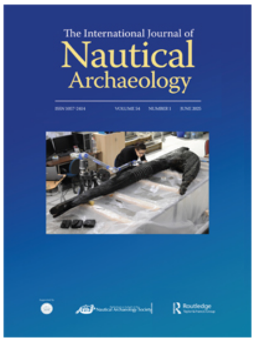

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Chiara Maria Mauro & Fabio Durastante

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NOTE

On the Use of Lights as Night Navigation Aids During Antiquity

Chiara Maria Mauro [a] and Fabio Durastante [b]

[a]Department of Prehistory, Ancient History and Archaeology, Complutense University of Madrid, Madrid, Spain; [b]Department of Mathematics, University of Pisa, Pisa, Italy

It is traditionally acknowledged that night navigation was commonplace during Antiquity, for several of the sea routes that were followed fairly regularly required more than one day of sailing. This is documented in both the written sources (e.g., the so-called *Periplus of Ps.-Skylax*) and proposed based on the archaeological record (e.g., the Uluburun and Cape Gelidonya shipwrecks) (Arnaud, 2020). Notwithstanding this, there are few studies devoted to the experience of night sailing, investigating how sailors coped with the drastic reduction of visibility when plying the seas at night and whether they implemented any strategies to improve their range of vision and to reduce the risks posed by natural hazards.

In this Note, the intention is to systematise, describe and analyse the different kinds of lights used to improve night navigation in Antiquity, recorded in both the literary sources and the archaeological record. For each type of light, (1) some archaeological and literary examples are offered, (2) the effect that it possibly had on the range of vision of crews is evaluated quantitatively and qualitatively, and (3) what its specific purpose might have been is discussed.

However, before starting with the classification of these lights, it is first necessary to draw a fundamental distinction between lights that were lit on board a ship – defined here as 'onboard lighting devices' or 'onboard lights' – or on the coast, as 'coastal lights' (for more on which, see Mauro et al., in press). In short, depending on their position (and intensity), these two types of lights presumably had different purposes.

Onboard Lighting Devices

Torches

In the tragedy *Rhesus*, tentatively attributed to Euripides but recently dated to the late 4th century BCE (Fantuzzi, 2020, pp. 24–41), Hector refers to torches (using the pleonastic expression 'λαμπάδας πυρός', *Rh.* 96; Lattimore, 1968, translates it as 'watch-fires', whereas Murray, 1913, as 'beacons') lit on board ships to help seafarers find their way across the sea:

> All through the night they kindle [αἴθουσι] flaming [πυρός] torches [λαμπάδας]: Yea, and methinks they will not wait the morn, but, burning [ἐκκέαντες] torches [πύρσ᾽] on the fair-benched ships, in homeward flight will get them from this land. (*Rh.* 95–98, trans. by Way, 1925; *cf.* with the translation by Coleridge, 1900, and with the interpretation of Morton, 2001, p. 210).

There are some archaeological examples of torches presumably used on board ships in the Museo delle Navi Antiche di Pisa (Italy): the four pieces, pertaining to three different torches and recovered from 1st-century CE flood layers, are made of vegetal fibres and present traces of combustion (Figure 1).

At this point, it is perhaps useful to evaluate whether or not the use of such torches could have really contributed to improve nighttime visibility (as implied in the tragedy *Rhesus*) and to what extent.

To understand and estimate the possible effect of a torch on nighttime visibility, it can be modelled as a point source of light positioned 4 m above the sea surface (this value is general and probably not effective for all the typologies of ships; it is the hypothetical height of the deck of a ship above the sea surface plus the height of the seafarer hanging the torch; Zamora Merchán, 2012). As for the intensity of the light emitted, this can be tentatively estimated at between 100 and 200 lumens (Table 1). Applying these values, the expected improvement in visibility when using a torch in complete darkness (e.g., on a moonless night) would have been in the region of 10 m (Figure 2). This implies that, as can be inferred from the description in the tragedy – in which torches are used to flee homeward from a foreign land – they might have made a modest contribution to improving visibility on board ship.

CONTACT Chiara Maria Mauro cmauro@ucm.es

Figure 1. The remains of three torches made of vegetal fibres, discovered in 1st-century CE flood layers from Cantiere delle Navi, Pisa, currently housed in the Museo delle Navi Antiche, Pisa, inv. SAFI 259590, 19 5121-1.428-429. Photo: Authors, published courtesy of Andrea Camilli, Museo delle Navi Antiche (Pisa, PI).

For comparative purposes, Figure 2 also includes a grey area denoting the amount of light emitted by a full moon with a brightness of 0.3 lux (Kyba et al., 2017). Since the expected improvement in visibility was around 10 m, it follows that, by and large, torches had a short-range effect. Indeed, it can be assumed that such onboard lighting devices were employed (in small to medium-sized vessels) to improve visibility during specific manoeuvres in particularly dangerous areas, to avoid close hazards (e.g., shoals, reefs) or to perform specific tasks on board a ship at night (whether at anchor or at sea). In other words, torches were of no use for illuminating the coastline.

To this observation should also be added that the scotopic vision range (i.e., the mode of vision involving the rods of the retina which is activated at night: Wandell, 1995, chapter 9) of a crew member holding a torch and anyone else in its cone of light would have been reduced, thus requiring a new period of dark adaptation (Reeves, 2009). In other words,

Table 1. A brief explanation of the units of measure used in this paper, including nautical miles (nm) for distance, candela (cd) for luminous intensity, lux (lx) for illuminance and lumen (lm) for luminous flux.

Nautical mile (nm)	A unit of distance equal to 1,852 m (1.852 km) and based on 1 minute of latitude along a meridian of the Earth.
Candela (cd)	The SI (International System of Units) base unit of luminous intensity, measuring the power emitted by a light source in a particular direction. One candela is roughly equivalent to the brightness of a common wax candle.
Lux (lx)	A unit of illuminance, measuring how much luminous flux (light) is spread over a given area. One lux is equal to 1 lumen per square metre (lm/m^2). It quantifies how brightly a surface is illuminated.
Lumen (lm)	A unit of luminous flux, measuring the total amount of visible light emitted by a source per second. One lumen is the light emitted in a unit solid angle (steradian) by a source with a luminous intensity of 1 candela.

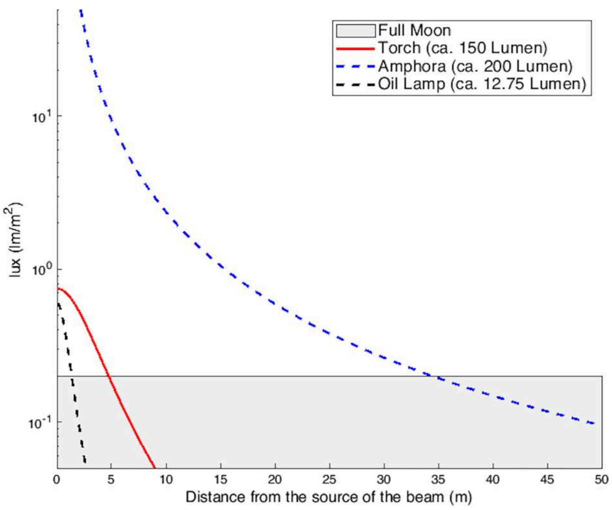

Figure 2. Quantity of lux (unit of illuminance or luminous flux per unit area) emitted by different light sources (a pierced amphora, a torch and an oil lamp). The grey area shows the amount of lux produced by a full moon (based on numerical value proposed by Kyba et al., 2017).

although the use of torches would have improved the short-range vision of crews, it would have also reduced their medium-range vision, thus making it harder to catch sight of the shoreline or any other feature at a distance of more than 10 m.

Pierced Amphorae and Stern/Prow Lights

Torches were not the only lighting devices employed on board ships at night, for there is also evidence of the use of pierced amphorae (or other pottery vessels), as well as other kinds of lights. There is still no scientific consensus on the exact application of these devices. As a matter of fact, whereas some scholars consider them as devices for improving the range of vision of crews at night (Gasull, 1986), others interpret them as positioning lights (Arnaud, 2020; Beltrame, 2002, p. 99). Since positioning lights could be fastened to the prow or stern of a vessel (e.g., Procopius, *Vandalic Wars*, 1.13.3, plus other sources mentioning positioning lights used for convoy sailing, e.g., Appianus, *Civil War*, 2.89; Xenophon, *Hellenica*, 5.1.8), their exact location on board a ship does not help to clarify or to take a definitive stance on this matter. Accordingly, in this contribution both options – i.e., that they were devices for improving the range of vision of crews and positioning lights – are discussed concurrently because, in our opinion, one did not necessarily exclude the other.

The first evidence of (pierced?) amphorae fastened to the prows of ships probably appears in a fresco found in the Tomb of Kenamun (Theban Tomb 162, Luxor, Egypt) and dated to the 14th century BCE. In this scene, several ships are depicted. In the left and middle (lower register) sections (Figure 3), some jars (left section) and a *pithos* (middle section, lower register) appear on the inboard side of the stems, perhaps waiting to be unloaded (i.e., the *pithos*) or containing drinking water for the crew (i.e., the jar tied to the stem with ropes passing through its handles). On the other hand, in the upper register of the middle section, five Canaanite ships are depicted one next to the other, with two amphorae firmly attached to the prows of two of them. Given the proximity of the five vessels, it is difficult to tell whether the two amphorae are standing on the outboard or inboard side of the stems; however, when comparing these amphorae with the jars and the *pithos* mentioned above, there is reason to believe that the former were lashed to the outboard side of the ship (and not the inboard, as occurs with the *pithos* and the jars) (*contra* Basch, 1974, for whom they are onboard). Firstly, the jars and the *pithos* seem to have flat bottoms, so that they could have been placed onboard the ship; furthermore, they do not appear to be fastened (apart from the jar on the right, such as the aforementioned one tied to the stem with ropes passing only through its handles, not around its body or neck). Secondly, as to the amphorae, the lines that can be seen around their necks and bodies probably represent the ropes used to tie them to the outer part of the prow. If the two amphorae were supposed to be unloaded shortly after arrival, then there was no need for them to be secured. Moreover, if they were actually lashed to the inner part of the stem to contain drinking water, it would have made more sense to opt for amphorae with flat bottoms, like the one depicted in the left section.

According to Gasull (1986, p. 195), amphorae (or other kinds of pottery vessels) fastened to the outboard side of the prow might have been used as a way for seafarers to facilitate night navigation. A similar function has been suggested by Fonquerle for an amphora associated with a 2nd-century BCE shipwreck discovered in the river Hérault (Languedoc, France) (Figure 4) and by Basch (1974) for the pierced vessel found in Porto Piccolo of Syracuse (Italy) (the latter has not actually been associated with any specific shipwreck) (Gargallo & Casson, 1962, fig. 4).

As for the discovery in the river Hérault, this is the body of a Dressel 1A type amphora, which – as noted

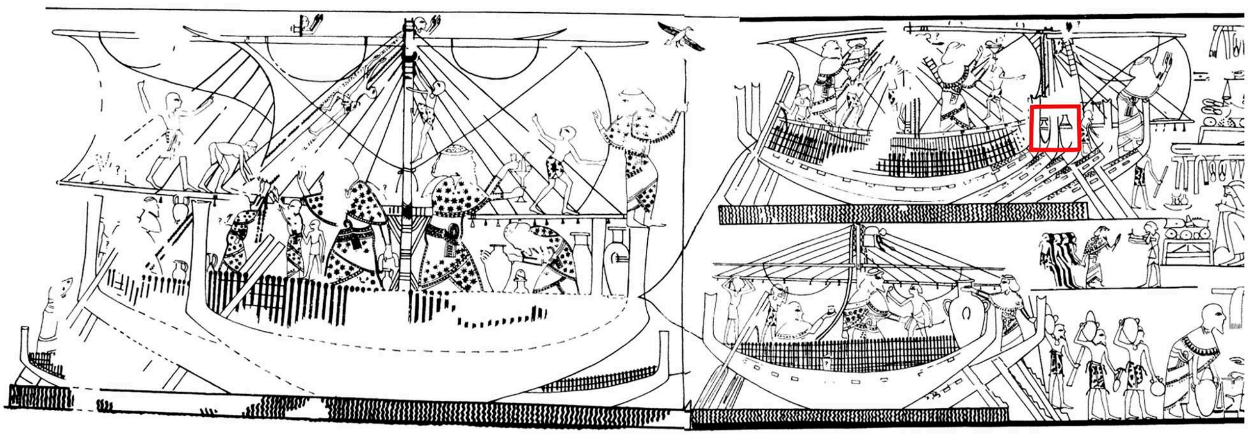

Figure 3. Sketches of the frescos of the Tomb of Kenamun made by N. de G. Davies, details of the left and middle sections (Davies & Faulkner, 1947, p. 40).

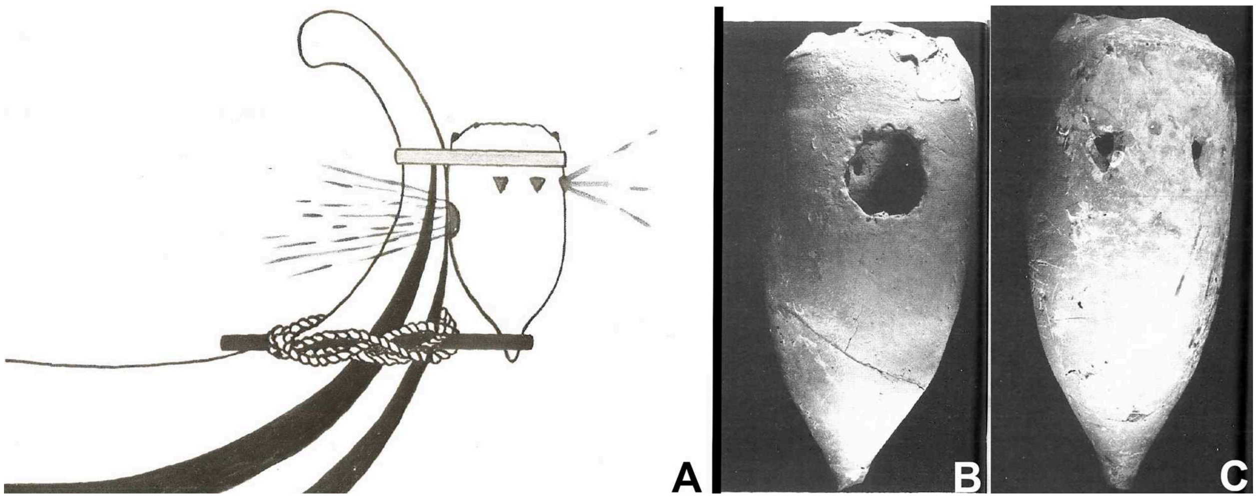

Figure 4. A reconstruction of the proposal put forward by Fonquerle; B: detail of the Dressel 1A amphora, the bigger, circular hole; C: detail of the Dressel 1A amphora, the smaller, triangular holes (Fonquerle, 1973, pp. 80, 78).

by Fonquerle (1973, pp. 67–68) – has a series of holes, plus marks of ligatures (probably from the rope used to fasten it to the ship) and traces of combustion. In an attempt to interpret this amphora, Fonquerle assumed that it was mounted on the prow of a ship and that the bigger, circular hole (10 cm in diameter) (see Figure 4b) would have served as a deck light (Figure 4a), and the five small triangular holes as positioning lights (more on these lights and their function below) (Figure 4c).

To our mind, there is a more reasonable explanation: as they were located at the top of the amphora, the small triangular holes can be interpreted as smoke vents, whereas the bigger hole served to illuminate the water around the prow. For if it had indeed been used as a deck light – following Fonquerle – it would have actually had a negative impact on the crew's short- and medium-range vision. This interpretation would also resolve the point raised by Basch (1974) who noted that, as it was located at a lower level, most of the light would have passed through the circular hole, rather than through the five small triangular holes higher up.

On the other hand, if it were meant to illuminate the water around the bow – as suggested here – the cone of light emitted by the bigger circular hole would have enhanced the crew's vision in the following ways: more intense than the diffuse light produced by a torch, the beam emitted by this pierced amphora would have been more focused, perhaps with an intensity of between 150 and 250 lumens, thus illuminating an area with a radius of 50 m (see Figure 2). Compared to torches, the possible use of pierced amphorae for improving nighttime visibility offered, therefore, two additional advantages. Firstly, such a device partially shielded the crew's eyes, since its body prevented the cone of light from directly affecting their vision, which would have reduced the loss of sensitivity noted with regard to the use of torches. Secondly, the light emitted was more focused and generally lasted longer (Mauro & Durastante, 2023).

As with the fresco in the Tomb of Kenamun that conceivably depicts amphorae fastened to the prows of two Canaanite ships, a 2nd-century CE relief on Trajan's Column in Rome illustrates the departure of a number of ships, one of which apparently has a bronze lamp hanging from its stern (Settis, 1988, tab. LXXIX) (Figure 5). This object has been interpreted as a positioning light, namely, for indicating a ship's position (Xen. *Hell.* 5.1–8), course (App. *BC* 2.13.89) or status (Livy, 29.25.10-11). Artefacts similar to the one represented on Trajan's Column have been found in the Grand Bassin B shipwreck (dated to 110–90 BCE; see Solier, 1981, pp. 59–85) (Figure 6) and the Comacchio shipwreck (25–1 BCE, Italy; see Berti, 1990) (for further examples, see Beltrame, 2002, pp. 97–99).

Stern/prow lights might have been used both to facilitate navigation and as positioning lights, whereas when a ship was at anchor, they presumably served to signal its position to approaching vessels.

Oil Lamps and Wall Brackets

The last kind of lighting devices that should be analysed are the numerous oil lamps and wall brackets found in several shipwrecks. The Uluburun shipwreck (late 14th century BCE), for example, yielded four ceramic Canaanite lamps (Pulak, 2008, p. 299) which, in view of the fact that they show evident traces of combustion (blackened areas), have been interpreted as lighting devices used on board ship. The oil was poured directly into the central, concave part of the lamp and, thanks to its saucer-shaped body, crew members could have easily moved around on board ship with them. Similar finds with traces of use have also been found in the shipwrecks of the Tektaş Burnu (5th century BCE, Tûrkiye; see Carlson, 2001, fig. 9), Ma'agan Mikhael (400 BCE, Israel; see Artzy & Lyon, 2003, pp. 197–198), Cala Culip IV (1st

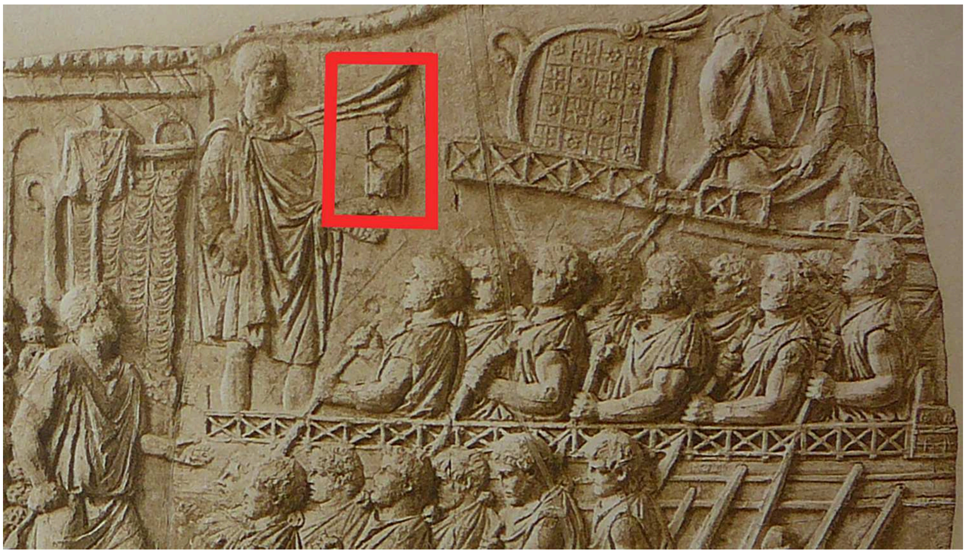

Figure 5. Detail of a scene depicting the departure of ships from a harbour (Trajan's Column): the ship with what is probably a bronze lamp hanging from its stern ('Trajan's voyage' scene LXXIX from Conrad Cichorius, *Die Reliefs des Ersten Dakischen Krieges*, Tafeln 1–57, Verlag von Georg Reimer, Berlin 1896, public domain/Wikimedia Commons).

century CE, Spain; see Nieto Prieto et al., 1989) and Comacchio (25–1 BCE, Italy; see Berti, 1990).

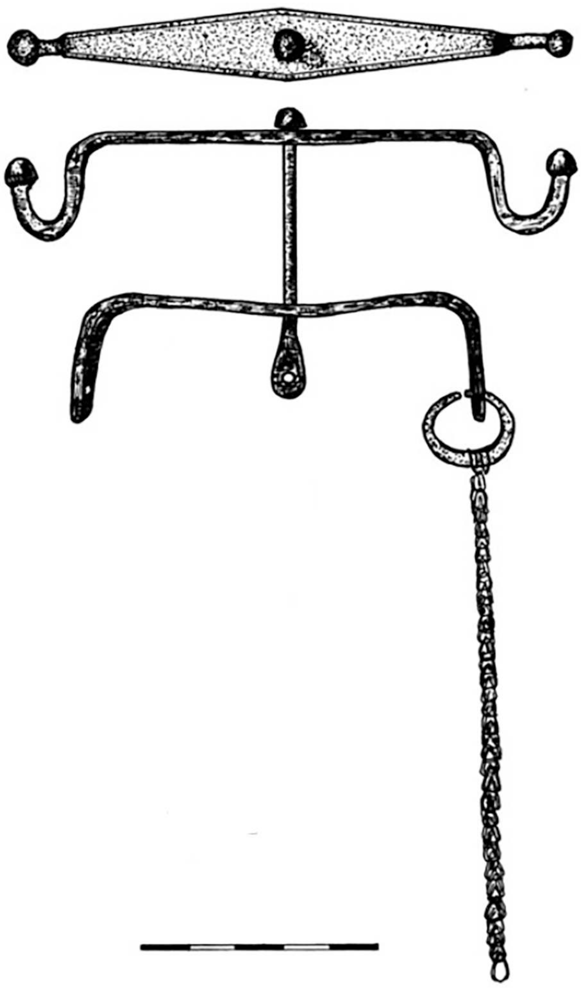

Figure 6. Elements pertaining to the bronze positioning light found in the Grand Bassin B shipwreck (Solier, 1981, p. 82).

Besides oil lamps, wall brackets presumably fixed to a ship's superstructure (e.g., the mast) are another fairly frequent find in shipwrecks. As those of the Uluburun shipwreck were discovered inside a *pithos* and displayed no traces of combustion, they probably were not intended for the personal use of the crew but destined to be sold as part of the cargo (Hirschfeld,

Figure 7. Supports for lanterns found inside the so-called 'first ship of Caligula' in August 1929. Museo delle Navi di Nemi, Italy. Photo: Authors, published courtesy of the Ministero della Cultura. Direzione Regionale Musei Lazio.

2011). The wall brackets found in the so-called 'first ship of Caligula' in Lake Nemi (1st century CE, Italy) (Figure 7), distributed along its entire length, differ in that they would have been attached to several parts of the ship for holding small lights.

Assuming that oil lamps or wall brackets were positioned at a height of between 1.3 and 1.6 m, as this would have corresponded roughly to that of the heads or hands of crew members, their cone of light would have illuminated an area with a radius of between 2.5 and 3.2 m. Obviously, the light emitted by an oil lamp or a wall bracket was more intense close up, whereas at the two maximum distances its intensity in lux was less than that of a full moon (see Figure 2). This implies that the improvement in visibility produced by a small lighting device was minimal and really only served to move around on deck, to check the status of the rigging and so forth. In this sense, they were employed when ships were at sea and at anchor.

Coastal Lights

Coastal Fires (Lit at Prominent Points on the Shoreline, on Top of Specific Buildings or in Real Lighthouses)

Despite the fact that a system for improving night sailing seems to have been only introduced in the 3rd century BCE with the construction of the first real lighthouses (Mauro, 2019, pp. 60–62; McKenzie, 2006, pp. 41–46), there is evidence suggesting the possible use of fires as navigation aids earlier, in the Late Bronze Age. In chronological order, the fires lit directly on top of high (and clearly visible) points along the coasts (as that mentioned by Homer, *Iliad* 19.375–378; 18.207–214; *Odyssey* 10.30; that these fires were lit deliberately as navigational aids is however a moot point, as observed by Morton, 2001, p. 210 and n. 94 with related bibliography) and on the roofs of religious structures which seafarers also sometimes used as landmarks (Frost, 2002) can be considered as the first evidence of these coastal lights. By the 6th century BCE, coastal fires were also probably lit on top of high buildings (generally towers) located either directly in harbour areas or, more often than not, very close to the shore (e.g., the tower at Cape Pyrgos, on the island of Thasos, bearing the telling inscription saying: 'I am here, on the extremity of the harbor, as a protective signpost for ships and sailors', *IG* XII.8.683). Finally, in the 3rd century BCE the first lighthouses explicitly built to improve navigation (as clearly stated by Suetonius, *Caius*, 46; and *Claudio* 20; Strabo 17.1.6) began to appear.

The majority of coastal lights were wood fires, whose luminous intensity can be estimated to have been in the region of 5000 cd (Papadopoulos & Graeme, 2009). However, this might have differed in the case of lighthouses, as the use of additional systems to enhance the intensity and range of the light that they emitted, such as polished metal surfaces, should not be ruled out. Having said that, the radius of visibility of wood fires not only depended on their luminous intensity but also on the height at which they were positioned, for which reason they were lit at prominent points on the shoreline or on top of high structures. Modelling the visibility of a fire at night, it can be observed that its flames were easily visible, especially if the general conditions of visibility were very poor (a range of vision of up to 0.5 nm), poor (from 1 to 2 nm) or moderate (from 3 to 4 nm) (see Figure 8 for a graphical representation of the different visibility regimes). This reasoning stems from the fact that models of light propagation depend on two key factors: the height of the light source and its luminous intensity, as described by Allard's Law. Under poor visibility conditions, the luminous intensity of fires was enhanced, thus making them more visible. Conversely, as visibility improved, the reduced height and lower luminous efficiency of coastal fires – especially those without technical enhancements – prevented them from reaching their theoretical maximum visibility range (Mauro et al., in press). On the other hand, although a fire was still discernible in conditions of good visibility, it had a significantly lower impact on night sailing.

Onboard Lights vs. Coastal Lights: (Almost the) Same Intensity but with Different Purposes

In this brief overview of the lighting devices possibly employed for night sailing, we have offered an initial

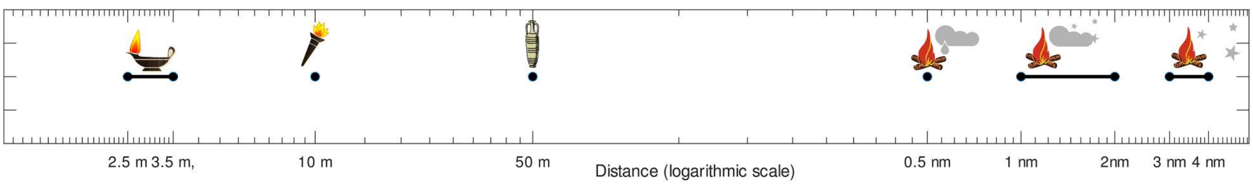

Figure 8. The figure provides a compact representation of the different visibility regimes for the different light sources discussed here. From left to right, it shows the visibility distances of oil lamps (and wall brackets), torches, pierced amphorae (and stern/prow lights) provided in metres, and of coastal fires under very poor, poor and moderate visibility conditions (expressed in nautical miles). The positioning of the intervals follows a logarithmic scale (Authors).

classification. In particular, we have attempted to demonstrate that the devices in use did not have the same function, even if the light emitted was (more or less) of a similar intensity. We have seen how some of the devices examined here (e.g., torches and, possibly, pierced amphorae or other lights fastened to the prow) were conceivably used to illuminate the sea around a ship, thus facilitating specific manoeuvres. Others served as positioning lights to transmit information on the position, course or status of a ship, being particularly useful when it was sailing in a convoy or in foggy conditions. Furthermore, some small lights (e.g., oil lamps and wall brackets) were used by crews to help them move about on deck after sunset. Finally, all the onboard devices analysed here could have been used both when a ship was at sea, thus facilitating navigation, or when it was at anchor, particularly when it was hard to light or manipulate such devices when at sea.

When used at sea, it can be claimed that onboard lights, in general, were useful for coastal navigation (i.e., for identifying hazards) rather than for approaching the coast itself or for orientation purposes. Indeed, it should be borne in mind that when a light onboard was lit, it reduced the dark adaptation of the crew who needed time to adapt to low-light conditions again (scotopic vision). In other words, when such lights were lit on board ship, they increased the minimum apparent brightness of the faintest visible star, thus making celestial navigation more difficult. Moreover, the use of onboard lights also increased the ambient light threshold, making it harder to perceive signal lights on the coast. There was a further disadvantage for ships engaging in covert naval operations at night, for such lights would have made them easier to spot. As a matter of fact, the improved visibility due to the use of lights on board ship was countered by a ship's greater visibility from the coast. In this regard, a directed light, such as a pierced amphora, was more effective than a torch emitting undirected light in an open environment (Mauro & Durastante, 2023).

Finally, although coastal lights were not controlled or managed directly by crews, they were particularly helpful for allowing them to get their bearings. Once identified, they could have indicated (depending on the case) the presence of a headland, a religious structure, a harbour or a human settlement.

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Author Contribution

C.M.M., as the PI of the project PR27/21–018, designed this study, while also addressing aspects connected with archaeology and ancient history. F.D. focused on the quantitative aspects. Finally, all the authors cowrote the research note and revised the manuscript.

Permission Statement

The authors obtained authorisation to publish the photos taken at the Museo delle Navi Antiche di Pisa and the Museo delle Navi di Nemi.

Declaration of Interest

The authors have no financial or proprietary interests in any material discussed in the article, while also confirming that it complies with all ethical standards.

ORCID

Chiara Maria Mauro http://orcid.org/0000-0001-8902-0697
Fabio Durastante http://orcid.org/0000-0002-1412-8289

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