J Mari Arch (2018) 13:55–66
https://doi.org/10.1007/s11457-017-9185-8

ORIGINAL PAPER

Recording, Publishing, and Reconstructing Wooden Shipwrecks

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Published online: 20 November 2017

Abstract Almost three decades ago J. Richard Steffy (in: Tzalas (ed) Tropis II, proceedings of the 2nd international symposium on ship construction in antiquity. Athens, pp 315–320, 1990, in: Tzalas (ed) Tropis III, proceedings of the 3rd international symposium on ship construction in antiquity. Athens, pp 417–428, 1995) voiced the need to standardize the recording and publication of shipwrecks. Cluster analysis of construction features is difficult if archaeologists record different and non-overlapping features. This paper discusses the necessity to standardize the recording and publishing of a set of consistent and compatible basic construction features when archaeologists assess, survey, or excavate wooden shipwrecks and proposes a methodology for the recording of wooden hulls. It also emphasizes the urgency of a wide and complete sharing of archaeological information in maritime archaeology.

Keywords Nautical archaeology · Standardization · Early modern shipwrecks · Databases

In 1995 J. Richard Steffy wrote that nautical archaeology was entering the computer age, and for an effective utilization of the available technology, a more complete and effective method of recording ship hull information must be adopted (Steffy 1995). Twenty-two years later, computers are faster, the internet is ubiquitous in the academic world, and the discipline of Nautical Archaeology has widened its scope to include the study of the

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landscapes where ships were built, worked, and lost. Even with all of these changes, the study of the history of wooden shipbuilding remains as important as ever, and the need for comprehensive and accurate recording of archaeological shipwrecks has become ever more important. The sample of shipwrecks available for study is growing continuously, the number of maritime archaeologists is growing as quickly, and the next generation of scholars are sharing data faster and more effectively than ever, shattering the secrecy that traditionally surrounded archaeological excavations. In light of this new climate, uniformity in the methods used to publish archaeological data is more important than ever, and as such it is appropriate to re-issue J. Richard (Steffy's 1995) proposal to standardize the publication of shipbuilding data.

The traditional situation of secrecy and lack of circulation of images and primary data in archaeology is changing drastically, together with the global rate of literacy, and it seems safe to assume that in the near future archaeology will be a global discipline, producing worldly narratives, based on a much wider concept of culture than in the past century. The most important factor in this situation is the need to publish and make available every excavation in the world. Title XIV of the rules the UNESCO Convention for the Underwater Cultural Heritage is clear on the importance of the dissemination of knowledge. Only a few years ago, in his introduction to the Oxford Handbook of Maritime Archaeology (2011), George Bass pointed out that, as a class, archaeologists have a past track record of negligence: it seems that we publish approximately 25% of the sites excavated. Bass' assumption is based on a number of studies suggesting that over the last 50 years, less than 25% of the materials and results of professional archaeological excavations have been properly published (Boardman 2009), 70% of the Near East excavations have not been published (Atwood 2007 and Owen 2009), and that perhaps 80% of all Italian archaeological materials remain unpublished (Stoddart and Malone 2001). It is difficult to argue that the situation in maritime archaeology is better than those mentioned above, and the authors intend this paper as a manifesto on the urgency of a wide and complete sharing of archaeological information in maritime archaeology. With the progressive growth of the field and the anticipated increase in ship excavations, standardization of the recording process is a necessity.

Ships can be studied from four basic viewpoints: from a social-oriented viewpoint, as "*a part of everyday existence and (…) as evidence for aspects of the past that can be known imperfectly from other kinds of evidence*," (Upton 1983); from a culture-oriented viewpoint, looking at their construction features as memes—here understood as units of cultural ideas that can be transmitted and modified—related to the different European cultures at play, something that Ole Crumlin-Pedersen called cultural fingerprints, and Eric Rieth referred to as architectural signature (Upton 1983; Crumlin-Pederson 1991; Rieth 1998); from a symbolic-oriented viewpoint, focusing on decorative and aesthetic elements, as well as the symbolic character of architectural solutions and the images ships evoked in people's minds (Bachelard 1957; Upton 1983); and from a more prosaic viewpoint, which we will call an object-oriented viewpoint, concerned with the ships as artifacts. This last viewpoint is fundamental and, we would argue, precedes the former. To understand ships we need to know when they were built, how they were conceived, built, and improved, how quality was perceived, where did knowledge reside, and how it was it transferred (Upton 1983).

This first step encompasses the study of ship remains. Ships are wooden artifacts built for transport, fishing, war, or pleasure, and must be studied from a technological viewpoint, which is a part of the process that aims at understanding their importance as means of deploying power, transferring wealth, carrying merchandise, people, diseases, and ideas. Ships have been vectors of commerce and exchange, and they are intimately related to the creation and accumulation of wealth and power. Technological differences between the ships of different core and periphery regions—to borrow the Eurocentric spatial/economical concepts from Immanuel Wallerstein's World Systems framework (2011a, b)—must be discussed in terms of performance, cost, durability, and purpose, as the study of ship design and construction. Studied in combination with an archaeological framework, this analysis may help anthropologists, sociologists, and historians understand comparative advantages between the ships of the last millennium. Tonnage, displacement, cost, number of crew members per ton, capacity in relation to displacement, speed, structural strength, and lifecycles are important factors influencing the development of a region, and nautical archaeology is capable of retrieving data that speaks to these aspects.

Richard Steffy Database

Starting in the 1980s, J. Richard Steffy saw computers as promising tools for the study of shipbuilding. Comparative studies seemed to him, as they seem to us now, like a natural way to understand shipbuilding as a particular type of human behavior, and his first step was inventorying and comparing construction features. This was not an easy endeavor. Of the ships studied by Steffy for his original database, he found little more than half had been formally published, and of the ones that were, the details recorded varied with different academic priorities and, as such, the information reported was difficult to compare across wrecks (Steffy 1990).

By the late 1990s, Steffy's database was a well-thought out combination of 13 large spreadsheets detailing construction features and scantlings and promised to become a powerful tool to explain the history of wooden shipbuilding in the western world. Focusing on classical, shell-based ships, Steffy called for a standard that provided clear information on 11 basic ship features, as indicated on Table 1 below:

Steffy warned that few ships would be preserved enough to supply all the information presented above, but asked that this list should be used as a checklist (Steffy 1995).

ShipLAB's Early Modern Ships Database

Inheriting its creator's database, the J. Richard Steffy Ship Reconstruction Laboratory (ShipLAB) team never ceased to work on it and develop its potential. It eventually became the base of a computer ontology developed by a Texas A&M University (FCT-IIS-0,534,314) computer science student (Monroy 2010). As it stands today, the Early Modern Ships database is a simplified version of Steffy's database, encompassing a small number of construction features, selected in relation with the scantlings and ship shapes studies. Developed in connection with the Texas A&M University Libraries, this database has a GIS component—developed under the direction of co-author Cecilia Smith—and intends to be shared online, in order to foster collaboration and exchange of information between scholars worldwide: http://modernshipwrecks.com/.

The time span was also reduced, as this study aims at the ships of the early modern period to the golden age of sail (1250–1850), which are directly related to the rise of capitalism and the intellectual revolution triggered by the European Renaissance, the Atlantic Expansion, and the Enlightenment (Wallerstein 2011a, b). The traits selected to be included in this database were narrowed down to the minimum data necessary to

Table 1 Checklist for the recording of shipwrecks (Steffy 1995)

1.	One or more scaled sectional drawings, either in reconstructed form or as found on the seabed, showing cross-sectional details of all structural components
2.	Keels—wood type(s); number of pieces in keel; sided and molded dimensions, taken at various locations if dimensions are not constant; scarf and end details; rabbet dimensions; distance from rabbet to top of keel
3.	False keels—wood type; number of pieces; fore and aft limits; method of attachment to keel; composition, dimensions, and distribution of fastenings
4.	Stems and sternposts—wood type; number of pieces; sided, molded, and other applicable dimensions (including cross-sectional sketches); method of attachment to keel, including scarf or mortise details; fastening types, composition, dimensions, and distribution of fastenings
5.	Planking—wood type(s); thickness, each strake; applicable widths, especially at amidships and ends; scarf details, such as type, length of scarf, and width of plank at scarf; type, size, direction, and location of fastenings used to hold down scarf tips; fastening types, composition, dimensions, and distribution (should include treenails where nails are driven through them, clenching details, treenail wedges or heads, etc.); hooding end details, including fastening patterns and planking shapes
6.	Mortise and-tenon joints-mortise dimensions (wide, deep, and thick) taken at numerous, widely scattered locations; tenon dimensions, average center-to center spacing, also noting extreme variations from the average, wood types for tenons and pegs; average peg diameters at inner and outer planking surfaces, average distances between peg centers and seams, orientation of mortises at scarfs (perpendicular to scarf or seam?), method of cutting mortises, if discernable, slips and other mortise fillers, remains of tenon lubricants
7.	Frames—wood type (number and management of pieces in frames; room and space (center to center distance at keel); framing plan, frame curvatures, where known, sided and molded dimensions at keel, heels and heads of timbers, and intermediate dimensions as applicable, butt, scarf, or chock details, method of attachment to keels, locations and dimensions of limber holes, edge chamfering details
8.	Keelsons—wood type, fore and aft limits, number of pieces, sided and molded dimensions; scarfs; steps, mortises, and other cuttings, method of attachment to keels and frames, description and dimensions of fastenings
9.	Ceiling (includes common ceiling, limber boards, ledges, footwales, stringers, clamps, and shelf clamps)—wood types, thicknesses, widths, where applicable, scarfs or butts, fastening information, end details
10.	Lead sheathing—thickness, sizes and shapes of sheets, sizes and directions of overlaps, fastening dimensions, composition, and distribution, composition and thickness of underlayment, methods of tucking around keels and posts
11.	Details of mast steps, knees, beams, stanchions, bitts, decks, pumps and sumps, anchors, and rigging artifact

characterize some of the differences and similarities observed among the European ships of the early modern age in the western world.

These traits are indicated below, on Table 2, and encompass seven clusters of data, which should be considered the minimum checklist for the recording of Early-Modern European shipwrecks, and are what the authors propose as a minimum standard for their publication.

The hull description indicated on items 4 and 5 can be standardized and loosely follow the construction sequence most common on ships of this period: keel, posts, stern panel (when present), frames, keelson, stringers, wales, planking and ceiling. Site plans should ideally be presented in three drawings: one indicating the ship's natural stratigraphy such as ceiling, stringers, keelson, mast step, stanchions, riders, and other features belonging on or at the level of the ceiling planking; two depicting the frames; and the third showing the hull planking and wales. Additionally, information on the connections of the timber should

Table 2 Checklist for the recording of European early modern shipwrecks

1.	Description and status of the site, including a site map and one or more scaled sectional drawings, either in reconstructed form or as found on the seabed, showing cross-sectional details of all structural components
2.	Tentative identification, dating, and location of the shipwreck
3.	Tentative interpretation of the site, indicating the possible typology and origin of the ship.
4.	Measurements, including the sites main dimensions
5.	Timber scantlings, if possible described along the lines indicated by J. Richard Steffy in items 2 through 11, and emphasizing the need to determine the timbers basic dimensions, especially the preserved length, section shape and sided and molded dimensions
6.	Construction features specifically related to European sailing ships designed for Atlantic navigation
7.	A section describing artifacts useful for the identification of the shipwreck

be indicated, including scarves and fasteners, especially connecting the basic structural elements (e.g. keel/keelson/frames, floor timbers/futtocks, planking/frames, etc.).

The construction features mentioned in item 6 are a list evolved from Thomas Oertling's seminal work on what characterizes the ships of the Iberian age of exploration (2005), completed with a number of shipwrecks published since, and indicated below, on Table 3.

The study of the relation between ship sizes and scantlings would be useful for nautical archaeologists, as for a given period or region there may be minimum and maximum sizes of vessels that can be assumed from partial scantling data. For example, if fragmentary or disarticulated ship timbers are identifiable and measurable, the data could be compared to similar vessels within the database and a likely minimum length or tonnage and a maximum length or tonnage could be assumed. Ratios between timbers or construction features and the overall size of the vessel may also exist, and vary less across the sample than others; these ratios could provide a more conservative and reliable estimation of size. The dimensions of the keel, for example, may closely correlate with the overall length or tonnage of a vessel for a given region or time period. If a keel has survived at a wreck site it could be used to assume overall size more accurately than other timber-size ratios, although these details are still unknown.

A correlation between region and period may also exist, and could also emerge from this study. Examining timbers in detail, as well as their related positioning and fastening patterns could help identify these factors as well. If the database can contain a significant enough sample size, and the data itself is standardized for both collecting and reporting, multivariate analyses can easily highlight such relationships. Such statistical studies rely on large samples of data that are highly controlled, and the accuracy depends upon

Table 3 Iberian and Atlantic architectural signatures

1.	Connection of the keel to the sternpost and to the stem
2.	Evidence for a number of pre-designed and pre-assembled central frames
3.	Planking fastening pattern
4.	Keel section
5.	Keelson and maststep arrangement
6.	Stern panel
7.	Rigging characteristics

practitioners and their adherence to standards for the data entered, so the cooperation and collaboration of scholars around the world is needed.

Collecting and analyzing archaeological data such as this does more than contribute to nautical archaeology theory and praxis however; it opens the door for any scholar to conduct studies that require quantitative and qualitative shipbuilding data sets across time and space. Such studies can be multiscalar, i.e. they combine consistent and compatible data from various spatial and temporal scales to address a single site, and is an approach that encourages holistic research. Multiscalar research is more encompassing and intrinsically collaborative as well, and brings together a variety of different practitioners and their skills to be effective. By incorporating data from nautical archaeology into existing theories of study, the field can expand in size, influence, and usefulness as it would be part of broader conversations that are still taking place.

There are a number of shortcomings that must be accounted for with this project. The development of taxonomies can encourage oversimplifications and foster confusion "*in the way we classify artifacts, strata, and people*" (Henry et al. 2017), and it is clear that this project is launching from an ethnocentric viewpoint, and this database was designed to compare Iberian ships to other contemporary European ships, hoping to identify patterns that will help us map the complicated paths taken by knowledge and convention from harbor to harbor, along the Mediterranean, Baltic, and Atlantic coasts, and through the rivers and lakes of the European continent. (Kristiansen 2008).

Recording Ship Structures and Shapes

Ship structures can yield clues for the understanding of technological solutions, which are intimately connected to the ways in which knowledge travels and the places where it resides. The contribution of nautical archaeology will provide a clear technological frame that may permit the development of shipbuilding families, and analyze the evolution and diffusion of these taxonomies through time. For accurate comparisons between shipwreck sites, *how* the aforementioned features are recorded is as important as to the selection of which features to record. A timber catalogue is the basic document of any ship recording. Like everything in archaeology, the development of a timber catalogue is an iterative process. Each timber should be tagged and entered in the catalogue with its position marked on a site plan. The dimensions exposed in each phase of excavation should be documented in a way that allows for a reconstruction of the complete timber. The minimum details needed to sufficiently document each timber are catalog number, location, function, condition, dimensions, joinery, fastenings, marks, coatings, and conversion.

An ordered and logical numbering system for timbers is one of the most important organizational items for interpreting a shipwreck, and if they are assigned immediately upon their first exposure during excavation, the timbers should receive just a number. When the timbers' function is clear from the beginning, a letter can be added to designate planking of frames or ceiling, to cite the most common examples. The location can be pointed out in the site plan, and be referenced with the grid number, or other type of coordinates. Scarves and fasteners must be recorded in detail, with positions, sections, materials, and dimensions. Pictures and sketches are fundamental. All fasteners were inserted from one side of the timber, and the insertion direction must be recorded as well. In salt water the size and shape or iron fasteners can be determined by cleaning and casting the concretions. Surface marks and coatings must be photographed and recorded in detail, both tool and construction marks are relevant for the reconstruction process. The eventual conservation of the timber is essential to a complete understanding of the construction process. Ideally the growth rings should be counted in both extremities, and the wood grain should be recorded along its surfaces, including knots.

Recording the shape of the hull is different, and requires the overall curvature of the hull remains, both transversely and longitudinally. Where possible, the recording of the bevels in frame timbers at regular spaces, (around 20 or 25 cm apart), contributes to a better understanding of the original hull shape. The shape of the midship section was always defined in relation with the ship's length, and its variation along the keel determined the shape of the frames, which were beveled by ways that are not yet well-understood. When reconstructing a hull, the bevels can give precious indications on the tangent of the reconstructed diagonals and waterlines, and its accurate recording is important.

To record the curvature of as many frames as possible is also important, and the archaeologist should keep in mind that frames can have complex shapes, obtained with battens and offsets, or resulting from the combination of a certain number of circular arcs, generally a turn of the bilge arc, a futtock arc, and sometimes a tumblehome arc. It is also important to remember that the methodology in building each vessel varied, that recording these differences is also crucial in identifying preferences and supposed corrections in the idiosyncrasies of the builders.

Available data published on the lower hull is currently inadequate for providing archaeologists an ample statistical sample size. It is crucial in moving forward that those who have the means to record the lower hull of early modern European ships collect and report on the data from surviving structures. Once a significant number have been described, archaeologists can then create a comparative analysis answering larger questions as to shipbuilding regional preferences and decision making of specific individuals on modifications in design in relation to the environment in which these ships were employed.

Scantlings and Ship Sizes

A preliminary analysis of a sample of shipwrecks by the authors suggested that the thickness of the planking, the sided dimension of the keel, the molded dimension of floor timbers and first futtocks, and the room and space are proportional to a ship's keel length, or length overall. The results of this analysis are presented in Tables 4, 5 and 6, and Figs. 1, 2, and 3 below. This analysis suggests that a division along well-identified shipbuilding traditions is in order, before trying to make sense of the dimensions that seem to follow some proportional rules of thumb. The tables presented below illustrate this feature, particularly in the ships of the northern coast of Europe, where several different shipbuilding traditions coexisted and evolved during the period under consideration. We believe that a wider study of these characteristics will allow a refinement of our criteria, providing that more vessels are published along the standards proposed below. It is likely that the characteristics selected will change as the sample of analyzed vessels grows.

Table 4 Dimensions of samples of Iberian-built ships

Name	LOA	Keel l	Keel S	Floors M	R&S	Planks
Aveiro F (1400)	?	?	11	12	24	4
Corpo Santo (1400)	?	?	11	12	32	4
Aveiro A (1450)	17	12.3	12	13	33	5
Molasses Reef (1510)	?	?	?	17	35	5
San Juan (1565)	22	14.7	21.5	20	37	5.5
Fuxa (1610)	26	17.1	25	21	40	6
Studland Bay (1525)	23	14.4	24	17	36	6
Highborn Cay (1510)	22	?	16	18	36	6
Playa Damas (1530)	?	?	?	18	36	6
St. John's Bahamas (1564)	?	?	?	20	48	6
San Diego (1600)	33	23.7	21	17	47	7
Belinho (1600)	23	15	23	18	36	7
Emanuel Point 1 (1559)	33	23.6	26	19	37	7.5
Green Cabin (1618)	?	?	?	19	43	8
C. Sodré (1500)	39	27.7	25	20	40	8
Sta. Margarita (1622)	?	?	?	22	45	8.5
Seychelles (1589)	?	?	?	18	36	9
Bom Jesus (1533)	?	?	?	18	47	9
San Esteban (1554)	?	?	31	23	43	10
N. S. Atocha (1622)	?	?	?	24	51	10
IDM-003 (1600)	39	27.7	28	24	46	?
P. Wreck (1606)	39	27.7	25	25	47	11

LOA and keel length in meters, remaining dimensions in cm

Table 5 Dimensions of samples of Mediterranean-built ships

Name	LOA	Keel l	Keel S	Floors M	R and S	Planks
Les Sorres X (1300)	10	?	7	5	22	2
Culip 6 (1300)	16	?	9	10	25	3
Contarina 1 (1450)	21	?	15	12	28	4
Yassiada (1580)	21	?	20	12	28	5.5
Calvi 1 (1580)	30	?	21	13	30	6
Gnalic (1583)	40	?	25	18	36	10
Mortella 3 (1555)	33	25	40	23	38	10
Lomelina (1516)	45	?	35	22	40	11

LOA and keel length in meters, remaining dimensions in cm

Table 6 Dimensions of samples of ships built in northern Europe

Name	LOA	Keel l	Keel S	Floors M	R and S	Planks
B and W 4 (1580s)	16.2	14	44	11.5	30	4.3
B and W 7 (1580s)	20	?	25	21	35	5
Cattewater (1500)	?	19.8	22	20	45	6
B and W 5 (1625–1640)	32.5	27.2	36	18	37	6.5
Rye A (1550)	?	?	?	21	59	7.6
B and W 2 (1620–1630s)	27	?	36	19	36.5	7.7
B and W 1 (1580s)	18.2	16.1	32	15	30	9
Mary Rose (1510)	42	31	38	20	65	10

LOA and keel length in meters, remaining dimensions in cm

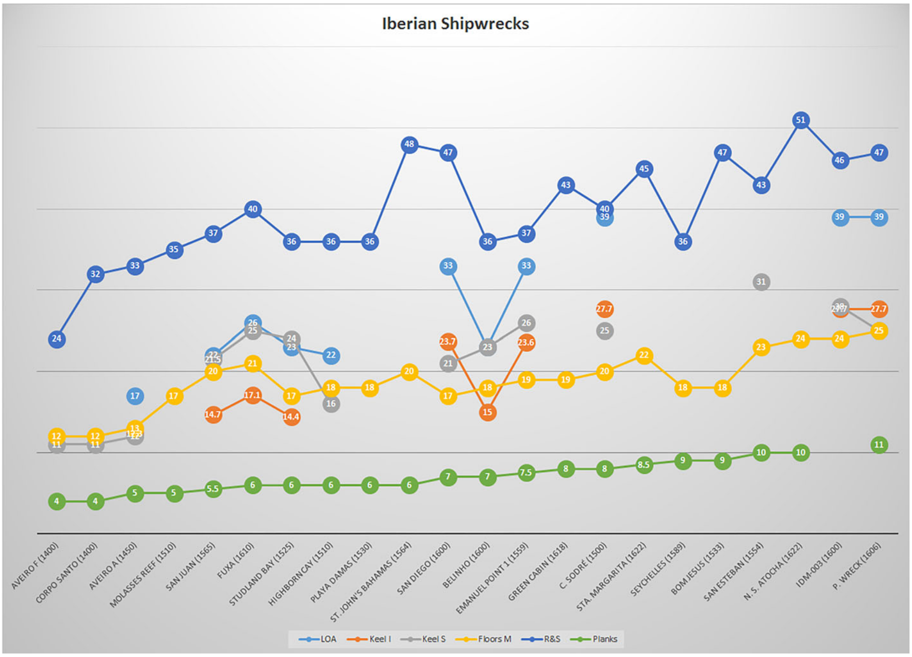

Fig. 1 Dimensions of samples of Iberian-built ships (LOA and keel length in meters, remaining dimensions in cm)

Conclusions

The drive to identify and classify each and every aspect of ship construction and use since J. Richard Steffy's original call for standardization has allowed for ever more complex and confident reconstructions of scant archaeological remains. The establishment of his original database and the continued refinement and expansion of the details recorded means that future correlations will be possible between aspects of documented data that were heretofore undiscernible. One concern, however, is the possibility of a false feedback-loop

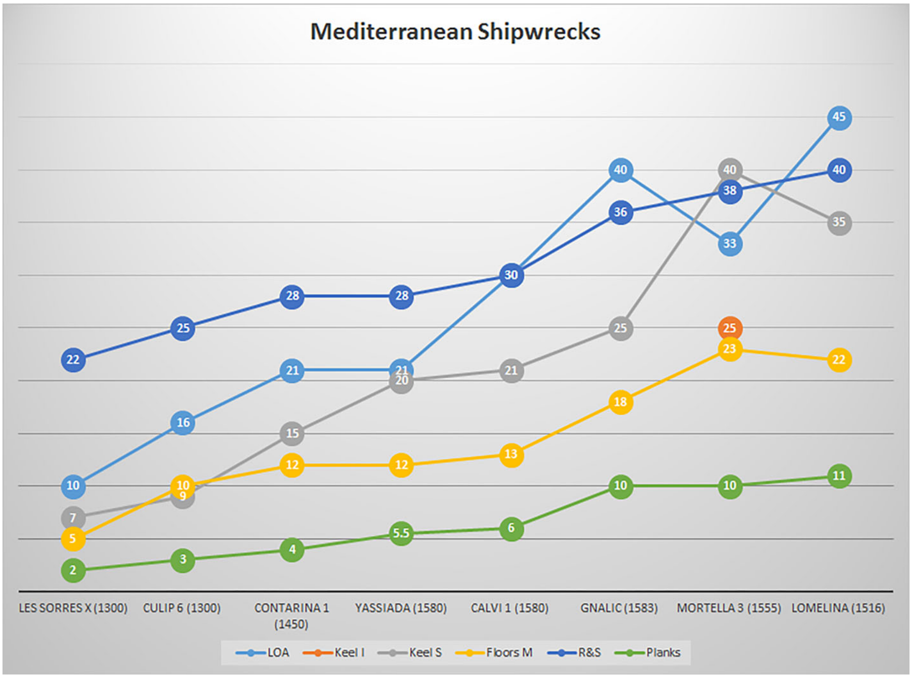

Fig. 2 Dimensions of samples of Mediterranean-built ships (LOA and keel length in meters, remaining dimensions in cm)

establishing itself in this database if the archaeological community is not vigilant and skeptical. The obvious example would be a shipwreck found with the keel dimensions and frame align nicely with a particular type of ship, that wreck might be assigned to that ship-type category in the database. If these similarities were merely a coincidence, the remaining dimensions from that wreck will then be a part of the classifying information for that ship type. Working with scant information, this type of stacking error is a real possibility and can lead to foundational faults in the database.

A second concern is the possible removal of unbiased scholarship. If a shipwreck is being studied and the measurements are fed into the database where the numbers align with a certain type of ship, it is possible the scholar studying the ship will unconsciously shape the data to fit their preconceived notion of what that ship type should look like. It is paramount that our database be used with zealous skepticism and pessimism, as our desire for classification can make us susceptible to accepting an overly-simplistic and convenient answer to our research questions.

A methodical examination of complex patterns in large data sets can produce unexpected and informative results unobtainable through traditional 'apples-to-apples' methods of comparison. The standardization of ship documentation practices for the purpose of eliciting these comparisons across archaeological studies will hopefully enable the database being built to fill in the gaps that exist on deteriorated or disarticulated sites. Any database is only as accurate as the data it is analyzing, and this database needs a wide array of shipwreck sites with excellent documentation. The power of this database will be in its accessibility to the international community of scholars and in the cooperation and open sharing of data among archaeologists.

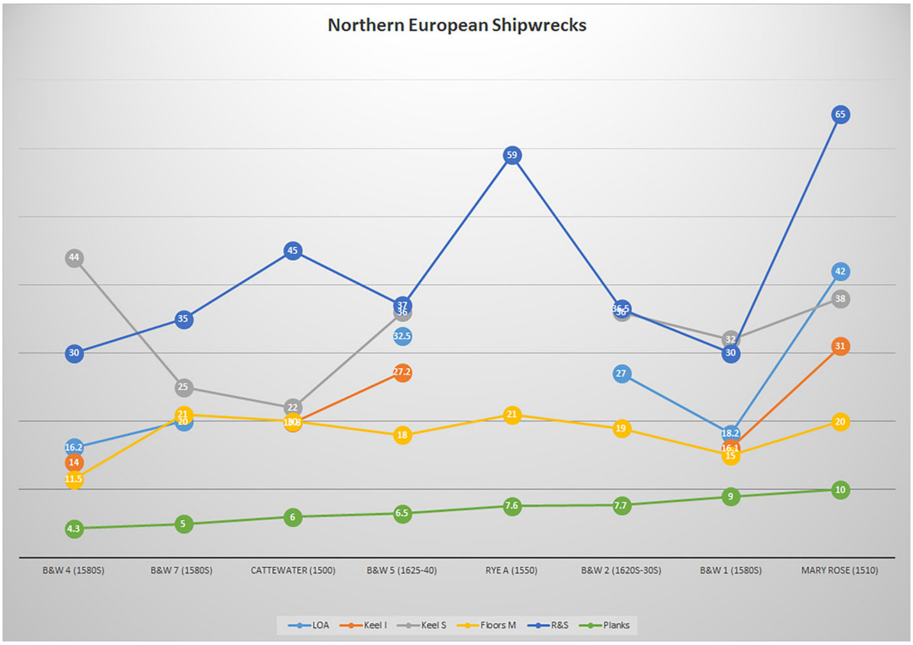

Fig. 3 Dimensions of samples of ships built in northern Europe (LOA and keel length in meters, remaining dimensions in cm)

Our final comments reiterate J. Richard Steffy's call for standardization and the establishment of categories, types, traits, traditions, standard measurements, etc., which requires an effort towards the formalization of knowledge, in search of technical tendencies, as proposed by André Leroi-Gourhan (1943, 1945). This call comes with the warning that, although this effort is absolutely necessary for the growth of the discipline, it requires a continuous discussion in search of a sound theoretical and methodological framework. A set of important questions must remain open and guide the management of eventual changes in the architecture of our database. Meaningful interpretations cannot be solely based on statistics. Social and economic history, art history, literature, and ethnography are paramount in helping us establish meaningful classes and types and determine what to measure and what to record.

Funding Funding was provided by Center for Maritime Archaeology and Conservation.

Compliance with Ethical Standards

Conflict of interest We declare that there are no conflicts of interest among any of the authors of this paper, and that the research presented in it is based on ethical standards.

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