1; Meiggs, 1982: 63–68); and the port of origin of the wrecked merchantman at Uluburun is currently thought to have been along the Carmel Coast based on petrographic analyses of the stone anchors and galley wares (Goren, 2013; Pulak, 2008). Determining the provenance of the cedar wood from these ships would help illuminate possible relationships between the source groves sought for shipbuilding, and the ships themselves. Such relationships could be dependent on fluctuating socio-political factors and regional trade limitations, or on the vessel's function and religious associations with certain forests and/or particular ship genres (Rich, 2013, 2016).

The method of strontium isotopic analysis works by comparing $^{87}Sr/^{86}Sr$ ratios of archaeological timber samples to established regional $^{87}Sr/^{86}Sr$ signatures of living forests (Table 1; Fig. 1). Trees absorb strontium from their local physical environment via soil and bedrock, but airborne and waterborne sources are equally important Sr contributors (summarized in Bentley, 2006). If these and other local geological and geographical contributing factors have remained relatively constant through the late Holocene, the $^{87}Sr/^{86}Sr$ ratio of archaeological wood can be compared to ratios determined for living forests to help determine the material's origin (Rich et al., 2012, 2015). Some of the earliest work using this method of dendroprovenance was accomplished in the American southwest (Graustein and Armstrong, 1983; Gosz and Moore, 1989; Durand et al., 1999). English et al. (2001) and Reynolds et al. (2005) provenanced archaeological timbers from Chaco Canyon, NM to their mountain sources by mapping $^{87}Sr/^{86}Sr$ ratios in living groves, and matching them with results of the archaeological wood. For ship timbers specifically, previous provenance studies have been accomplished through dendrochronology (Bridge, 2012), but an absolute chronology must be available, as there is for Northern European oaks (*Quercus* sp.), and such a chronology does not yet exist for *Cedrus* sp. before the Medieval period (Rich et al., 2012; Manning et al., 2014). Palaeogenetic analysis of cpDNA from early-modern oak ship timbers may also be a useful provenance method, but degradation in ancient waterlogged woods could complicate cpDNA amplification (Speirs et al., 2009; Deguilloux et al., 2004; Dumolin-Lapègue et al., 1999; but see Jiao et al., 2015). Dendroarchaeological investigations have identified wood species found in boat assemblages and can suggest a range of distribution (from modern or assumed growth areas) common to all species (Liphschitz, 2007; Liphschitz and Pulak, 2007/2008; Liphschitz, 2012a, b, c). This method can help narrow down possible sources but assumes that modern distributions are the same as in antiquity, a claim which is better substantiated with palynological studies (Allevato et al., 2009; Muller, 2005; Giachi et al., 2003). It also relies on degraded, archaeological samples being identified to the species level, a category that is not always agreed upon by taxonomists or even distinguishable by wood anatomical specialists (Jagels et al., 1988; Kim, 1990; Blanchette, 2000). Naturally, the application of $^{87}Sr/^{86}Sr$ isotopic analysis to dendroprovenance also comes with limitations: “It is only ever possible to disprove a source hypothesis, never to prove one” (Pollard, 2011: 637). That is, a sample could feasibly match thousands of forest areas on a ‘strontium map’, but if a hypothesis suggests a source forest area and the strontium ratios clearly disagree, then the hypothesis should be re-opened for discussion. Like those described above, this method is most effective when used in conjunction with others, whether of a similar geochemical nature (rare earth elements, e.g.), biological, or historical/archaeological (as demonstrated below). New methods of dendroprovenance are being developed all the time, with organic chemical markers and other stable isotopes (e.g., $^{143}Nd/^{144}Nd$) demonstrating great potential (Traoré et al., 2016); however, the caveats associated with Sr isotope analysis would apply equally to those methods.

Table 1
Summary of the of $^{87}Sr/^{86}Sr$ results of sampled cedar forest sites (Rich et al., 2015).

Location	No.	Mean	Median	Min.	Max.	Std. Dev.	Std. Error
Cyprus: Pafos Forest, western Troodos							
Cyprus	13	0.70882	0.70886	0.70832	0.70913	0.00027	0.00008
Turkey: Elmalı İşletmesi, Cığlıkara Forest, Antalya, central Taurus							
Antalya	10	0.70848	0.70848	0.70810	0.70894	0.00021	0.00007
Turkey: Feke, Düşmüş Orman Deposu, eastern Taurus-northern Amanus							
Feke[a]	5	0.71236	0.71162	0.71106	0.71539	0.00173	0.00078
Lebanon: Tannourine al-Faouqa, Barouk, Bcharre, the Lebanon (LS = limestone)							
Leb. LS	6	0.70833	0.70830	0.70824	0.70848	0.00009	0.00004
Lebanon: Horsh-Ehden, the Lebanon							
Leb. Edn	4	0.70803	0.70796	0.70769	0.70850	0.00034	0.00017
Lebanon: Tannourine-Hadeth, the Lebanon (SS = sandstone)							
Leb. SS	4	0.70881	0.70881	0.70850	0.70911	0.00028	0.00014

[a] This site shows significantly higher results than the other sampled forest areas and does not align with any of the archaeological timbers analyzed here. To keep this anomaly from overshadowing the nuances of the other sites, it has been excluded from the graphs.

We present here the latest results from six analyzed cedar forest areas in the East Mediterranean (Rich et al., 2015) in relation to 12 samples of timbers from three ancient watercraft. Because diagenetic and biostratinomic sources for Sr in archaeological wood is such a concern, all samples presented here were washed to remove precipitates (e.g., NaCl) before being analyzed via MC-ICP-MS at Ghent University's Department of Analytical Chemistry in accordance with the procedures for cedar digestion and Sr isolation detailed in Rich et al., 2012 (800–801, Tables 2, 3; see also Vanhaecke et al., 2009; Balcaen et al., 2010). As demonstrated below, sets of archaeological samples retrieved from the seabed differ significantly in their measured ratios of $^{87}Sr/^{86}Sr$, and as such, these ratios are understood to reflect biogenic, not diagenetic, Sr (i.e., samples from different sites on the same seabed produced different results). Archaeological samples were provided by the Cornell Tree Ring Laboratory where wood identifications and dendrochronological analyses were conducted.

3. Results

3.1. The Carnegie boat

The first of the three ancient vessels to be examined is Egyptian Pharaoh Senwosret III's Carnegie Boat (early-mid nineteenth century BC: Manning et al., 2014), discovered at the pharaoh's funerary complex at Dahshur, Egypt (Fig. 1) between 1894, when three other boat pits were discovered, and 1901, when Andrew Carnegie purchased this boat, identical to the other three. Core samples were taken at the Carnegie Museum (Pittsburgh, PA) in August 1988 (Ward, 1984a, 1984b; Patch and Haldane, 1990).

Because strontium isotopic analysis is a destructive process, great care was taken to select and remove wood from cores with plenty of heartwood rings opposite the bark on the other side of the pith, or which could be split in half without damaging the core. Six samples were taken from five different cores, and a duplicate sample was taken from one core to demonstrate measurement and sample consistency (Table 2). The results form a tight grouping (mean 0.70781 ± 0.00002), which is a prerequisite for successful provenance.

The boat's narrow isotopic range falls within the lowest range of the sampled forests, the Lebanese site of Horsh-Ehden (Leb. Edn.; Fig. 2). The similar median values suggest that these timbers from the Carnegie boat were cut in this forest area: compare 0.70781 for the Carnegie boat to 0.70796 for Leb. Edn. (Tables 1, 2). In part, this finding coincides with what is already suspected of Old and Middle Kingdom timber trade with the Levant. Multiple texts cite Byblos as the port where cedar wood was acquired, but these do not date earlier than the New Kingdom (Meiggs, 1982: 65–66). So although it has long been surmised that Egyptian cedar imports came from the Lebanon, these results are the first direct

Table 2
Samples of the Carnegie boat and their $^{87}Sr/^{86}Sr$ results with statistical summary.

Sample ID	No. rings measured	Sample location	$^{87}Sr/^{86}Sr$ value	2 s
EG-PIT-09	59	Gunwale plank	0.70784	0.00007
EG-PIT-12 A	61	Strake, center port	0.70778	0.00008
EG-PIT-12 A(2)	61	Strake, center port	0.70781	0.00006
EG-PIT-12C	212	Strake, center port	0.70778	0.00007
EG-PIT-14	76	Strake, center starboard	0.70781	0.00006
EG-PIT-20	61	Central strake, stern	0.70782	0.00006

No. samples	Mean	Median	Minimum	Maximum	Std. Dev.	Std. error
6	0.70781	0.70781	0.70778	0.70784	0.00002	0.00001

indication that Lebanese cedar was exported to Egypt as early as the Middle Kingdom. Considering the precise range and homogenous $^{87}Sr/^{86}Sr$ signature of the Carnegie boat, further sampling including the other three Dahshur boats could determine if all timbers were derived from the same source forest.

3.2. The Uluburun shipwreck

The second set of ship timbers to be analyzed are from the hull and keel of the Uluburun shipwreck, which sank off the southern coast of Kaş Uluburun (Turkey), ca. 1330–1300 BCE (Pulak, 2002; Manning et al., 2009) (Fig. 1). The origin of this vessel has been a hot topic of debate since its discovery in 1982 (excavations beginning in 1984) because of the initial assumption of an Aegean origin based on the belief in a Mycenaean thalassocracy in the Late Bronze Age Mediterranean (Bass, 1986; Pulak, 1988). Since then, the Syro-Palestinian coast and Cyprus have both been contenders, but the most recent examinations into its port of origin have used optical mineralogy on the stone anchors and ceramic fabrics from the assemblage, the overwhelming majority of which point to the Carmel coast (Goren, 2013: 57–60). This finding corresponds to the earlier evaluation of personal items belonging to the crew members, weight sets, and icons as all being indicative of a Canaanite origin for the ship (Bass et al., 1989; Pulak, 1998). Its timbers, on the other hand, may still have come from further afield, particularly since the natural distribution of cedar does not extend that far south (Hajar et al., 2010).

The Uluburun samples are all very similar, but when compared to the sampled cedar forest sites, the archaeological samples rest well above the five similar forests (Fig. 3) and far below the site of Feke (Table 1). While the Uluburun's median value is 0.70922 (Table 3; note that many regions around the planet have a signature similar to this, not just seawater – see also Section 2), the maximum value for Cyprus is 0.70913, and for Tannourine-Hadeth 0.70911, while the minimum value for Feke is 0.71106 (Table 1). When looking at the alignment, it is clear from the lack of overlap between the structural timbers and the forest areas sampled so far, that the Uluburun's ratios do not match any of these regions very closely (Fig. 3). Because the archaeological samples are so uniform, it stands to reason that they should fit more snugly within a single site, as is the case with the Carnegie boat above. However, at least two other eligible forest areas have not yet been sampled: the south and central Amanus (Feke is located near the boundary of the Taurus and northern Amanus) and the Syrian Coastal Range (Fig. 1). It seems likely, given the ship's probable origin from a southern Canaanite port and the fact that Ugarit was another of the most prominent port cities in the LBA, that the Syrian Coastal Range cedars should be a strong contender for the source of the ship's building material. This suggestion is in concurrence with observations that the overlapping distributions of the four tree species (*C. libani*, *Tamarix* sp., *Quercus cerris*, and *Q. coccifera*) associated with the Uluburun wood assemblage point to a locale between southeastern Turkey and Lebanon, but not Cyprus because *Q. cerris* does not grow on the island (Liphschitz and Pulak, 2007/2008: 74; Liphschitz, 2012c), although a close relative, *Q. alnifolia* does (Tsintides et al., 2002: 116–117; Neophytou et al., 2007). Since the ship's isotope ratio results do not coincide with the investigated forests of Lebanon, Cyprus, or Turkey, cedar source areas from further north in the Levant should be evaluated. For the time being, the provenance of the Uluburun ship timbers continues to remain inconclusive, but the data provided here do not disprove the existing hypothesis of a north Levantine origin for the ship's timbers.

3.3. The Athlit ram

The third and final set of ship timbers analyzed in this study comprise the cedar wood from either the stem or ramming timber of the Athlit Ram, the only recovered part of a Ptolemaic warship that sank off the coast of Israel around the late third or early second century BC (Steffy, 1983; Casson et al., 1991, est. 204–164 BCE in Murray, 1991) (Fig. 1). This wood was attached to the bow-end of the keel where it was encased inside the bronze ram and preserved underwater until its discovery in 1980. The vessel has been tentatively provenanced to Cyprus based on iconographical similarities between symbols from the bronze-cast ram and coinage from the region and period (Murray, 1991).

At 0.70891, the median/mean $^{87}Sr/^{86}Sr$ value of Athlit Ram samples (Table 4) is significantly lower than the narrow range of the Uluburun dataset (Table 3; again addressing concerns for seawater diagenesis in the Uluburun group). However, the overlap between Cyprus and Tannourine-Hadeth (Leb. SS) is problematic for the Athlit Ram because its range runs parallel to the upper end of the 25–75% range for both sites (Fig. 4). The two forest areas have nearly identical median values, at 0.70886 for Cyprus and 0.70881 for Leb. SS, and registering just slightly lower than the Athlit Ram's median at 0.70891 (Tables 1, 4).

Table 3
Samples of the Uluburun shipwreck and their $^{87}Sr/^{86}Sr$ results with statistical summary. No ring-width data is available for these samples.

Sample ID	No. rings measured	Sample Location	$^{87}Sr/^{86}Sr$ value	2s
TU-KAS-6	105	Frame?	0.70922	0.00006
TU-KAS-7	66	Keel	0.70919	0.00008
TU-KAS-10-2	108	Dunnage/chock?	0.70922	0.00010
TU-KAS-10-6	108	Dunnage/chock?	0.70923	0.00010

No. samples	Mean	Median	Minimum	Maximum	Std. Dev.	Std. error
3[a]	0.70921	0.70922	0.70919	0.70923	0.00002	0.00001

[a] TU-KAS-10-2 and TU-KAS-10-6 are two samples from the same timber and have been averaged to calculate the mean.

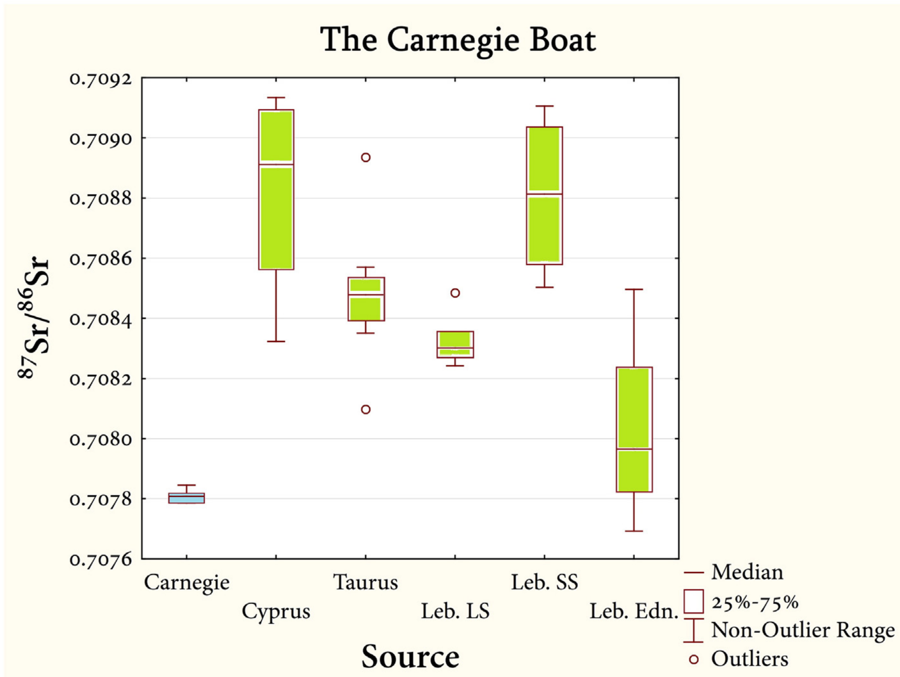

Fig. 2. The $^{87}Sr/^{86}Sr$ results of the six samples from the Carnegie boat align with the lower end of the anomalously low values for the Horsh-Ehden (Leb. Edn) cedar forest in northern Lebanon, suggesting that the wood from this boat may have originated from that forest. Outliers are determined using the Tukey 2-sided test, with a hinge distance factor (outlier coefficient) of 1.5 and a corresponding o.c. of 3 to identify extremes, of which there are none.

This is a case where other factors must be employed to make a clearer distinction between the two possible source areas. The other bow timbers were identified as elm (*Ulmus* sp.) for the chock and nosing timber; red pine (*Pinus* sp.) for the planks, keel, and wales; and live (evergreen) oak (*Quercus* sp.) for the tenons and tenon pegs (Steffy, 1991: 17). Although Steffy does not identify the ram's timbers beyond the genus, Liphschitz (2012b) provides identifications to the species level: *U. campestris*, *P. nigra*, and *Q. coccifera*. As with the Uluburun assemblage, she points to a region of origin between southeastern Turkey and Lebanon, citing the lack of *Q. coccifera* and *U. campestris* on Cyprus. However, *Q. coccifera* does grow on Cyprus, and *U. campestris* is synonymous with *U. minor*, a subspecies of which is *U. canescens*, which also grows on Cyprus (Melville, 1957; Collin, 2002; Tsintides et al., 2002: 115, 122; Neophytou et al., 2007). Of the $^{87}Sr/^{86}Sr$ data available, the southeast Turkish area is quite distinct from the Athlit Ram sample (and all ship samples in this paper) – and so appears an unlikely

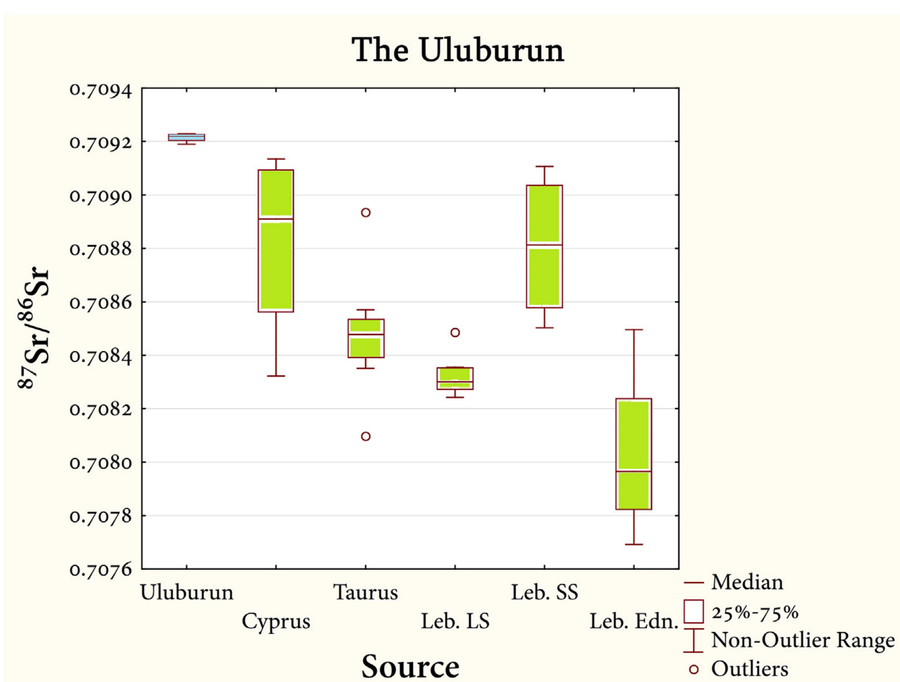

Fig. 3. The Uluburun $^{87}Sr/^{86}Sr$ results rest well above the ranges for the western Troodos forest area on Cyprus and Tannourine-Hadeth (Leb. SS) in Lebanon. Ruling out all six forest areas so far sampled (also see Feke, Table 1), the lack of a match may support the hypothesis that the ship originated in the northern Levant, in the unsampled areas of the Syrian Coastal Range or Amanus.

Table 4
Samples of the Athlit Ram shipwreck and their $^{87}Sr/^{86}Sr$ results with statistical summary.

Sample ID	No. rings measured	Sample location	$^{87}Sr/^{86}Sr$ value	2s
IS-RAM-1	182	Ramming timber or stem	0.70894	0.00008
IS-RAM-2	182	Ramming timber or stem	0.70889	0.00010

No. samples	Mean	Median	Minimum	Maximum	Std. Dev.	Std. error
2 (from same timber)	0.70891	0.70891	0.70889	0.70894	0.00003	0.00002

provenance (see Feke in Table 1; cf. Table 4). Given the dendroarchaeological and isotopic evidence, Cyprus cannot be ruled out as a possible origin. Therefore, our findings are potentially consistent with Murray's (1991) iconography- and numismatics-based hypothesis of a Cypriot origin for the ship. With Paphos having been a major shipyard of the Ptolemaic period, this hypothesis resonates historically and geographically as well (Fig. 1).

4. Discussion

The results of the $^{87}Sr/^{86}Sr$ analyses lead to the following conclusions based on the existing data: 1) Senwosret III's Carnegie boat timbers align only (and well) with the Lebanese forest of Horsh-Ehden (Fig. 2); the Uluburun shipwreck's timbers are not represented by any of the six regional and forest signatures compiled so far (Fig. 3; Table 1); and 3) the Athlit Ram's cedar timber is narrowed down to two cedar forest areas, the western Troodos in Cyprus and Tannourine Hadeth (Leb. SS) in Lebanon (Fig. 4).

It comes as no great surprise that the Carnegie boat timbers likely came from the Lebanon; however, this is the first clear indication that such exchanges took place as early as the Middle Kingdom. Furthermore, the strong association between timber samples and the Horsh-Ehden forest suggest that with further sampling in this area, a relatively clear Byblos-region signature could emerge. Under these circumstances, it would be of great interest to analyze and compare samples from the Carnegie's three sister boats housed at Chicago's Field Museum (1) and the Cairo Museum (2) (Creasman, 2010).

Given the thirty-year period of debate over the ship's origin, it is perhaps not surprising that the results for the Uluburun timbers are inconclusive. However, by using the process of elimination, we can suggest a possible origin in the Syrian Coastal Range or south-central Amanus (Fig. 1). Dendroarchaeological (Liphschitz and Pulak, 2007/2008: 74) investigations have also suggested a north Levantine origin, and it seems reasonable that the mountains nearest Ugarit, one of the LBA's most prominent ports, may have provided the ship's timbers. It could have either been built there (as some ceramics and a couple of the anchors also come from Ugarit (Goren, 2013: 58–59)), or the lumber may have been transported to a shipyard elsewhere to be constructed, perhaps along the Carmel Coast. Having a clearer idea of the timbers' origin helps us to better understand which and how forests were used to supply Syro-Palestinian merchant ships, as well as the various motivating factors behind timber acquisition.

Finally, the Athlit Ram's stem or ramming timber aligns with forest areas on Cyprus and at Tannourine-Hadeth in Lebanon. Although a dendroarchaeological investigation excluded Cyprus on the basis of the Ram's wood assemblage and stated species distribution (Liphschitz, 2012c: 96), these conclusions should be reconsidered in light of the presence of *Q. coccifera* and *U. minor* on Cyprus. The iconographical study of the bronze ram suggests a Ptolemaic Cypriot origin for the ship (Murray, 1991), and the dendroarchaeological and historical evidence along with the current isotopic study also support the possibility of Cyprus as the origin of the ship's timbers. Pliny the Elder (*Natural History* 16.203) recounts Demetrius of Macedon felling a record tall cedar in Cyprus for the main-mast of a warship, and Arrian (*Anabasis*

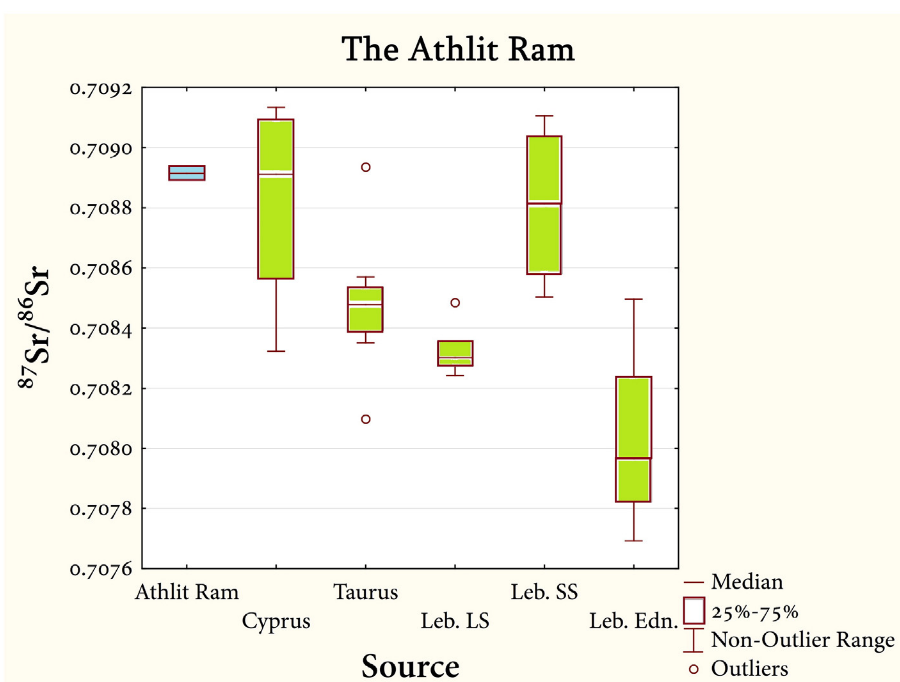

Fig. 4. The $^{87}Sr/^{86}Sr$ results for the Athlit Ram align with the upper edge of Cyprus and Tannourine-Hadeth (Leb. SS), suggesting one of those forests as a possible origin of the ram's cedar wood; this potentially supports Murray's hypothesis that the ship was Cypriot (Murray, 1991).

Alexandri 11.21.8–22.2) credits the Cypriots with building the quinqueremes used in the siege of Tyre, so the island's role in naval shipbuilding during the Ptolemaic period merits further attention (Hauben, 1987).

5. Conclusions

Our results show the potential for $^{87}Sr/^{86}Sr$ analysis to contribute to East Mediterranean cedar wood provenance. Further sampling of cedar forests across the region will strengthen the existing reference dataset to enable better provenance discrimination. Results may then give credence to or contradict hypotheses of cedar artifact origin. In turn, modified hypotheses may provide some clarity to questions surrounding timber acquisition, management, and trade, among others. Although the limitations of sampling deforested areas are noted (as trees respond to Sr contributors other than just substrate and cannot be accurately estimated using geology maps alone: Rich et al., 2012, 2015; Bentley, 2006: 148–153), one method of increasing the dataset to include previously forested areas is to analyze securely provenanced historic cedar artifacts. In this way, archaeological wood samples may be correlated, not just with forests living today, but with those flourishing in the past as well.

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References

Adams, J., 2001. Ships and boats as archaeological source material. World Archaeol. 32, 292–310.
Akkemik, Ü., 2003. Tree rings of *Cedrus libani* at the northern boundary of its natural distribution. IAWA J. 24, 63–73.
Allevato, E., Russo Ermolli, E., de Pasquale, G., 2009. Woodland exploitation and Roman shipbuilding: preliminary data from the shipwreck Napoli C (Naples, Italy). Méditeranée 112, 33–42.
Balcaen, L., Moens, L., Vanhaecke, F., 2010. Determination of isotope ratios of metals (and metalloids) by means of inductively coupled plasma-mass spectrometry for provenancing purposes: a review. Spectrochim. Acta B At. Spectrosc. 65, 769–786.
Bass, G.F., 1986. A Bronze Age shipwreck at Ulu Burun (Kaş): 1984 campaign. Am. J. Archaeol. 90, 269–296.
Bass, G.F., Pulak, C., Collon, D., Weinstein, J., 1989. The Bronze Age shipwreck at Ulu Burun: 1986 campaign. Am. J. Archaeol. 93, 1–29.
Bentley, R.A., 2006. Strontium isotopes from the Earth to the archaeological skeleton: a review. J. Archaeol. Method Theory 13, 135–187.
Black, J.A., Cunningham, G., Ebeling, J., Flückiger-Hawker, E., Robson, E., Taylor, J., Zólyomi, G., 2006. The electronic text corpus of Sumerian literature. Available at: http://etcsl.orinst.ox.ac.uk (accessed 11 July 2016).
Blanchette, R.A., 2000. A review of microbial deterioration found in archaeological wood from different environments. Int. Biodeterior. Biodegrad. 46, 189–204.
Boydak, M., 2003. Regeneration of Lebanon cedar (*Cedrus libani* A. Rich.) on karstic lands in Turkey. For. Ecol. Manag. 178, 231–243.
Bridge, M., 2012. Locating the origins of wood resources: a review of dendroprovenancing. J. Archaeol. Sci. 39, 2828–2834.
Casson, L., Steffy, J.R., Linder, E., 1991. The Athlit Ram (Nautical Archaeology Series 3). Texas A&M University Press, College Station.
Collin, E., 2002. Strategies and guidelines for the conservation of the genetic resources for *Ulmus* spp. In: Turok, J., Eriksson, G., Russel, K., Borelli, S. (Eds.), Noble Hardwoods Network: Report of the Fourth Meeting, 4–6 September 1999, Gmunden, Austria, and the Fifth Meeting, 17–19 May 2001, Blessington, Ireland. International Plant Genetic Resources Institute, Rome, pp. 50–67.
Creasman, P.P., 2010. A further investigation of the Cairo Dahshur boats. J. Egypt. Archaeol. 96, 101–125.
Dagher-Kharrat, M.B., Mariette, S., Lefèvre, F., Fady, B., Grenier-de March, G., Plomion, C., Savouré, A., 2007. Geographical diversity and genetic relationships among *Cedrus* species estimated by AFLP. Tree Genet. Genomes 3, 275–285.
Daly, A., 2007a. Timber, trade and tree-rings: a dendrochronological analysis of structural oak timber in Northern Europe, c. CE 1000 to c. CE 1650. Unpublished PhD dissertation, University of Southern Denmark.
Daly, A., 2007b. The Karschau Ship, Schleswig-Holstein: dendrochronological results and timber provenance. Int. J. Naut. Archaeol. 36, 155–166.
Daly, A., 2008. The Bøle Ship, Skien, Norway – research history, dendrochronology and provenance. Int. J. Naut. Archaeol. 37, 153–170.
Deguilloux, M.-F., Pemonge, M.-H., Petit, R.J., 2004. DNA-based control of oak wood geographic origin in the context of the cooperage industry. Ann. For. Sci. 61, 97–104.
Dumolin-Lapègue, S., Pemonge, M.-H., Gielly, L., Taberlet, P., Petit, R.J., 1999. Amplification of oak DNA from ancient and modern wood. Mol. Ecol. 8, 2137–2140.
Durand, S.R., Shelley, P.H., Antweiler, R.C., Taylor, H.E., 1999. Trees, chemistry, and prehistory in the American southwest. J. Archaeol. Sci. 26, 185–203.
English, N.B., Betancourt, J.L., Dean, J.S., Quade, J., 2001. Strontium isotopes reveal distant sources of architectural timber in Chaco Canyon, New Mexico. Proc. Natl. Acad. Sci. U. S. A. 98, 11891–11896.
George, A.R., 2003. The Babylonian Gilgamesh Epic: Introduction, Critical Edition and Cuneiform Texts. Oxford University Press, Oxford.
Giachi, G., Lazzeri, S., Mariotti Lippi, M., Macchioni, N., Paci, S., 2003. The wood of "C" and "F" Roman ships found in the ancient harbour of Pisa (Tuscany, Italy): the utilization of different timbers and the probable geographical area which supplied them. J. Cult. Herit. 4, 269–283.
Goren, Y., 2013. International exchange during the late second millennium B.C.: microarchaeological study of finds from the Uluburun ship. In: Aruz, J., Graff, S.B., Rakic, Y. (Eds.), Cultures in Contact. From Mesopotamia to the Mediterranean in the Second Millennium B.CMetropolitan Museum of Art, New York, pp. 57–61
Gosz, J.R., Moore, D.I., 1989. Strontium isotope studies of atmospheric inputs to forested watersheds in New Mexico. Biogeochemistry 8, 115–134.
Graustein, W.C., Armstrong, R.L., 1983. The use of strontium-87/strontium-86 ratios to measure atmospheric transport into forested watersheds. Science 219, 289–292.
Hajar, L., François, L., Khater, C., Jomaa, I., Déqué, M., Cheddadi, R., 2010. *Cedrus libani* (A. Rich) distribution in Lebanon: past, present and future. C. R. Biol. 333, 622–630.
Haneca, K., Daly, A., 2014. Tree-rings, timbers and trees: a dendrochronological survey of the 14th-century cog, Doel 1. Int. J. Naut. Archaeol. 43, 87–102.
Hauben, H., 1987. Cyprus and the ptolemaic navy. Report of the Department of Antiquities Cyprus 1997, pp. 213–226.
Jagels, R., Seifert, B., Shottafer, J.E., Wolfhagen, J.L., Carlisle, J.D., 1988. Analysis of wet-site archaeological wood samples. For. Prod. J. 38, 33–38.
Jiao, L., Liu, X., Jiang, X., Yin, Y., 2015. Extraction and amplification of DNA from aged and archaeological *Populus euphratica* wood for species identification. Holzforschung http://dx.doi.org/10.1515/hf-2014-0224.
Kim, Y.S., 1990. Chemical characteristics of waterlogged archaeological wood. Holzforschung 44, 169–172.
Kuniholm, P.I., Griggs, C.B., Newton, M.W., 2007. Evidence for Early Timber Trade in the Mediterranean. In: Belke, K., Kislinger, E., Külzer, A., Stassinopoulou, M.A. (Eds.), Byzantina Mediterranea: Festschrift für Johannes Koder zum 65. Geburtstag. Böhlau Verlag, Vienna, pp. 365–385.
Liphschitz, N., 2007. Timber in Ancient Israel: Dendroarchaeology and Dendrochronology. Institute of Archaeology, Tel Aviv University, Tel Aviv.
Liphschitz, N., 2012a. Dendroarchaeology of shipwrecks in Israel. Bocconea 24, 95–104.
Liphschitz, N., 2012b. Dendroarchaeological studies of shipwrecks along the Mediterranean coast of Israel. In: Efe, R., Ozturk, M., Ghazanfar, S. (Eds.), Environment and Ecology in the Mediterranean Region. Cambridge Scholars Publishing, Newcastle upon Tyne, pp. 1–12.
Liphschitz, N., 2012c. The use of *Cedrus libani* (Cedar of Lebanon) as a construction timber for ships as evident from timber identification of shipwrecks in the East Mediterranean. Skyllis Z. Unterwasserarchaeologie 12, 94–98.
Liphschitz, N., Pulak, C., 2007/2008. Wood species used in ancient shipbuilding in Turkey: evidence from dendroarchaeological studies. Skyllis Z. Unterwasserarchaeologie 8, 74–83.
Manning, S.W., Pulak, C., Kromer, B., Talamo, S., Bronk Ramsey, C., Dee, M., 2009. Absolute Age of the Uluburun shipwreck: a key Late Bronze Age time-capsule for the East Mediterranean. In: Manning, S.W., Bruce, M.J. (Eds.), Tree-rings, Kings and Old World Archaeology and Environment: Papers Presented in Honor of Peter Ian Kuniholm. Oxbow Books, Oxford, pp. 163–187.
Manning, S.W., Dee, M.W., Wild, E.M., Bronk Ramsey, C., Bandy, K., Creasman, P.P., Griggs, C.B., Pearson, C.L., Shortland, A.J., Steier, P., 2014. High-precision dendro-^{14}C dating of two cedar wood sequences from First Intermediate Period and Middle Kingdom Egypt and a small regional climate-related ^{14}C divergence. J. Archaeol. Sci. 46, 401–416.
Meiggs, R., 1982. Trees and Timber in the Ancient Mediterranean World. Oxford University Press, Oxford.
Melville, R., 1957. *Ulmus canescens*: an eastern Mediterranean elm. Kew Bull. 12, 499–502.
Muller, S.D., 2005. Palynological study of Antique shipwrecks from the western Mediterranean Sea, France. J. Archaeol. Sci. 31, 343–349.
Murray, W., 1991. The provenience and the date: the evidence of the symbols. In: Casson, L., Steffy, J.R., Linder, E. (Eds.), The Athlit Ram (Nautical Archaeology Series 3). Texas A&M University Press, College Station, pp. 51–67.
Neophytou, Ch., Palli, G., Dounavi, A., Aravanopoulos, F.A., 2007. Morphological differentiation and hybridization between *Quercus alnifolia* Poech and *Quercus coccifera* L. (Fagaceae) in Cyprus. Silvae Genet. 56, 271–277.
Patch, D.C., Haldane, C.W., 1990. The Pharaoh's Boat at the Carnegie. The Carnegie Museum of Natural History, Pittsburgh, PA.

Pollard, A.M., 2011. Isotopes and impact: a cautionary tale. Antiquity 85, 631–638.
Pulak, C., 1988. The Bronze Age shipwreck at Ulu Burun: 1985 campaign. Am. J. Archaeol. 92, 1–37.
Pulak, C., 1998. The Uluburun shipwreck: an overview. Int. J. Naut. Archaeol. 27, 188–224.
Pulak, C., 2001. Cedar for ships. Archaeol. Hist. Lebanon 14, 24–36.
Pulak, C., 2002. The Uluburun hull remains. In: Tsalas, H. (Ed.), Tropis VII, Seventh International Symposium for Ship Construction in Antiquity Proceedings. Hellenic Institute for the Preservation of Nautical Tradition, Athens, pp. 615–636.
Pulak, C., 2008. The Uluburun shipwreck and Late Bronze Age trade. In: Aruz, J., Graff, S.B., Rakic, Y. (Eds.), Beyond Babylon: Art, Trade, and Diplomacy in the Second Millennium B.C.Metropolitan Museum of Art, New York, pp. 288–310
Reynolds, A.C., Betancourt, J.L., Quade, J., Patchett, P.J., Dean, J.S., Stein, J., 2005. $^{87}Sr/^{86}Sr$ sourcing of ponderosa pine used in Anasazi great house construction at Chaco Canyon, NM. J. Archaeol. Sci. 32, 1061–1075.
Rich, S.A., 2013. Ship Timber as Symbol? Dendro-provenancing and Contextualizing Ancient Cedar Ship Remains in the Eastern Mediterranean/Near East. Unpublished PhD dissertation, University of Leuven.
Rich, S., 2016. Cedar Forests, Cedar Ships: Lore, Allure & Metaphor in the Mediterranean Near East. Archaeopress, Oxford.
Rich, S.A., Manning, S.W., Degryse, P., Vanhaecke, F., Van Lerberghe, K., 2012. Tree-ring and strontium isotope signatures of *Cedrus brevifolia* in Cyprus. J. Anal. At. Spectrom. 27, 796–806.
Rich, S.A., Manning, S.W., Degryse, P., Vanhaecke, F., Van Lerberghe, K., 2015. Provenancing East Mediterranean cedar wood with the $^{87}Sr/^{86}Sr$ strontium isotope ratio. J. Archaeol. Anthropol. Sci. http://dx.doi.org/10.1007/s12520-015-0242-7.
Speirs, A.K., McConnachie, G., Lowe, A.J., 2009. Chloroplast DNA from 16th Century waterlogged oak in a marine environment: initial steps in sourcing the Mary Rose timbers. In: Haslam, M., Robertson, G., Crowther, A., Nugent, S., Kirkwood, L. (Eds.), Archaeological Science Under a Microscope: Studies in Residue and Ancient DNA Analysis in Honour of Thomas HLoy (Terra Australis 30). ANU Press, Canberra, pp. 175–189.
Steffy, J.R., 1983. The Athlit Ram: a preliminary investigation of its structure. Mariner's Mirror 69, 229–247.
Steffy, J.R., 1991. The ram and bow timbers: a structural interpretation. In: Casson, L., Steffy, J.R., Linder, E. (Eds.), The Athlit Ram (Nautical Archaeology Series 3). Texas A&M University Press, College Station, pp. 6–39.
Traoré, M., Kaal, J., Cortizas, A.M., 2016. Application of FTIR spectroscopy to the characterization of archaeological wood. Spectrochim. Acta A Mol. Biomol. Spectrosc. 153, 63–70.
Tsintides, T.C., Hadjikyriakou, G.N., Christodoulou, Ch.S., 2002. Trees and Shrubs in Cyprus. Anastasios G. Leventis and the Cyprus Forest Association, Lefkosia.
Vanhaecke, F., Balcaen, L., Malinovsky, D., 2009. Use of single-collector and multi-collector ICP-mass spectrometry for isotopic analysis. J. Anal. At. Spectrom. 24, 863–886.
Ward, C., 1984a. The Dashur Boats. Unpublished MA thesis, Texas A&M University.
Ward, C., 1984b. A fourth boat from Dashur. Am. J. Archaeol. 88, 389.
Ward, C., 2000. Sacred and secular: ancient Egyptian ships and boats. Boston, Archaeological Institute of America. University of Pennsylvania Museum, Philadelphia.