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TECHNICAL BRIEFS

Connecting Sunken Actors: Social Network Analysis in Maritime Archaeology

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Abstract The concept of a "social network" has become a popular term thanks to online tools such as Facebook or Twitter, allowing us to connect with everyone. Specific to archaeology, social network analysis (SNA) is well established as a method, but its theoretical application in maritime archaeology is an incipient initiative. This paper presents the use of SNA in maritime archaeology as a potential instrument to reinterpret underwater sites by integrating spatial and nonspatial patterns of cultural contact. The method implies an abstraction of an historical phenomenon in concepts of network analysis to be represented as network data. Using early Australian shipwrecks as examples, this paper shows how the application of SNA in maritime archaeological contexts can help to analyze and visualize flow of material goods, power, influence, and social control. As a result, it can be argued that exploring the structural position of actors in a network can reveal information about developing relationships in maritime contexts during the past.

Resumen El concepto de "red social" se ha convertido en un término popular gracias a herramientas en línea como Facebook o Twitter, que nos permiten conectarnos entre todos. Específico de la arqueología, el análisis de redes sociales (ARS) está bien establecido como método, pero su aplicación teórica en la arqueología marítima es una iniciativa incipiente. Este artículo presenta el uso de ARS en arqueología marítima como un instrumento potencial para reinterpretar sitios submarinos mediante la integración de patrones espaciales y no espaciales de contacto cultural. El método implica una abstracción de un fenómeno histórico en conceptos de análisis de redes para ser representado como datos de red. Al usar los primeros naufragios australianos como ejemplos, este artículo muestra cómo la aplicación de ARS en contextos arqueológicos marítimos puede ayudar a analizar y visualizar el uso de bienes materiales, poder, influencia y control social. Como resultado, se puede argumentar que explorar la posición estructural de los actores en una red puede revelar información sobre el desarrollo de relaciones en contextos marítimos durante el pasado.

Résumé Le concept d'un « réseau social » est devenu un terme populaire grâce aux outils en ligne tels que Facebook ou Twitter, lesquels nous permettent de nous connecter avec chacun. L'analyse de réseau social (SNA—Social Network Analysis) qui est spécifique à l'archéologie, est bien établie à titre de méthode mais son application théorique en archéologie maritime est une initiative à ses prémices. Cet article est une présentation de l'utilisation de la SNA en archéologie maritime en tant qu'instrument potentiel

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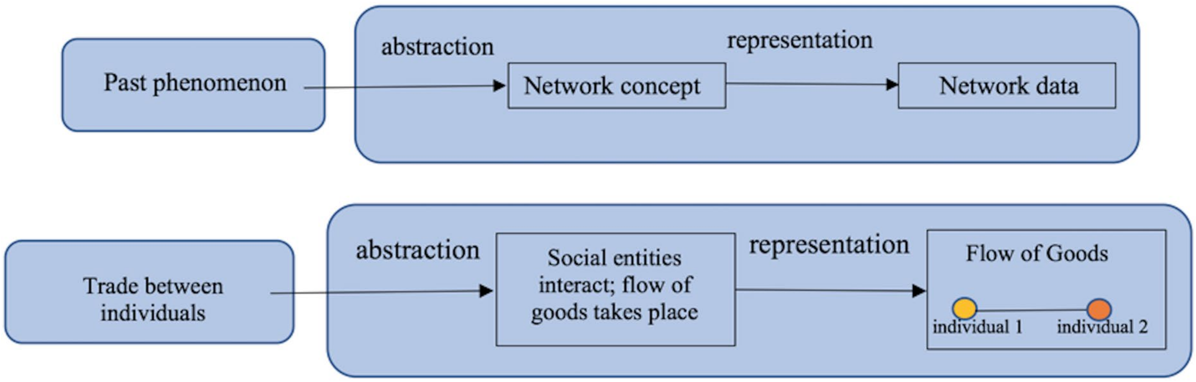

Fig. 1 Representation of a network model and its application (after Collar et al. [2015:5]).

permettant une réinterprétation des sites sous-marins par l'intégration de modèles spatiaux et non-spatiaux de contact culturel. La méthode implique une abstraction d'un phénomène historique suivant des concepts d'une analyse de réseau pour leur représentation en tant que données de réseau. S'appuyant sur d'anciennes épaves australiennes à titre d'exemples, cet article démontre comment l'application de la SNA dans des contextes d'archéologie maritime peut contribuer à analyser et visualiser le flux de biens matériels, de pouvoir, d'influence et de contrôle social. Il peut être postulé en conséquence que l'exploration de la position structurelle des protagonistes au sein d'un réseau peut révéler des informations quant au développement de relations dans des contextes maritimes au cours du passé.

Keywords networks · connectivity · material culture · maritime archaeology · shipwrecks

Introduction

The term social network has become popular thanks to online tools such as Facebook and Twitter, which allow users to connect with others in a virtual environment. This notion of network has influenced not only our daily lives, but also science. Currently, the network approach covers a range of interdisciplinary fields as diverse as computer sciences (Pham et al. 2011), physics (Hunt and Manzoni 2015), and social sciences (Lazega and Snijders 2015). In maritime archaeology, social network analysis (SNA) is well established as a method, but its theoretical application to create network models still is an emerging initiative (Leidwanger and Knappett 2018).

SNA has been defined as an interdisciplinary behavioral science specialty. It is grounded in the observation that social actors[1] are interdependent and that the links among them have important consequences for every individual (Freeman 2000:350). Some authors see SNA as "its own paradigm" (Leinhardt 1977), containing a unique approach to understanding the social world (Prell 2013:19). This statement is not free from criticism. From psychology to anthropology, the diverse fields to which SNA has been applied have emphasized different aspects, such as the interplay between cognition and social relations (Prell 2013:20). As a result, a network can be defined most broadly as "a set of items … with connections between them" (Newman 2003:168).

A relationship network, then, would consist of additional information, which can be shown graphically (De Nooy et al. 2018). Network concepts can be used to abstract the phenomena under investigation (Fig. 1) (Collar et al. 2015:4); for example, links between actors permit the flow of material goods, information, power, influence, social support, and social control (Freeman 2000:350). Finally, the application of methods and theory from network science to archaeology has increased dramatically in recent years. Already in the 1960s, archaeologists

[1] An actor or agent is thus defined as the "source of an action regardless of its status as a human or non-human" (Cresswell et al. 2010:2). In a network structure an actor also refers to a node, which is "[d]efined as an atomic discrete entity representing a network concept" (Collar et al. 2015:22).

were using incipient network methods. For example, Voronoi tessellations (Thiessen polygons) were used to model zones of influence in the 1970s (Renfrew 1975). Nevertheless, only in the last decade has network analysis become more widely applied with the use of complex models (Collar et al. 2015:2; Mills 2017).

Application of Network Analysis in Archaeology

One of the most potent ideas from social sciences is the notion that individuals are embedded in thick webs of social relations and interactions (Borgatti et al. 2009:1). Network analysis provides a conceptual bridge between individual agents and complex systems that has obvious applications for archaeology (Brughmans 2013:625). Malkin's (2011:17) *A Small Greek World* is a good example of how a network approach can change interpretation of archaeological contexts:

> Imagine filling up the coastlines with dots (or "nodes" in network parlance), representing all Greek maritime cities. Imagine the connecting lines ("ties") among them, as well as some content moving along those lines ("flows").

Malkin did not create a visual model in his work, but turning to a network approach in his archaeological analysis yielded a "wide-angle vision of the ancient Mediterranean" (Malkin 2011:19). His introduced concepts, including similarities, social relations, interactions, and flow, provided the framework to define the relationships between actors in a network system. Interactions are produced in the context of social relations, and flows are those interchangeable items—tangible or intangible—that result from the interactions. In commercial trading, for example, merchants (social relations) reach an agreement (interactions) to exchange products. Armed with such network concepts, past phenomena can be abstracted into network concepts that then can be represented visually (Fig. 1) (Brandes et al. 2013:10; Collar et al. 2015:4). This process can reveal new insights into archaeological data, from which new interpretations are possible—insights that were previously beyond conventional archaeological analysis.

Currently there are two major approaches to characterizing networks, depending on theoretical perspective and interpretation: nodal position and network structure (Mills 2017:382). The first focuses on the position of a node and how the network as a whole affects the behavior and future of that node. On the other hand, network structure focuses on the entire network and its attributes, and how they might define variabilities such as centrality. According to SNA, centrality means that nodes in more central positions have not only more direct ties (hence more occasion to get firsthand information or products), but also enjoy controlling privileges over valuable information exchanged by their acquaintances (Hanneman and Riddle 2005). In his study of hierarchy in Japan's initial Kofun period, Mizoguchi (2009) used diverse measurements from centrality to determine that the relationship between social groups was more important for the development of hierarchies than the attributes of these groups, such as control of raw materials. Similarly, Mol, Hoogland, and Hofman's (2015) egonetwork study of the 14th-century site of Kelbey's Ridge 2, on the island of Saba, showed how centrality affects the analysis of a network. They demonstrated that the position of one person in a network could identify his or her opportunities to broker a deal or mediate between other people (Mol et al. 2015:278). A relevant example of the use of relational networks in archaeology is the studies applied in Roman pottery (Brughmans 2010; Brughmans and Poblome 2016) based on the idea that "social relations are channels of social contagion and persuasion, and as such instrumental to the diffusion process" (Brughmans 2013:635). Finally, Carl Knappett's book, *An Archaeology of Interaction: Network Perspectives on Material Culture and Society*, played a pivotal role in integrating network methods and theory into archaeology (Knappett 2011:3–12). Knappett argued that network analysis can make an innovative contribution to archaeology because it "[f]orces a consideration of relations between entities"; has the "flexibility to be both social and physical"; is a "strong method for articulating scales"; "[c]an incorporate both people and objects"; and "[c]an incorporate a temporal dimension."

Mills, Clark, and colleagues (Mills, Clark et al. 2013:381) provided some additional insights in their review of the application of network theory to archaeology, arguing several benefits, such as its ability to handle large datasets; its compatibility with other analytical methods, geographic information systems

(GIS), and agent-based models; its ability to produce complex computer visualizations; and its basis in relational concepts commonly used in the study of the past.

Based on this framework authors such as Brughmans (2013:18) have argued that "archaeologists only became aware of SNA once they had been inspired into networking thinking by the exciting developments in complexity science, especially the work of Watts and Strogatz (1998) and Barabási (2002)." He also contended that archaeologists were not familiar with the earlier network studies in archaeology from the 1960s and 1970s, and noted that a number of issues needed to be addressed in future applications (Brughmans 2010:10): the role of archaeological data in networks; the diversity of network structures and their consequences and interpretation; the critical use of quantitative tools; and the influence of other disciplines, especially sociology.

Promoting the Use of SNA in Maritime Archaeological Contexts

The application of SNA in maritime archaeological contexts can be used mainly as an approach to explore connectivity for sea and coastal spaces. However, these models are open to a wide scope of applications beyond the example shown in this article. This paper uses a context based on a shipwreck as "basic unit of study," to be considered from a maritime archaeology perspective. The network that represents ties between nodes of two different kinds (Mills 2017:383) is later collapsed into a one-mode network, that in this case has been represented as an ego network.

First, an SNA based on a two-mode network is used to analyze the "exports" of products, which is applied to visualize trade interactions at an interregional scale. The SNA assists in the process of revealing participants and mechanisms of exchange within complementary economic spheres. Second, the scale of analysis is changed and an ego network is used to evaluate the role of a single actor and its related context. To develop these models, this example uses evidence from early Australian shipwrecks as a case study. More precisely, the two-mode network uses data from Staniforth's (2003) research. This author argues that "rather than obtaining all of its material culture from Great Britain (the core of the network) as World Systems Theory might suggest, the early Australian colonists at Port Jackson (Sydney) obtained a significant portion of their necessities and luxuries from, or at least through, British merchants resident in India, principally Calcutta" (Staniforth 2003:27). On the other hand, the ego network is based on the archaeological remains of the *Sydney Cove* shipwreck (Nash 2002) in order to visualize the data analysis in more specific detail and show how it can be applied to SNA.

Material and Methods

Network models based on the typology/categories of artifacts enable interrogation of the dataset and the presentation of information in a visually accessible and intuitive structure. To create and identify patterns and trends in the material groups, the SNA software (Gephi 0.9.2) (Gephi 2022) was used to create network graphs connecting sites and artifact categories for visualization and data analysis.

This research is not centered on the use of the various statistical and mathematical functions exploited in SNA (for example, Scott and Carrington [2011]), but rather to use the graph operations of Gephi to produce visual representations of the connections and structures within the data (De Nooy et al. 2005). The SNA techniques, such as centrality or betweenness, were applied to cluster vertices of similar strength, improving the arrangement of data for visual inspection or statistical interrogation (De Nooy et al. 2005:20–21; Krempel 2014:560).

The primary categories for nodes used in two-mode network models (Fig. 2) have been compiled from the list of arrivals from India between 1790 and 1810 at Port Jackson (Staniforth 2003:70, table 5.2).

British traders considered Port Jackson a convict settlement with a tiny population and a minimal market. Consequently, from the beginning, trade had to be generated from scratch using all the mechanisms available to the traders. Therefore, the lack of supplies was a reality, generating episodes of scarcity. However, Port Jackson transformed, first incipiently in the period between 1790 and 1810, but especially from 1810 onwards when Sydney became a fully established mercantile port (Aplin 1988:1). Authors such as Staniforth (2003:72) argue that this transformation is produced primarily by the development of

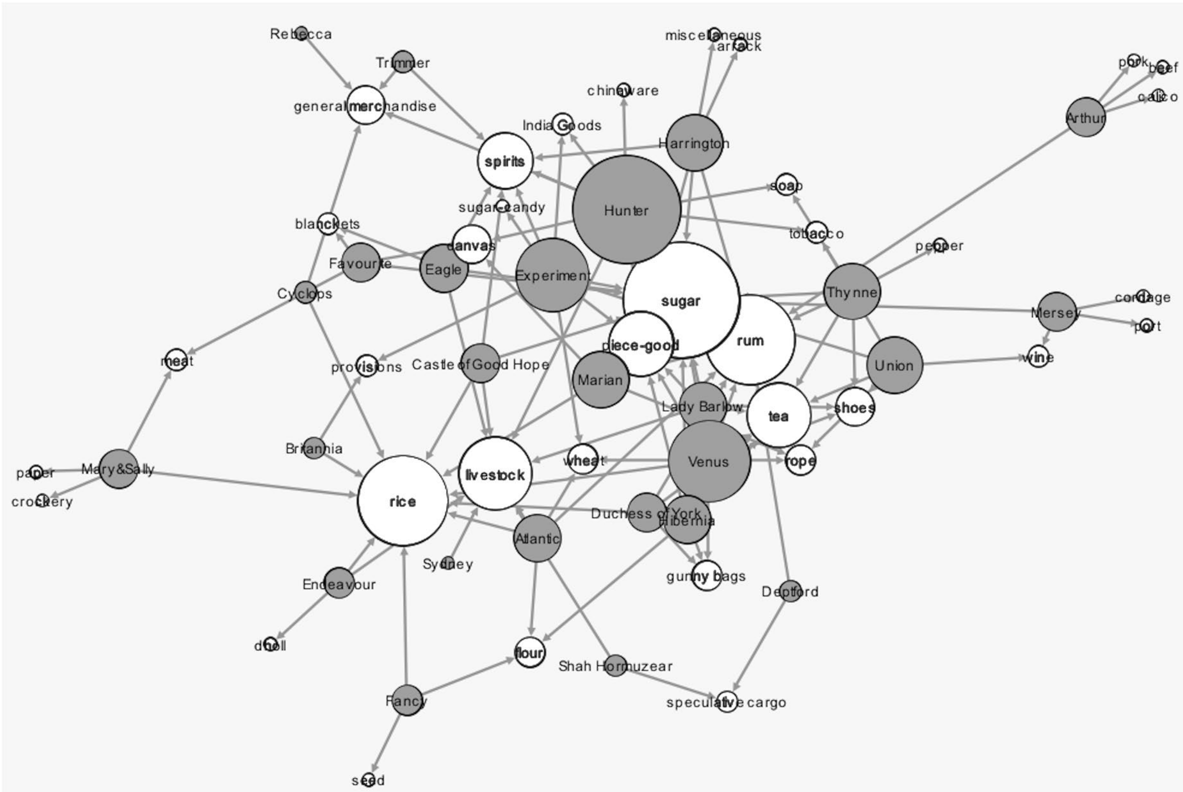

Fig. 2 Two-mode network. Node representing products (white) and ships (gray) interconnected by copresence (links). The layout used in Gephi was ForceAtlas2 (algorithm that simulates a physical system in order to specialize a network). (Graphic by author, 2019.)

a mercantile strategy that, rather than drawing all of its material cultures from Britain (the core), as World Systems Theory might suggest, the early Australian settlers at Port Jackson obtained a significant part of their necessities and luxuries from British traders resident in India (mainly in Calcutta), or at least through them. Therefore, the case of Port Jackson is a relevant case study to show through SNA a visualization of this hypothesis using the historical data available to us, as discussed below.

Here ships are related to others through co-occurrence of products and vice versa, so that typology or ships can be related by occurrence to the same classes of cargo. The rationale behind this type of network is that it is assumed that the greater the similarity between assemblages at different sites, the greater the probability that these sites, and the socioeconomic and cultural landscape they represent in consequence, were in more frequent or intense interaction and contact than the sites with less similarity in assemblages (Peeples and Roberts 2013). Calculating pairwise similarities between site assemblages results in a network that can be seen as a proxy for social interactions and has become one popular basis for analyzing social networks in archaeology (Hart and Engelbrecht 2012; Mills, Clark et al. 2013; Munson 2013; Mills, Peeples et al. 2015). In terms of the typological element data, this could illustrate the flow of material goods, information, affect, power, influence, social support, and social control. By focusing on exploring the relationships between the structural positions of actors in a network and the moment at which they adopt an innovation, this model reveals information about developing relationships in maritime trade during the past. A number of analyses—centrality, betweenness, closeness, and similarity—in this sense can be applied in order to assess the network model and obtain detailed information:

Centrality: The general goal of a centrality measure is to provide a ranking of the nodes or edges, that is, a node centrality is a function that assigns a value to each one, so that they can be ordered according to this value. Centrality measures usually exploit structures and capture the embedding of nodes or edges within the network. Centrality measures are also used in network clustering, where the goal is to provide a grouping of nodes or edges. To give a basic example, the degree of centrality assigned is the number of links a particular node has with other nodes. For example, if a node has 10 links, it has a degree centrality of 10 (Hanneman and Riddle 2005).

Betweenness: The betweenness of a node is defined as the number of times it acts as a bridge on the shortest path between two other steps. Thus, nodes with high betweenness can be regarded as important waypoints on the connections between others, but also as bottlenecks in the network (Hanneman and Riddle 2005).

Closeness: The closeness of a node is defined as the inverted sum of its shortest paths to all others in the network. This means that nodes with a high closeness can reach all others in fewer steps than those with low closeness in the network (Hanneman and Riddle 2005).

Similarity: Similarity is used as a criterion for social connectivity/interaction. The use of this criterion allows the creation of a similarity network model that complements the ego network model by describing the weighted, unweighted, symmetric, and asymmetric similarities and then ranking correlations among uniformly weighted attributes (Habiba et al. 2018:64). The difficulty of navigation coefficient (obtained from the GIS model as seen in the next section) will be used as the similarity measure establishing a weighted link in a range between 0 and 400 between any two nodes A and B in the network.

The diverse dataset uses a script designed to use the *.csv (comma separated value) file format. Microsoft Excel is used to produce files in this format from any tabular data. Tables are formatted with each of the samples/sites/observations as rows and each of the categorical variables as columns. The first row of the spreadsheet is a header that labels each of the columns. The first column contains the name of each unit. Row names have to be unique, that is, they cannot be repeated, and all of the remaining columns contain numerical count or percent data.

```
 A,B,C,D,E
A,0,0,1,0,1
B,0,0,1,1,0
C,1,1,0,0,1
D,0,1,0,0,1
E,1,0,1,1,0
```

Fig. 3 Example adjacency matrix. (Graphic by author, 2019.)

An adjacency matrix is created to show the correlation between sites. The adjacency matrix is then a table of rows and columns with the node labels as row and column header. When there is a link between two nodes, for example node A and node C, the corresponding cell value at row A and column C is set to 1. When there is no link between two nodes the respective cell value is set to 0. The adjacency matrix of the network would then look like the example shown in Figure 3.[2]

Continuing with early Australian trading in the Indian Ocean as the example, a specific case study of the *Sydney Cove* shipwreck has been selected. *Sydney Cove* left Calcutta on 4 November 1796 for Port Jackson. The 250-ton ship carried a diverse cargo. Historically recorded products were textiles, leather shoes, rice, sugar, tobacco, salt meat, cattle, and

[2] In the case of undirected networks this matrix is symmetric over the diagonal, whereas in directed networks it can become asymmetric.

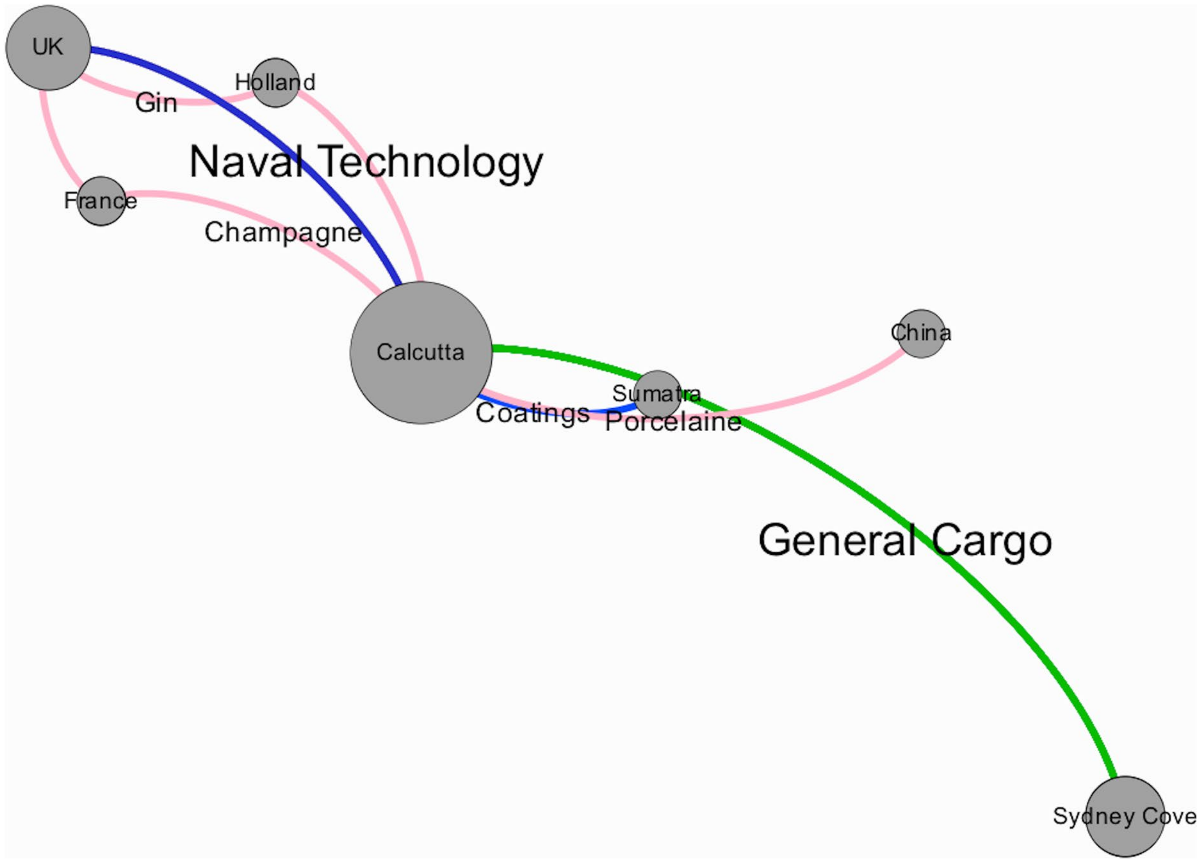

Fig. 4 Ego network. Nodes represent provenance and links represent copresence of specific products (blue [dark gray in print] = naval technology; red [light gray] = specific product; green [medium gray] = final cargo of the *Sydney Cove* shipwreck). (Graphic by author, 2019.)

Chinese goods, including tea and pottery. The main cargo was 7,000 gallons of alcohol in bottles and barrels (Nash 2002:28). On 13 December, *Sydney Cove* encountered a severe storm south of the equator, which opened significant leaks in the ship's hull and caused it to sink in shallow water on 9 February in Bass Strait (Tasmania), where the crew recovered much of the cargo (Staniforth 2003:75–98). The wreck was located in 1977 at a depth of between 4 m and 6 m. Since its discovery, the wreck has been the subject of several studies from the 1980s and 1990s to the present day, revealing the material culture that the archaeological context has offered us (Nash 2009). More detailed descriptions and illustrations of the artifacts from *Sydney Cove* are available (Staniforth 1995a, 1995b; Nash 1996, 2009).

It is possible to narrow the scale of the study and look at an ego-network level (Fig. 4). In this case the model is defined as a network consisting of a node (called ego), the nodes directly connected to the ego, and the edges between the other nodes (called alters) (Collar et al. 2015:21). The edges connecting the site to other nodes in the ego network will be defined by the artifacts of the *Sydney Cove* shipwreck assemblage (Nash 2002). The *Sydney Cove* shipwreck site is not technically a fixed node, such as a settlement, production center, or other locale, since it represents a somewhat random event that occurred along a network edge. This does not negate, however, the applicability of an ego network, which is effective for representing the connections represented by the site artifacts. From the analysis of centrality, it is possible to create a ranking based on the number of connections of different artifacts and their provenance, allowing us to examine the nature of the relation as well. In this case, the graph (Fig. 4) makes evident that "locally obtained materials, such as timber and cordage, were widely used in the building and fitting out of the Country vessels, but many items, such as copper sheathing, anchors, and cannon, were imported from Europe" (Nash 2002:47).

Discussion

In this paper the two-mode network has established the diversity of connections and identified those sites and products with the highest connectivity, within the maritime context of the early colonial period in Australia. This model is simplified to an ego network by affiliation to highlight specific relationships in a network focused on the SNA application to a specific shipwreck, *Sydney Cove*. This is done also in order to explore the type characterization of the shipwreck with respect to external actors. This provides a window onto the sociocultural dynamics of a society acting in a cultural connectivity analysis. Thus, whereas the two-mode network can be viewed more as an overview of the maritime trade of Australia's new colonial reality in relation to external actors, the ego network is focused on identifying a specific reality—maritime connectivity.

Figure 4, as explained above, shows the graphical results of the ego network for *Sydney Cove*, in which each node corresponds to a good's provenance (including *Sydney Cove* itself), while edges between nodes represent the copresence of products (graphical symbol based on type of product). The ranking of sites (node size) is based on betweenness, which provides a visual indication of the relevance of specific sites within a network. In this case, the ego-network graph is directed, meaning the relationships between pairs of actors, or dyads, are not necessarily equivalent. The two-mode network revealed who was connected to whom, but it did not necessarily reflect the level of reciprocity in the relationships. The ego network, on the other hand, is directed; each pair of nodes is connected by two opposing links that reflect different levels of exchange. This allows a site's degree of centrality to be characterized as degree out (the total outward flow of exchange goods from the site) and degree in (the total intake of goods exchanged from other sites). Similar degrees in and out can be indicative of a strongly connected network, but a third measure, betweenness, provides an even better indication of this.

In network theory, a node's betweenness is defined as "the fraction of the number of geodesics passing through this node over the number of geodesics between all pairs of nodes in the network" (Collar et al. 2015:1–32). This gives actors positioned "between" other unconnected actors power or influence over the others' transactions and their status in the network. Thus, the more embedded an actor is within a network, that is to say, the more connected they are between other actors in the network, the more those other actors are dependent upon them for information and material, the more they can control exchanges within the network and the more they are able to profit from their position. Similarly, in terms of products, the control over rice, rum, and sugar seems to indicate that they are key elements within the commercial circuit.

Conclusion

For some time, archaeologists have been concerned with the visualization of maritime contacts to create accurate contexts in which network models can be better interpreted. The examples used here offer a very precise hypothesis about a specific historical phenomenon, society, and consumption of early Australian colonialism. Ships, having a pivotal role in this historical episode can be used to demonstrate that SNA models can reveal additional information through nodal attributes. In the examples, it was possible to identify the strengths of intersite relationships on common trading patterns, showing in the first case the relevant cargoes (e.g., sugar, rum, and rice) and the main actors (ships) connected through them. The study showed strong evidence that products relating to Calcutta were the most relevant in this relationship, although the network models also have been used to demonstrate their limitations. Further research into maritime networks of the early colonial presence in Australia would require a higher volume of data, which was out of the scope of this paper. Furthermore, the use of a small-world model visualization to interpret links between sites is sufficient to evaluate the copresence of one or more artifact types and to identify joint affiliation.

This paper introduces maritime network analysis as an appropriate approach to explore connectivity in sea and coastal spaces. The use of SNA in maritime archaeological contexts affects not just the theoretical framework, but also the methodology, as the "relationship between the past phenomena and network data representation (methods) are separated" (Brughmans et al. 2016:7). Questions arise, though, when trying to implement specific analyses within this theoretical framework: namely, how to find adapted archaeological contexts of mobility and exchanges. The answer is two-fold: first, by studying transport contexts and, second, by studying the connectedness contexts—in short, by using information provided by shipwrecks and contact zones/harbors. Maritime archaeologists (e.g., Leidwanger et al. [2014]) have turned their focus to studying maritime trade and associated interactions through interregional and local trade based on "nodes of density in a matrix of connectivity" (Horden and Purcell 2000:393) in order to reveal participants and mechanisms of exchange within these complementary economic spheres. Harbor and contact zones can be interpreted as nodes in a matrix where diverse cultures converged. On the other hand, it can be questioned whether shipwrecks represent nodes or links. Following this it can be argued that shipwrecks be interpreted as "an intertwined system of multiple ports with multiple nodes of production and distribution for each item on board" instead of a static dot in a map (Fulton 2016:9). Without categorically specifying a material assemblage as resulting from a shipwreck, researchers could adopt a similar interpretation of contact zones (see Dietler [2010] for this term), viewing the shipwreck cargo as representing multiple ports and multiple stages of production, consumption, and distribution for each item in the assemblage.

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Declarations

Conflict of Interest The author declares that they have no conflict of interest.

References

Aplin, Graeme
1988 Preface. In *A Difficult Infant: Sydney before Macquarie*, G. Aplin, editor, pp. 1–5. New South Wales University Press, Kensington, Australia.

Barabási, Albert-László
2002 *Linked: The New Science of Networks*. Perseus, Cambridge, MA.

Borgatti, Stephen P., Ajay Mehra, Daniel J. Brass, and Giuseppe Labianca
2009 Network Analysis in the Social Sciences. *Science* 323(5916):892–895.

Brandes, Ulrik, Garry Robins, Ann McCranie, and Stanley Wasserman
2013 What is Network Science? *Network Science* 1(01):1–15.

Brughmans, Tom
2010 Connecting the Dots: Towards Archaeological Network Analysis. *Oxford Journal of Archaeology* 29(3):277–303.

Brughmans, Tom
2013 Thinking Through Networks: A Review of Formal Network Methods in Archaeology. *Journal of Archaeological Method and Theory* 20(4):623–662.

Brughmans, Tom, Anna Collar, and Fiona Coward
2016 *The Connected Past: Challenges to Network Studies in Archaeology and History*. Oxford University Press, Oxford, UK.

Brughmans, Tom, and Jeroen Poblome
2016 Pots in Space: Understanding Roman Pottery Distribution from Confronting Exploratory and Geographical Network Analyses. In *New Worlds from Old Texts: Revisiting Ancient Space and Place*. Elton Barker, Stefan Bouzarovski, Christopher Pelling, and Leif Isaksen, editors, pp. 255–280. Oxford University Press, Oxford, UK.

Collar, Anna, Fiona Coward, Tom Brughmans, and Barbara J. Mills
2015 Networks in Archaeology: Phenomena, Abstraction, Representation. *Journal of Archaeological Method and Theory* 22(1):1–32.

Cresswell, Kathrin M., Allison Worth, and Aziz Sheikh
2010 Actor-Network Theory and its Role in Understanding the Implementation of Information Technology Developments in Healthcare. *BMC Medical Informatics and Decision Making* 10(1):1–11.

De Nooy, Wouter, Andrej Mrvar, and Vladimir Batagelj
2005 *Exploratory Social Network Analysis with Pajek: Revised and Expanded Edition for Updated Software*. Cambridge University Press, Cambridge, UK.

De Nooy, Wouter, Andrej Mrvar, and Vladimir Batagelj
2018 *Exploratory Social Network Analysis with Pajek: Revised and Expanded Edition for Updated Software*, 3rd edition. Cambridge University Press, Cambridge, UK.

Dietler, Michael
2010 *Archaeologies of Colonialism: Consumption, Entanglement, and Violence in Ancient Mediterranean France*. University of California Press, Berkeley.

Freeman, Linton C.
2000 Social Network Analysis: Definition and History. In *Encyclopedia of Psychology*, Vol. 6, Alan E. Kazdin, editor, pp. 350–351. Oxford University Press, Oxford, UK.

Fulton, Carrie Atkins
2016 *Lost in Transportation: Trade Networks and the Materiality of Cargoes in the Ancient Mediterranean*. Doctoral dissertation, Cornell University, Ithaca, NY. University Microfilms International, Ann Arbor, MI.

Gephi
2022 The Open Graph Viz Platform [free download]. Gephi <https://gephi.org>. Accessed 12 December 2022.

Habiba, Jan C. Athenstädt, Barbara J. Mills, and Ulrik Brandes
2018 Social Networks and Similarity of Site Assemblages. *Journal of Archaeological Science* 92:63–72.

Hanneman, Robert A., and Mark Riddle
2005 *Introduction to Social Network Methods*. University of California, Riverside.

Hart, John. P., and William Engelbrecht
2012 Northern Iroquoian Ethnic Evolution: A Social Network Analysis. *Journal of Archaeological Method and Theory* 19(2):322–349.

Horden, Peregrine, and Nicholas Purcell
2000 *The Corrupting Sea: A Study of Mediterranean History*. Wiley-Blackwell, Oxford, UK.

Hunt, Allen G., and Stefano Manzoni
2015 *Networks on Networks: The Physics of Geobiology and Geochemistry*. Morgan & Claypool, Kentfield, CA.

Knappett, Carl
2011 *An Archaeology of Interaction: Network Perspectives on Material Culture and Society*. Oxford University Press, Oxford, UK.

Krempel, Lothar
2014 New Intermediaries of Personal Information: The FB Ecosystem. In *Encyclopedia of Social Network Analysis and Mining*, Reda Alhajj and Jon Rokne, editors, pp. 1144–1152. Springer Reference, New York, NY.

Lazega, Emmanuel, and Tom Snijders
2015 *Multilevel Network Analysis for the Social Sciences: Theory, Methods and Applications*. Springer, Heidelberg, Germany.

Leidwanger, Justin, and Carl Knappett
2018 *Maritime Networks in the Ancient Mediterranean World*. Cambridge University Press, Cambridge, UK.

Leidwanger, Justin, Carl Knappett, Pascal Arnaud, Paul Arthur, Emma Blake, Cyprian Broodbank, Tom Brughmans, Tim Evans, Shawn Graham, Elisabeth S. Greene, Barbara Kowalzig, Barbara Mills, Ray Rivers, Thomas F. Tartaron, and Robert Van de Noort
2014 A Manifesto for the Study of Ancient Mediterranean Maritime Networks. *Antiquity* 342(88):1–5.

Leinhardt, Samuel
1977 Social Network Research. *Journal of Mathematical Sociology* 5(1):1–4.

Malkin, Irad
2011 *A Small Greek World: Networks in the Ancient Mediterranean*. Oxford University Press, New York, NY.

Mills, Barbara. J.
2017 Social Network Analysis in Archaeology. *Annual Review of Anthropology* 46(1):379–397.

Mills, Barbara J., Jeffery J. Clark, Matthew A. Peeples, W. Randall Haas, Jr., John M. Roberts, Jr., J. Brett Hill, Deborah L. Huntley, Lewis Borck, Roland L. Breiger, Aaron Clauset, and M. Steven Shackley
2013 Transformation of Social Networks in the Late Pre-Hispanic US Southwest. *Proceedings of the National Academy of Sciences* 110(15):5785–5790.

Mills, Barbara J., Matthew A. Peeples, W. Randall Haas, Jr., Lewis Borck, Jeffery J. Clark, and John M. Roberts, Jr
2015 Multiscalar Perspectives on Social Networks in the Late Prehispanic Southwest. *American Antiquity* 80(1):3–24.

Mizoguchi, Koji
2009 Nodes and Edges: A Network Approach to Hierarchisation and State Formation in Japan. *Journal of Anthropological Archaeology* 28(1):14–26.

Mol, Angus A. A., Menno L. P. Hoogland, and Corinne L. Hofman
2015 Remotely Local: Ego-Networks of Late Pre-Colonial (AD 1000–1450) Saba, North-Eastern Caribbean. *Journal of Archaeological Method and Theory* 22(1):275–305.

Munson, Jessica
2013 From Metaphors to Practice. *Journal of Archaeological Method and Theory* 22(2):428–460.

Nash, Michael
1996 *Cargo for the Colony: The Wreck of the Merchant Ship*, Sydney Cove. Braxus Press, Sydney, Australia.

Nash, Michael
2002 The *Sydney Cove* Shipwreck Project. *The International Journal of Nautical Archaeology* 31(1):39-59.

Nash, Michael
2009 *Sydney Cove*: The History and Archaeology of an Eighteenth-Century Shipwreck. Navarine, Hobart, TX.

Newman, Mark
2003 Analysis of Weighted Networks. *Physical Review* 70(5):56–131.
Peeples, Matthew A., and John M. Roberts, Jr.
2013 To Binarize or Not to Binarize: Relational Data and the Construction of Archaeological Networks. *Journal of Archaeological Science* 40(7):3001–3010.
Pham, Manh Cuong, Ralf Klamma, and Matthias Jarke
2011 Development of Computer Science Disciplines: A Social Network Analysis Approach. *Social Network Analysis and Mining* 1(4):321–340.
Prell, Christina
2013 *Social Network Analysis: History, Theory and Methodology*. Sage, Los Angeles, CA.
Renfrew, Colin
1975 Trade as Action at a Distance: Questions of Integration and Communication. In *Ancient Civilization and Trade*, Jeremy A. Sabloff and C. C. Lamberg-Karlovsky, editors, pp. 3–59. University of New Mexico Press, Albuquerque.
Scott, John, and Peter J. Carrington
2011 *The SAGE Handbook of Social Network Analysis*. SAGE, Thousand Oaks, CA.
Staniforth, Mark
1995a Draft Report on Casks Excavated from the *Sydney Cove*. Report to Tasmanian National Parks and Wildlife Service, Hobart, Australia.
Staniforth, Mark
1995b Draft Report on Bottles Excavated from the *Sydney Cove*. Report to Tasmanian National Parks and Wildlife Service, Hobart, Australia.
Staniforth, Mark
2003 *Material Culture and Consumer Society: Dependent Colonies in Colonial Australia*. Kluwer Academic, New York, NY.
Watts, Duncan J., and Steven. H. Strogatz
1998 Collective Dynamics of “Small-World” Networks. *Nature* 393(6684):440–442.