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RESEARCH

Nocturnal Seafaring: the Reduction of Visibility at Night and its Impact on Ancient Mediterranean Seafaring. A Study Based on 8–4th Centuries BC Evidence

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Abstract
The practice of nocturnal navigation in the Mediterranean Sea could be inferred from both archaeological and written records. While there is sufficient proof that the ships and their crew were quite familiar with nighttime sailing, current scholarship has not satisfactorily investigated how the reduction of visibility could have affected the nautical practice. For this reason, the aim of this contribution is twofold: (1) to evaluate to what extent visibility was reduced at night, and (2) to understand what kind of strategies (if any) could be put in place to overcome the difficulties of a low level of visibility. Amongst the strategies, we will also assess the impact on visibility of fixed and portable lighting devices, such as torches and pierced amphoras, as documented by the archaeological and literary evidence.

Keywords Sight · Sailing · Mediterranean sea · Antiquity · Onboard lighting devices

Introduction

Recent advances made in the study of ancient seafaring have repeatedly acknowledged the role of visibility (Bar-Yosef Mayer et al. 2015, 9–12; Arnaud 2020a, 34–40; Medas 2022, 97–103). In particular, in the Mediterranean Sea—which is an almost enclosed maritime space filled with islands—mutual visibility had long stood at the heart of maritime

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connections (Horden and Purcell 2000, 393), theoretically allowing one to go from one side to another without ever losing sight of the land.

Even though open-sea crossings were fairly regular during the Archaic period,[1] small and medium-sized vessels frequently preferred (whenever possible) to follow sea paths in which the mainland fell within their radius of visibility. In maritime scholarship, this practice is commonly referred to as 'pilotage' or 'environmental navigation' and it consisted of progressing from one point to the next by following a chain of landmarks identified and memorised during previous sea journeys (McGrail 1991, 86; Morton 2001, 186; Mauro 2022a, 132).

Given the importance that the detection of landmarks had for ancient seafaring, a primary, logical inquiry would be to ascertain from what distances specific items could be seen. In 1968 Schüle first tried to answer this question by creating a map of the Mediterranean based on a geometric calculation of the visual basin (Schüle 1970; cf. Henkel 1901). Within the same study, Schüle noticed that the land was easily spottable while sailing around the Mediterranean and that there were only a few Mediterranean maritime areas from where one could not catch sight of land. From that moment on, Schüle's map and conclusions have been largely quoted and replicated, but are now understood to simply be conjecture. As a matter of fact, without the intention of denying the importance of Schüle's contribution (as it inevitably set a starting point in visibility studies), it must be acknowledged that he worked by employing an oversimplified and incomplete definition of 'visibility'. The concept of 'visibility' with which Schüle worked failed, in fact, to incorporate any variation dictated by the season (cf. Mauro and Durastante 2022) or by the time of the day. In this sense, Schüle's study offered a purely theoretical evaluation of the visibility radius, and the conclusions that he reached could hardly correspond with real-world situations.

Keeping in mind the importance of visibility in ancient seafaring and in light of the considerations just offered, this contribution aims at fostering a concept of visibility that is more inclusive and compliant with reality. Specifically, we would like to assess to what extent visibility could be reduced during nighttime and how the decrease in visibility at night could have possibly affected ancient seafaring practices within the Mediterranean context. Whilst the considerations that we express in this paper could be virtually applied to any chronological span, we have decided to ground our contribution in the time frame between the Archaic and Classical periods (eighth—fourth centuries BC). This choice has been motivated by two main observations: first, there are abundant testimonies referring to this period and speaking in favour of the practice of nocturnal seafaring; second, as far as this period is concerned, there were not yet fixed maritime infrastructures specifically aimed at improving visibility at night. As a matter of fact, the first proper lighthouse (the lighthouse of Alexandria of Egypt, on the island of Pharos) is dated to the first decades of the third century BC (Mauro 2019, 60–62; for an example of how visibility and navigation are connected in the presence of lighthouses, see Meléndez and Campos Carrasco 2020).

As for the first point, even if nocturnal navigation was performed since the 6–4th millennium BC (Agouridis 1997; Medas 2004, 156), starting from the eighth century BC, the extant data on this practice perceptibly increases, and the archaeological evidence (e.g. the shipwrecks Elissa and Tanit, dated to the eighth century BC, identified at approximately 30

[1] The *Odyssey* and the *Iliad* repeatedly describe open-sea crossings, e.g. in Hom. *Od.* 14.250–256, when Odysseus tells Eumaeus that he set sail from Crete and reached Egypt on the fifth day. At an archaeological level, we can find support for the existence of open-sea routes in the eighth century BC shipwrecks—named Tanit and Elissa—identified 48 km (31 nm) off the coast of Ashkelon, Israel (Stager 2005).

nautical miles from the coast of Ashkelon, Israel, which Stager 2003) was further sustained by literary evidence. In fact, both the *Odyssey* and, to a lesser degree, the *Iliad* contained descriptions of maritime ventures, many of which were taking place at night (Hom. *Il.* 18.483–489; *Od.* 3.176–178). Despite the doubts on the extant chronology of the two poems, today it is widely accepted that they reached their final form sometime around the end of the eighth century BC (Sherratt 1990; Raaflaub 1997). In this sense, we might expect that, at that specific point in time, both the writer and the audience were quite familiar with the idea that seafaring was practised even at night. Although most of the historic writings relate night sailing with the military sphere (Hdt. 8.9; Thuc. 1.48, 2.81–84, 4.31, 4.42, 8.101.3) and could therefore suggest the idea that this practice was taking place only when strictly necessary, the reading of other genres' texts reveals that this was not exactly the case. As an example, Xenophon reported that the Paralos–the Athenian state ship–arrived at Athens at night to announce the disaster of the Aegospotami in 405 BC (Xen. *Hell.* 2.2.3). Additionally, by the third quarter of the fourth century BC, the geographical work commonly known as the *Periplus of Ps.-Skylax* recurrently mentions sea-routes that required consecutive days and nights of sailing in order to be followed (Ps.-Skyl. §§ 20 and 111.6).

Taken altogether, this evidence discloses that night sailing could be practised either for tactical reasons, such as carrying out naval operations under the cover of darkness, or due to technical observations, including the benefit of early morning or late evening breezes or because the voyage itself required more days in order to be completed (Davis 1999, 295). This was not uncommon during the period under consideration (Morton 2001, 206).

On the other hand, the second observation that led us to select this chronological period is that, before the fourth century BC, fixed maritime infrastructures specifically aimed at improving visibility at night were still not fully developed. This means that—even if alternative measures to increase visibility at night might possibly have been already in use in certain maritime areas (such as fires burning on top of coastal towers or religious structures)—light signals were still not so widespread and their presence was not systematic along the Mediterranean shores. For these reasons, the considerations that we are going to advance on this topic could result particularly relevant, as—between the eighth and the fourth centuries BC—it was necessary for seafarers to cope with the reduction of visibility at night, without having the possibility (or having only partially the possibility) to count on the aid of coastal lights for guiding their paths along the sea.

Considering all of the above, the questions we aim to address within this contribution are the following:

(1) To what extent the reduction in visibility experienced at night could have affected maritime travels within the Mediterranean context? Is it possible to estimate it?
(2) What were the tools and/or the strategies (if any) adopted by the crews to possibly counteract the diminished visibility?

In the next sections, we will seek to provide adequate answers to these two matters.

Computing the Visibility Reduction at Night

To approach the problem in a quantitative way, we first need to precisely define several concepts related to the physiology of vision and the physics of light diffusion through the atmosphere. With the term 'vision' (or also 'sight' or 'eyesight') we refer here to the ability

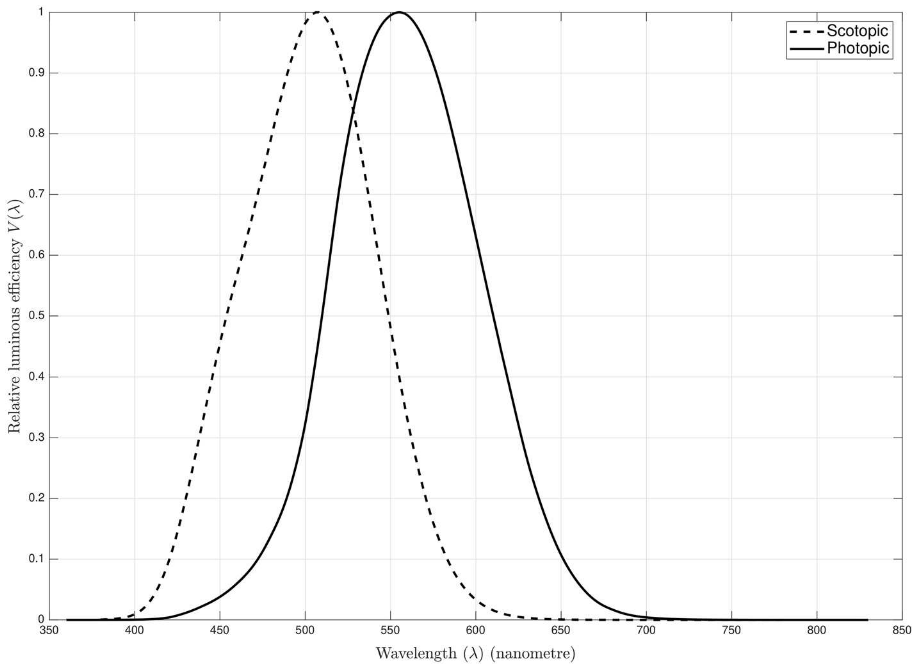

Fig. 1 Relative luminous efficiency of the human eye for monochromatic radiation for scotopic (dashed line) and photopic (continuous line) at different wavelengths (nanometres). The data obtained from the downloadable standard data sets of the CVRL database (http://www.cvrl.org/) and described in (CIE Proceedings 1951)

to interpret the surrounding environment through the eye. Specifically, as far as night navigation is concerned, the modality of vision that interests us is that of the scotopic vision, the part of vision that involves the rods of the retina, as opposed to the vision mode used during the day which is called photopic vision, which involves the retinal fovea (Wandell 1995, chapter 9). The different parts of the eye involved in the phenomena of scotopic vision cause the wavelengths of perceived light to be different; under the scotopic regime the eye is more sensitive to certain wavelengths (λ) (Wandell 1995, chapter 3). We know that the human eyes respond to wavelengths between 380 and 780 nanometres, indeed this is what is usually called the spectrum of visible light (Sliney 2016). We can measure how the eye perceives light of different colours (wavelengths) in terms of the luminous efficiency function (sometimes called luminosity function) $V(\lambda)$. In Fig. 1 we report the value of $V(\lambda)$ in the two regimes using the data taken from the CIE Proceedings (1951), and observe that in the scotopic range, the maximum luminous efficiency corresponds to a wavelength $\lambda = 507$ nanometres (instead of the 555 nanometres of the photopic regime). In other words, under the scotopic regime (nighttime vision), the human eye better perceives lights resulting in light green colours; whereas, under the photopic regime (day-light vision), the better perceived lights are yellow.

The $V(\lambda)$ curve also tells us that the light most easily perceived by the eye will be the one emitted in the vicinity of this wavelength and which will degrade towards the impossibility of being seen as we move away from this value (Fig. 1). The wavelength of light and its perceptibility by the eye are therefore the first part of the phenomenon we have to describe. Once having established this, we have to take into consideration that light is spread through a medium, such as the atmosphere, that causes a deterioration of the transmitted signal (Horvath 1993). In this setting the visibility radius is called Meteorological Optical Range (MOR) and can be computed using Allard's equation.[2] To obtain the estimate of the visual range we first fix *E* in Allard's equation to a threshold value depending on the ambient luminance, we select the intensity of the target light source and the extinction coefficient (see Horvath 1993 for a review concerning the physical mechanism of light absorption in the atmosphere). Then, we solve the equation for the *x*, the distance of perception. We also need to stress that the value obtained by this approach is only valid for a qualified observer, such as a subject with normal vision, after a period of adaptation to the surrounding environment to accustom its eyes to the darkness of the night and that is reflected by the chosen threshold value (Reeves 2009).

To showcase some values of the visual range *x* from Allard's equation, we need to determine reference values for the threshold value *E* and for the absorption coefficient σ. For the latter, we can adopt the same technique discussed in Mauro and Durastante (2022) to consider atmospheric and seasonal effects, that is, to infer it from the instrumental data collected nowadays.[3] For the determination of threshold values *E* we can turn to the reference literature of atmospheric science (Larsson et al. 1970).[4] The described procedure can be repeated in all the cases in which we possess an estimate of the absorption coefficient σ. If instrumental readings, such as those obtained from the AERONET federation[5] (Giles et al. 2019) or from special data collection campaigns, are not available, it is possible to obtain a rough estimate using the visibility radius during the day (see "Appendix 1").

To provide a practical example and reference values, we elaborate a table (Fig. 2) in which, for a given MOR we compute the distance at which a 100 cd point source is just visible. As thresholds *E*, we employ the three different values corresponding, according to the WMO (2021, 331), to *Twilight*, *Full Moon*, and *Complete Darkness* conditions. In this way, we have reference values of the nighttime visibility range in three representative scenarios. The left side, the *y*-axis, identifies a daytime visibility radius, thus a given combination of it and condition it is possible to read the nighttime visibility radius on the intersection. Visibility of 5.39 nm (10 km) during the day, corresponds to 2.61 nm (4.84 km) at twilight, 3.99 nm (7.39 km) with the full moon, and 5.9 nm (10.93 km) in complete darkness for a light source of 100 cd. It follows that the lower the ambient illumination is, the higher the visibility of a given light source is.

2 In Allard's equation E = Ix-2e-σx, *E* is the illuminance of a point light source and is expressed in terms of the intensity I of the light from the point source, the observer-object distance x and the extinction coefficient σ. This relation is obtained under the hypothesis that the threshold of vision for the point source we are considering is nothing more than a special case of the threshold of brightness contrast. We stress that Allard's equation cannot be solved for the visibility radius *x* in closed form, but a numerical method must be employed to obtain its value to the desired accuracy.

3 This is a reasonable procedure since the climatic variation in the last 6000 years does not differ drastically from the time of the measurements (Pryor 1995; Murray 1987; McGrail 2001, 89; Morton 2001; Finné et al. 2011).

4 Studies of this type have been also conducted in the aeronautical setting to determine optimal flight conditions.

5 The AERONET (AErosol RObotic NETwork) program is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire; Univ. of Lille 1, CNES, and CNRS-INSU) and by several networks (RIMA, AeroSpan, AEROCAN, NEON, and CARSNET) and collaborators from national agencies, institutes, universities, individual scientists, and partners.

Visual Range (m)	Twilight	Full Moon	Complete Darkness
100	247	290	341
200	422	506	605
500	831	1028	1266
1000	1341	1715	2172
2000	2090	2784	3651
5000	3502	5002	6970
10000	4842	7395	10934
20000	6258	10329	16429
50000	7894	14500	25891

Threshold E

Fig. 2 Relation between the Meteorological Optical Range and the distance at which a 100 cd point source is just visible for three values of threshold (*Twilight*, *Full Moon*, and *Complete darkness* conditions). The values (in metres) are obtained by solving the Allard equation for x with an assumed value of the extinction coefficient σ derived from the MOR as in "Appendix 1"

Having considered how far a standard light could be seen under different nighttime conditions, we now turn our attention to the problem of evaluating the visibility of the coast under the full moon and in complete darkness. Thus, from this evaluation we have omitted the twilight case since technically this is defined as the time interval when the geometric centre of the sun is at most 12° below the horizon (Bowditch 2002, 227); indeed, being some sunlight still available during the twilight, sailors were generally able to identify the coastline and be guided by its natural and artificial landmarks independently of the Moon's conditions.

From Theoretical Computation to Measurable Outcomes

The application of the Allard's equation made for obtaining Fig. 2 shows how, during the night, visibility experiences a severe reduction, decreasing even under optimal visibility conditions. The mathematical model we are applying therefore gives us an estimate of the reduction in visibility between night and day at 1.4% (Fig. 3). To provide a practical example, if—during the day—the crew of a ship was potentially able to catch sight of the shoreline from a distance of 21.12 nm (39.12 km), to maintain the same visual contact during the night it was necessary to sail at a *maximum* distance of 0.29 nm (0.55 km) from the coast; thus, $1.4\% = \frac{0.29}{21.12} \times 100$. However, it is fundamental to keep in mind that this example has been calculated considering the minimum extinction coefficient (0.0001), so it

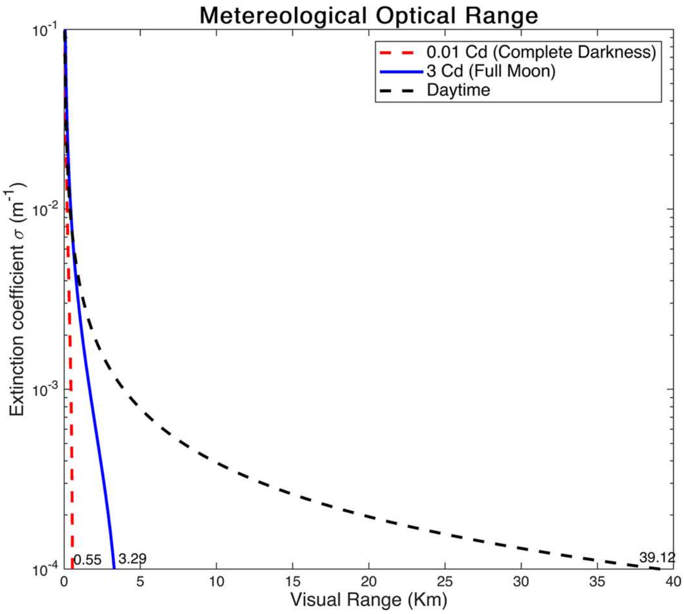

Fig. 3 The figure reports three curves relating the extinction coefficient σ (m^{-1}) and the visibility radius (km) under daytime and nighttime regimes. For the daytime regime the Koschmeider model has been used as described in Mauro and Durastante (2022). For the nighttime we employ the threshold values for full moon, and complete darkness conditions (WMO 2021). The values of light intensity assumed are 0.01 cd and 3 cd respectively

refers to a sail under the best possible atmospheric conditions; if the evaluation is repeated using larger extinction coefficients, the result will therefore be an even smaller radius of visibility (see Fig. 3, in which these cases are reported) (El-Fandy 1952; Dayan and Levy 2005; Mauro and Durastante 2022). Before proceeding with further considerations, it is essential to remember that such results are based on a computation carried out with fixed, standard values; in this sense—although they are highly reliable and easily replicable—they might not be exactly in line with the outcome of future, possible experimental sailings, as only the latter could enrich these computations both with the nuances given by human factors and by the instrumental readings of the extinction coefficient (for an example of an experimental archaeological project evaluating visibility in the hinterland, see Campayo et al. 2015).

Be that as it may, when using the measurable outcome obtained through the theoretical computation, we can state that, in order to maintain the coast visible at night, the ship had to sail at less than 0.29 nm (0.55 km) from the coast. Such a proximity certainly offered some beneficial aspects (i.e. it allowed the crew to find shelter or to disembark relatively rapidly when weather conditions started to exacerbate); however, at the same time, it could have resulted in being extremely hazardous, as the topography of some coasts actually tended to intensify the dangers caused by adverse weather conditions (Rougé 1981, 18–20; Taylor 1956, 30–32; on the pros and cons of coastal navigation, see also Synes. *Ep.* 4). In any case, maritime spaces located at less than 0.29 nm (0.55 km) from the shore are also places where breaking waves, which only occur in relatively shallow waters, are more likely to impact the ship's hull. Furthermore, if the ship accidentally happened to enter the area of foam, it also risked being brought ashore fiercely and against the crew's will (Ap. Rhod. *Argon*. 2.245–350; Morton 2001, 145–150).

Nocturnal coastal sailing was, therefore, possible, but the option to maintain the shoreline within one's radius of visibility could have come at a considerable cost for the crew (i.e. increasing dangers). Even so, despite the above mentioned risks, sometimes the choice of keeping closer to the coastline at night was made at any rate. Amongst others, Thucydides relates that the Peloponnesian fleet, after setting sail from the Arginousai (islands off the Dikili Peninsula, Turkey) 'when the night was still deep' (ἔτι πολλῆς νυκτὸς), reached Sigeion (Kumkale, Turkey) on the evening of the same day (Thuc. 8.101). The navigation was safely conducted, but—as underlined by the same text—the fleet had to 'hug the coast' (παρέπλεον) of the Thracian Chersonesos (Thuc. 8.102).

A key issue in carrying out the nocturnal coastal navigation, while minimizing the risk, was to also maintain a certain level of control, such as having familiarity with that particular stretch of the shoreline. This is what seems to suggest the comparison between the above mentioned episode referring to the Peloponnesian fleet and the disastrous outcome of the coastal navigation conducted by the Persian fleet in 492 BC, when they tried to pass Mount Athos without maintaining a considerable distance from it (Hdt. 6.44; this coastal route failed, despite having been conducted during the day).

Whether, in general, sailing at night was made quite difficult for the low conditions of visibility, there was still one situation that allowed for a satisfactory level of luminosity, i.e. sailing under the full moon (Taylor 1956, 9; McGrail 2001, 100). With an emitted brightness equal to 0.3 lx (Kyba et al. 2017), a full moon could act as a suitable source of light. When sailing under the full moon, the normal, daylight radius of visibility is reduced to 8.4% (cf. with the 1.4% reduction of visibility normally found in complete darkness conditions). This means that in the case described above, with daytime visibility computed as 21.12 nm (39.12 km) and complete darkness visibility as 0.29 nm (0.55 km), the radius of visibility under the full moon could be increased up to 1.77 nm (3.29 km). However, it is equally necessary to stress that, bearing in mind the schedule of the moonrise and of the moonset, the temporal window capable of providing an acceptable radius of visibility when sailing under the full moon was reachable uniquely during certain hours of the night. The timing depends on the stage of the Moon cycle; in its first half it rises before sunset and peaks before midnight while the second part of the night has no moonlight and we are in the opposite situation during the second part of the cycle (see Śmielak 2023). During the rest of the time, the level of nocturnal visibility returns to the values determined for the complete darkness setting.

Discussion

From the above-depicted situation, it can be understood that the decision to sail at night had significant repercussions so the crew of the ship had to seriously consider whether or not to continue their path or interrupt their journey while waiting for the sun to rise again (in that case spending the night in the harbour or anchored at sea). If the crew decided to prolong their path during the night, they had to take into account the severe reduction of visibility and decide how to act in order to overcome, or at least reduce, the effect of such a difficulty. Clearly, such a decision depended on several factors, such as the aim of that journey, the typology of the ship employed, its seaworthiness, the experience of the crew and their familiarity with that particular maritime area.

Fundamentally, they had two viable options:

1. One was going out to sea and avoiding the numerous dangers of coastal navigation, rendered even more difficult to spot by the low level of visibility.
2. The other was to get nearer to the coast to maintain the shore within the nocturnal radius of visibility.

In the past decades, both qualitative (Murray 1993; McGrail 2001; Morton 2001; Arnaud 2022a) and quantitative (Whitewright 2011; Alberti 2018; Safadi and Sturt 2019; Gal et al. 2023) studies have already acknowledged the existence of both these sailing options under normal, daylight conditions. As a consequence, they elaborated different navigational models that can be applied to understanding the status of maritime connections during Antiquity in different areas of the Mediterranean Sea (Safadi and Sturt 2019; Trapero Fernández and Aragón 2022; Gal et al. 2023). Therefore, the possibility that these two sailing options, continuing out to sea or moving closer to the coast, could also be conducted at night when visibility was lower, does not significantly alter the perspective that such models show as to the limitations of navigational models due to the fragmentary and material nature of the data, the functioning and change of social processes over long timespans, and the unpredictability of the human factor (see Brughmans et al. 2016; Arnaud 2020a). On the contrary, such considerations enrich these models with another dimension, in the sense that they open up the possibility that some of those routes could also be travelled at night.

In the next subsections, we are going to discuss in more detail how each one of these two sailing possibilities could have been conducted at night when, as noted above, the radius of visibility could not have exceeded 0.29 nm (0.55 km).

Going Out to Sea

If deciding to go out to sea (or to maintain the open-sea route), the crew would have almost completely lost the possibility of resorting to artificial and natural landmarks, so they necessarily had to find alternative sources of orientations, such as astronomical and meteorological references (Farr 2006). When the sky at night was clear and the amount of moonlight reduced, the direction of the ship could be determined thanks to the use of constellations. Winds could also be used for orienteering purposes (for orientation according to the winds, see Taylor 1956, 14–20; Arnaud 2020a, 61–70; Mauro 2022b, 8–13). This is confirmed, amongst others, by Strabo, who, in a passage of the *Geography* (16.23–24), states that the Phoenicians stood out for their studies in astronomy due to their familiarity with the stars that they acquired during their nocturnal sailings (Medas 2022, 103–106). Once the direction of North was established, it would have been possible for the crew to divide the horizon into sectors and estimate approximate changes in latitude (Agouridis 1997, 17). The use of stars in nocturnal seafaring can be inferred by the numerous references to celestial navigation found in Homer (*Od.* 5.270–281 and 14.301–302).[6] The main

[6] With celestial navigation we refer here to the possibility of maintaining or choosing an approximate direction by means of the position of the stars. For 'celestial navigation' we do not mean, therefore, 'astronomical navigation', that is the possibility to determine exactly the ship's position at sea by uniquely employing the astronomical references (Medas 2004, 155).

constellations employed to establish the position of North were the two Bears, the Ursa Minor and the Ursa Major (Taylor 1956, 9; Medas 2004, 165). According to the surviving sources, the use of the one or the other varied according to two different nautical traditions: while the Greeks tended to employ the Ursa Major for orienteering purposes, the Phoenicians preferentially made use of the Ursa Minor (Manil. 1.294–302; Sil. Ital. 3.665). At the Mediterranean latitudes, both the Ursa Major and the Ursa Minor are circumpolar, since they never set below the horizon, so they were two valuable references (from this situation it derives the famous literary image according to which the Bears '….have no part in the baths of Ocean…', Hom. *Od.* 5.275); however, choosing one or another presented a series of advantages and disadvantages. The Ursa Major, preferred by the Greek tradition, was certainly easier to locate with its brightness. In particular, the brightest star of the Ursa Major is *Epsilon Ursae Majoris* with an apparent magnitude of 1.76^m;[7] nonetheless, it was some distance from the Celestial Pole, so it was actually not as valuable an indicator of a northerly direction (Morton 2001, 216). On the other hand, the Ursa Minor—mostly used by the Phoenician seafarers—was more difficult to identify but it provided a more accurate reference, since it stands (and stood) nearer to the Pole Star (Medas 2004, 166). Kochab (*Beta Ursae Minoris*, with an apparent magnitude of 2.08^m; compared with the apparent magnitude of 1.76^m of *Epsilon Ursae Majoris*), another member of this constellation, was situated, in Homer's days, only 8° from the North Pole, so following it would have allowed a ship to maintain a continuous direction (Taylor 1956, 12; McGrail 1996).

Beyond the evidence provided by written sources, the use of stars to direct the sea routes can also be gleaned from the depictions found on pottery. Since the Geometric period, ships are frequently portrayed on pottery (Kirk 1949), with such representations being sometimes accompanied by stars (Figs. 4, 5 and 6) (see also Morrison and Williams 1968: Geom. 8.3 and Geom. 26). Even if it could be claimed that stars were included as mere decorative elements, it is equally possible that their presence could have also been related to the fundamental role that they played in nocturnal seafaring (Mauro 2022b). The knowledge of the stars finds further support in a representation discovered in the late twentieth century at Pithekoussai (Ischia, Naples, Italy) and dated to the eighth century BC. On the inner side of the fragment, originally pertaining to a krater, a graffito depicts some stars joined together as if in a constellation. One of these stars is accompanied by the letter β in the Chalcidian alphabet (Coldstream and Huxley 1996; Monti 1998–1999), likely standing for Boötes, one of the brightest constellations in the night sky (Fig. 7). The constellation of Boötes (whose brightest star is Arcturus, with an apparent magnitude of -0.04^m) is also mentioned by a famous Homeric passage (*Od.* 5.269–278), when Calypso is explaining to Odysseus the route to follow for reaching the island of the Pheacians and she suggests to the helmsman to keep Boöotes on the left (Taylor 1956, 40).

Moving Closer to the Coast

The second option for a ship that had to sail during the night was to keep the coast within the visible radius even in complete darkness. As it has been previously underlined (see the section titled 'From theoretical computation to measurable outcomes'), sailing near the coast exposes a ship to multiple dangers, as this is precisely where the

[7] We recall that the magnitude scale is reverse logarithmic, i.e. the brighter an object is, the lower its magnitude number; therefore, the stars with faintest magnitude that are visible under optimal condition have an apparent magnitude that is below 8^m (Curtis 1903).

Fig. 4 Fragments of a Geometric krater attributed to the Dipylon Master and dated to the third quarter of the eighth century BC (750–725 BC). Some stars are depicted above the bow of the ship. Louvre Museum, inv. no. A 528 = s 519. Photo (C) RMN-Grand Palais (musée du Louvre)/Stéphane Maréchalle

Fig. 5 Ship depicted on a Geometric krater attributed to the Dipylon Master (ca. 750 BC). The sky is decorated with stars, birds and double axes. Louvre Museum, inv. no. A 517 = S 568. Photo (C) RMN-Grand Palais (musée du Louvre)/Hervé Lewandowski

majority of hazards—rocks, shoals, reefs, seaweeds and mud—are usually found. Commonly, the task of spotting visible landmarks and detecting possible dangers on the vessel's path was entrusted to the lookout (πρῳράτης), who was normally stationed on a raised platform on the bow of the ship or, less frequently, on a sort of crow's nest (Casson 1971, 301; Beresford 2012, 184; Mauro 2022a, 19). However, at night, with the severe reduction of visibility noted above, the role of the lookout was hardly reliable, as

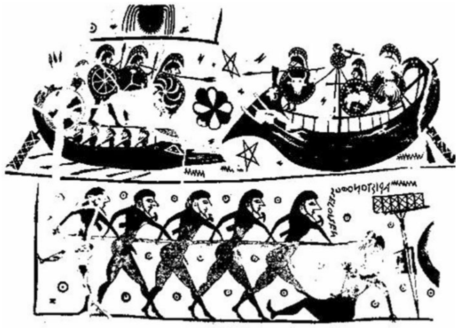

Fig. 6 Reproduction of two scenes from the so-called Aristonothos' krater, second half of the seventh century BC. In the background of the naval battle, some stars could be noticed. Walters (1905), plate XVI

they might have noticed the presence of coastal hazards when it was already too late to avoid them. Said differently, if coastal navigation was already difficult, it could become even more challenging in the presence of poor visibility conditions (i.e. nocturnal visibility). The precariousness of coastal navigation, in fact, rises in an inversely proportional fashion when compared to the level of visibility; the worse the visibility is, the higher the possibility for a ship to strand, run afoul of rocks and shoals, or even to collide with other vessels (Taylor 1956, 4; Beresford 2012, 204).

Given the huge risk that it implied, nocturnal sailing along the coast was usually and, whenever possible, avoided at night and ships were rather heaved to or waited for the dawn. However, in some cases, the crew of a ship may have been desperate to move in that direction (Bar-Yosef Mayer et al. 2015, 15) and could have decided to sail overnight despite the danger. As a matter of fact, whereas the interruption of the sea-journey was possible for big and medium-sized vessels sailing for commercial reasons, the situation could have been different in warlike contexts or for those vessels operating under economic or social pressures (Bar-Yosef Mayer et al. 2015, 12). The passage by Thucydides mentioned above (8.101–102), for instance, illustrates that a fleet could have been

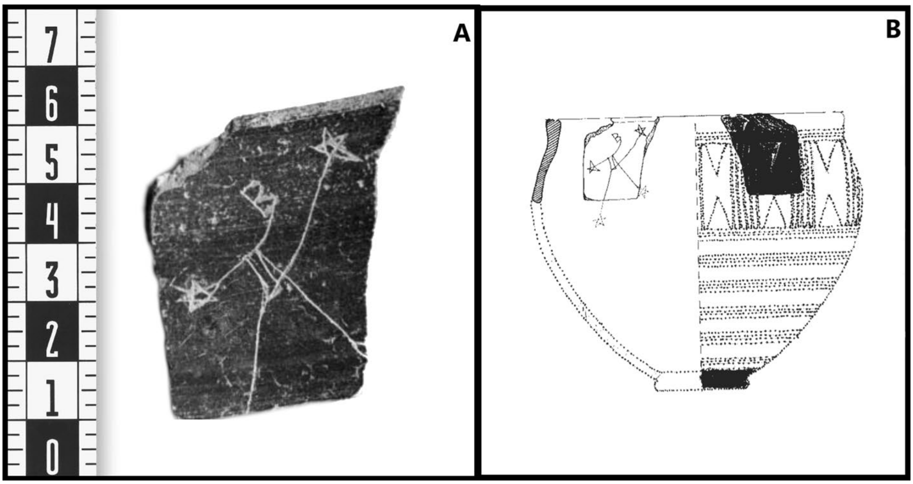

Fig. 7 **a** Fragment of the krater with the incision representing the constellation of Boötes; **b** Reconstruction of the krater (Mauro 2022b, Fig. 5)

forced to continue its journey overnight and that, in some cases, the option of moving closer to the coast could have been adopted and preferred to the open-sea route.

In case the crew decided (or had) to continue the journey, a set of tools could have been employed to reduce dangers derived from the decrease of visibility at night. First, it was necessary to sharpen the senses: strange as it may sound, it is fairly known that a sailor's marine sense involves not only their sight, but also hearing, smell, and the observation of the way in which the water breaks around the hull of the ship (Rainbird 2007, 47). Considered altogether, these signals could provide precious information, helping the sailors to approximately infer the position of their ship in relation to the coast or to potential hazards, even if the radius of visibility was dramatically low. Unfortunately, since no actual ancient pilot book survived (Janni 2002, 410; Medas 2004, 14), it is difficult to establish with a certain level of precision what exactly this 'marine sense' could have consisted of. However, ethnographic comparisons and ancient literature could be used to gain an overall idea of how the sea was lived and experienced (Ingold 2000, 230 and 241–242, and 2010). Ethnographic comparisons, for instance, successfully demonstrate that any experienced sailor can feel the wind or the waves, or be guided by smells. As for ancient literature testimonies, traces of this 'marine sense' can be gleaned from the Homeric corpus, in which there are frequent references to sailors *hearing* and *feeling* the wind or the waves crashing on the shore or into cliffs (*Il*. 2.394–397, 4.421–426, 15.619–620; *Od*. 5.401–403). Another significant passage came from the Acts of the Apostles (1.27): albeit falling outside the period under examination (first century AD), this source could be used to show the profound relationship of the sailors with their maritime environment. Within the same passage, during nocturnal navigation, the crew somehow 'felt' (ὑπενόουν) that the ship was approaching the land and this sensation encouraged them to use the sounding lead.

The second strategy could also be inferred from the passage just mentioned. To confirm what was suggested by their marine sense (or simply to gather information on the seafloor), the crew could resort to the use of the sounding lead. Documented in the Mediterranean area since the 3rd millennium BC (McGrail 1991; Agouridis 1997, 15), the sounding lead and its use are carefully described by Herodotus (2.5.2). In case of poor visibility, this tool was particularly valuable, for it provided a means by which the depth of water and the nature of the seafloor could be tested. By analysing the material dredged up from the seafloor, sailors may, in fact, find their way across the sea, avoiding shoals or rocky patches (Morton 2001, 207).

Finally, another possibility for the crew to relatively improve their radius of visibility and facilitate the manoeuvres of the ship was to ignite artificial lights on the ship. The use of oil lamps, torches, or other devices on ancient ships is poorly known, as the evidence is scattered (Beltrame 2002, 97–99; Arnaud 2020b). In the tragedy called Rhesus and tentatively attributed to Euripides, Hector refers to torches (using the word πυρός) lit onboard to find the path of the ship across the sea (*Rh*. 95–96). Could such torches really contribute to enhancing the nighttime visibility or is this image just a literary product? If we want to keep evaluating the effect of luminous sources on nighttime visibility, we can understand a bit more in detail what the use of torches could practically entail. We can model a torch as a point source of light kept at 4 m on the ship's deck (Zamora Merchán 2012) and a quantity of light emitted in between 100 and 200 lumens. Applying these values, the expected improvement of visibility when using a torch in complete darkness would be around 10 m (Fig. 8); this means that, as described in the tragedy, the employment of torches could actually increase visibility. However, this improvement had only a short-range effect, so torches could be ignited just to ease nautical manoeuvres in dangerous areas or to avoid close hazards; their usage did not serve, in other words, for a direct illumination of the coastline.

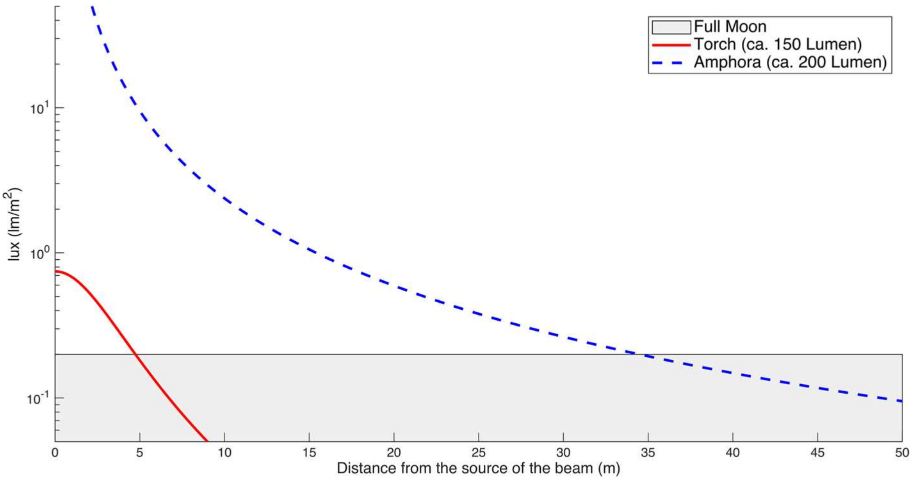

Fig. 8 Graphic showing the luminous flux per unit area emitted by an average torch and a pierced amphora with a fire lit inside. The grey area represents the average luminous flux of a full moon

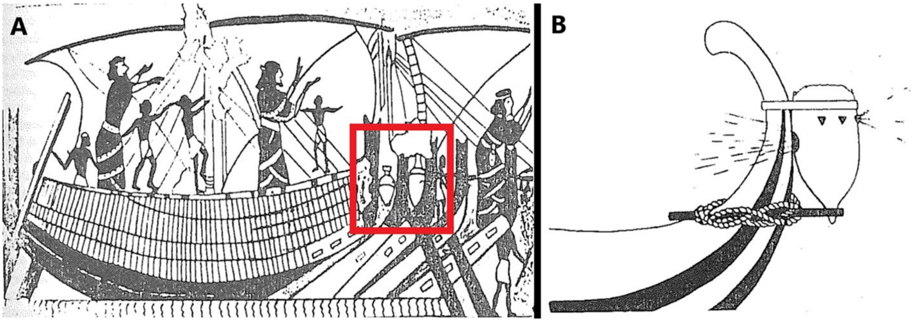

Fig. 9 **a** Reproduction from the New Kingdom Egypt depicting the two amphoras fastened to the bows of the Canaanite ships; **b** Reconstruction of the proposal advanced by Fonquerle (after Gasull 1986, Figs. 2 and 3)

To this observation, we should also add that, for the member of the crew who handled the torch, as for anyone who happened to be within its cone of light, the illumination emitted would have decreased the threshold of discernibility for scotopic vision, thus requiring a new period of adaptation to the darkness. According to Reeves (2009), the waiting time for someone to completely recover a normal scotopic vision after having been within the cone of light of a torch would be up to 25 min, however, the first improvements could be noticed 10 min after the moment in which the eyes were hit by the cone of light. (Reeves 2009, Fig. 1). In other words, while the use of torches could actually improve the short-range vision of the crew, it debilitates their medium-range perception, thus making it more difficult to catch sight of the shoreline or of any other elements that stood at a distance of more than 10 m.

Torches were not the only devices used to rapidly improve nighttime vision. Much earlier (fourteenth century BC), but equally relevant to the present discussion, are the amphoras depicted on a fresco found on Kenamon's tomb (Theban Tomb 162, Luxor, Egypt)

(Fig. 9a). Firmly fastened to the bow of two Canaanite ships, these vessels have been traditionally interpreted as lights used in nocturnal navigation (Gasull 1986, 195). A similar system has been hypothesised for an amphora associated with a second century BC shipwreck found in the river Hérault (Languedoc, France) (Fig. 9b) (*contra* Basch 1974). The amphora, a Dressel1A cut at the body-level, presented, as noticed by Fonquerle (1973, 67–68), a series of holes and traces of ropes (probably to fasten to the ship) and combustion: Fonquerle, thus, supposed that the bigger hole, circular in shape, would have served for lighting up the deck of the ship; whilst the five small triangular holes would have acted as position lights (meant to give information on the ship's position, heading or status).[8] While the interpretation of the small holes could be sustained (the small holes, being located on the upper side of the amphora (see Fig. 9b), could also have doubled as a way of removing the smoke produced by combustion), it seems more reasonable to claim that the larger hole was meant to illuminate the water around the bow. If it was directed towards the ship, as Fonquerle proposed, the light would have had, in fact, only a negative effect on the crew's vision since it would have worsened their short and medium range vision capability. On the other hand, if it was meant to illuminate the water ahead of the bow, this cone of light could have enhanced the vision in the following terms: more intense than the undirected light produced from a torch, the light beam emitted from a pierced amphora would have been more focused and it could have reached an intensity of between 150 and 250 lumens, thus offering around 50 m of illumination (see Fig. 9b). Furthermore, the use of amphoras as lighting devices offered two other advantages. First, they partially shield the users' eyes, since the body of the vessel impedes the cone of light on the crew's vision; this would have reduced the loss of sensitivity that we noticed with regards to the use of torches. Second, the light emitted was more focused and it generally lasted longer. It must be taken into consideration that changes in the quality and intensity of the light produced are also given by the type of burnt substance. In a study published 20 years ago, Roussos and Chalmers (2003) examined the spectral data of various fuels of historical interest (including beeswax, olive oil, sesame oil and animal fat) using a spectroradiometer to determine the main extant differences; such results can be useful for determining the wavelengths of the emitted light and thus selecting the appropriate extinction coefficients for the evaluation of the illuminated area.

Conclusions

Within this contribution, we sought to untangle the problems connected with nocturnal seafaring in the Mediterranean Sea during the period between the eighth and the fourth centuries BC. By using the value of the threshold that identified the *best* possible atmospheric conditions, we computed that the nocturnal radius of visibility barely corresponds to the 1.4% of what can be seen under the same atmospheric conditions with daylight. Sailing under the full moon could guarantee better conditions of visibility (8.4% of what can be observed during the day): however, since this condition is not frequent and since the moon illuminates the sky just for a brief part of the night, the organisation and planning of a nocturnal route cannot strictly depend on it.

[8] A literary testimony about the use of amphoras hung to the bow proceed from fifth century AD author Procopius (*Vand.* 1.13.3).

Within this contribution we suggested that, in front of the severe reduction of visibility experienced at night, the crew of a ship could either decide to go out to sea and rely completely on astronomical and meteorological signs, or they could sail along the coast and proceed with their journey. The latter choice could result in being particularly dangerous; however, as the reading of ancient literary sources has revealed, nocturnal coastal navigation was still sometimes performed. In those cases, the crew had to count on a set of tools, such as marine sense, nautical instruments, and onboard lighting devices. The last, which can be fixed or portable, while enhancing the short-range vision, had to be used with caution, as they can negatively affect the photo sensibility of those who fell within their cone of lights, and could have made it more difficult to catch sight of elements situated at more than 50 m (i.e. the shoreline and its silhouette), and identify stars of small apparent magnitude.

Appendix 1

Let us call P the Meteorological Optical Range (MOR), i.e. 'the length of path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp, at a colour temperature of 2700 K, to 5% of its original value' (WMO 2021: 330). This permits to use the Bouguer–Lambert law to uncover the relationship between the transmission factor and the MOR, thus letting us compute σ in terms of P as

$$\sigma = \frac{1}{P}\ln(1/0.05) \approx \frac{3}{P}$$

And then use it solving for x in Allard's equation. We stress that the Bouguer–Lambert law and hence the previous relation is the model used by several types of transmissometer to measure the extinction coefficient σ. Transmissometers are usually made by an emitter and receiver. They measure the transmissivity of a beam of direct light between the emitter and the receiver to calculate visibility range by estimating the extinction coefficient σ. Indeed, the roughness of the approximation we are suggesting here is produced entirely by the poor precision of an ocular estimate of the range of visibility.

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Declarations

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References

Agouridis C (1997) Sea routes and navigation in the third millennium Aegean. Oxf J Archaeol 16(1):1–24. https://doi.org/10.1111/1468-0092.00022

Alberti G (2018) TRANSIT: a GIS toolbox for estimating the duration of ancient sail-powered navigation. Cartogr Geogr Inf Sci 45(6):510–528. https://doi.org/10.1080/15230406.2017.1403376

Arnaud P (2016) Ancient sailing-routes and trade patterns: the impact of human factors. In: Robinson D, Wilson A (eds) Maritime archaeology and ancient trade in the Mediterranean (Oxford Center for maritime archaeology monographs). Oxford University Press, Oxford, pp 61–80

Arnaud P (2020a) Les routes de la navigation antique. Itinéraires en Méditerranée et mer Noire. Errance, Paris

Arnaud P (2020b) Aides à la navigation, pratique de la navigation et construction des paysages maritimes en Atlantique du Nord-Est: quelques éléments de réflexion. Gallia 77(1):29–43. https://doi.org/10.4000/gallia.5298

Bar-Yosef Mayer DE, Kahanov Y, Roskin J, Gildor H (2015) Neolithic voyages to Cyprus: wind patterns, routes, and mechanisms. J Isl Coast Archaeol 10(3):412–435. https://doi.org/10.1080/15564894.2015.1060277

Basch L (1974) A propos de la navigation de nuit dans l'Antiquité. Archéologia 74:79–81

Beltrame C (2002) Vita di bordo in etá romana. Istituto Poligrafico e Zecca dello Stato, Rome

Beresford J (2012) The ancient sailing season. Brill, Leiden

Bowditch N (2002) The American Practical Navigator [bicentennial edition, 1st edition 1802]. National Imagery and Mapping Agency, Bethesda (Maryland)

Brughmans T, Collar A, Coward F (eds) (2016) The connected past: challenges to network studies in archaeology and history. Oxford Academic, Oxford. https://doi.org/10.1093/oso/9780198748519.001.0001

Campayo C, Moya Maleno PR, Bastos AD (2015) Territorio y comunicaciones bajomedievales en el Alto Valle del Jabalón durante el siglo XIII: experimentalidad y propuestas. In: Moya-Maleno PR, Gallego D (coords.) Campo de Montiel 1213: Entre el Islam y el Cristianismo. Centro de Estudios del Campo de Montiel, Almedina, pp 189–231

Casson L (1971) Ships and seamanship in the Ancient World. Princeton University Press, Princeton

CIE Proceedings (1951) Vol. 1, Sec 4; Vol 3, p. 37. Bureau Central de la CIE, Paris.

Coldstream JN, Huxley GL (1996) An astronomical Graffito from Pithekoussai. La Parola Del Passato 51:221–224

Curtis HD (1903) On the limits of unaided vision. Lick Obs Bull 38:67–69. https://doi.org/10.1126/science.17.443.1010-a

Davis D (1999) Maritime space and night-time sailing in the ancient Eastern Mediterranean. Tropis 7(1):291–309

Dayan U, Levy I (2005) The influence of meteorological conditions and atmospheric circulation types on PM10 and visibility in Tel Aviv. J Appl Meteorol 44:606–619. https://doi.org/10.1175/JAM2232.1

El-Fandy MG (1952) Visibility in the eastern Mediterranean. Geofis Pura Appl 21:58–62

Farr H (2006) Seafaring as social action. J Mari Arch 1:85–99. https://doi.org/10.1007/s11457-005-9002-7

Finné M, Holmgren K, Sundqvist HS, Weiberg E, Lindblom M (2011) Climate in the eastern Mediterranean, and adjacent regions, during the past 6000 years—a review. J Archaeol Sci 38(12):3153–3173. https://doi.org/10.1016/j.jas.2011.05.007

Fonquerle D (1973) Découverte d'un dispositif de signalisation de la navigation antique. Archéologia 64:67–70

Gal D, Saaroni H, Cvikel D (2023) Mappings of potential sailing mobility in the Mediterranean during Antiquity. J Archaeol Method Theory 30:397–448. https://doi.org/10.1007/s10816-022-09567-5

Gasull P (1986) Problemática en torno a la ubicación de los asentamientos fenicios en el sur de la Península. Aula Orientalis 4:193–202

Giles DM, Sinyuk A, Sorokin MG, Schafer JS, Smirnov A, Slutsker I, Eck TF, Holben BN, Lewis JR, Campbell JR, Welton EJ, Korkin SV, Lyapustin AI (2019) Advancements in the Aerosol Robotic Network (AERONET) Version 3 database—automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements. Atmos Meas Tech 12:169–209. https://doi.org/10.5194/amt-12-169-2019

Henkel L (1901) Die Grenze der Sichtbarkeit des Landes auf dem Meere. In: Haack H (ed) Dr. A. Petermanns Mitteilungen aus Justus Perthes'Geographischer Anstalt, vol 47. Perthes, Gotha, pp 284–285

Horden P, Purcell N (2000) The corrupting sea: a study of Mediterranean history. Blackwell, Oxford

Horvath H (1993) Atmospheric light absorption—a review. Atmos Environ A-Gen 27:293–317. https://doi.org/10.1016/0960-1686(93)90104-7

Ingold T (2000) The perception of the environment. Essays in livelihood, dwelling and skill. Routledge, London. https://doi.org/10.4324/9781003196662

Ingold T (2010) Footprints through the weather-world: walking, breathing, knowing. In: Marchand THJ (ed) Making knowledge: explorations of the indissoluble relation between mind, body and environment (Journal of the Royal Anthropological Institute 16). Wiley, Malden, pp 115–132

Janni P (2002) Nautica. In: Santini C, Mastrorosa I, Zumbo A (eds) Letteratura scientifica e tecnica di Grecia e Roma. Carocci, Rome, pp 395–412

Kirk G (1949) Ships on geometric vases. Annual of the British School at Athens 44:93–153. https://doi.org/10.1017/S0068245400017196

Kyba C, Mohar A, Posch T (2017) How bright is moonlight? Astron Geophys 58(1):1–31. https://doi.org/10.1093/astrogeo/atx025

Larsson AJ, Marut JK, Northedge RL (1970) Tables of runway visual range values as a function of transmittance and various values of pilot's illuminance threshold and light targets. Final Rept. for the Federal Aviation Administration Washington Dc Systems Research and Development Service. Report n° AD0713495. https://apps.dtic.mil/sti/citations/AD0713495

Mauro CM (2019) Archaic and Classical Harbours of the Greek World: the Aegean and Eastern Ionian contexts. Archaeopress, Oxford. https://doi.org/10.2307/j.ctvndv7h2

Mauro CM (2022a) The Periplus of Pseudo-Skylax and its relationship with earlier nautical knowledge. Mariner's Mirror 108(1):6–30. https://doi.org/10.1080/00253359.2022.2009241

Mauro CM (2022b) Sailing the wine-dark sea: maritime travel during the Geometric Period. In: Mauro CM, Chapinal-Heras D, Valdés Guía M (eds) People on the move across the Greek world. Universidad de Sevilla, Seville, pp 123–140

Mauro CM, Durastante F (2022) Evaluating visibility at sea: instrumental data and historical nautical records. Mount Etna from the Calabrian Ionian coast (Italy). J Isl Coast Archaeol 17(1):21–42. https://doi.org/10.1080/15564894.2020.1755394

McGrail S (1991) Early sea voyages. Int J Naut Archaeol 20(2):85–93. https://doi.org/10.1111/j.1095-9270.1991.tb00303.x

McGrail S (1996) Navigational techniques in Homer's Odyssey. Tropis 4:311–320

McGrail S (2001) Boats of the world from the Stone Age to Medieval Times. Oxford University Press, Oxford

Medas S (2004) De Rebus Nauticis: l'arte della navigazione nel mondo antico. L'Erma di Bretschneider, Rome

Medas S (2022) Nautica antica. Itinerari nel mondo della navigazione, tra storia, archeologia ed etnografia. L'Erma di Bretschneider, Rome

Meléndez JB, Campos Carrasco JM (2020) Maritime signalling in Antiquity: the *Lanterna* of the harbour of *Onoba Aestuaria*, a new lighthouse along the Atlantic (Huelva, Spain). J Mari Arch 15:475–498. https://doi.org/10.1007/s11457-020-09276-8

Monti P (1998–1999) Homeric tradition in the Mediterranean Navigation of the Pithekoussans. Talanta 30–31:115–132

Morrison JS, Williams RT (1968) Greek Oared Ships, 900–322 B.C. Cambridge University Press, Cambridge
Morton J (2001) The role of the physical environment in Ancient Greek Seafaring. Brill, Leiden
Murray W (1987) Do modern winds equal ancient winds? Mediterr Hist Rev 2(2):139–167. https://doi.org/10.1080/09518968708569525
Murray W (1993) Ancient sailing winds in the Eastern Mediterranean: the case for Cyprus. In: Proceedings of the international symposium, cyprus and the sea, Nicosia, pp 33–44
Pryor JH (1995) The geographical conditions of galley navigation in the Mediterranean. In: Morrison J, Gardiner R (eds) The age of the galley: mediterranean Oared vessels since pre-classical times. Conway Maritime, London, pp 206–216
Raaflaub KA (1997) olitics and interstate relations in the world of early greek poleis: homer and beyond. Antichthon 31:1–27. https://doi.org/10.1017/s0066477400002240
Rainbird P (2007) The archaeology of islands. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511619007
Reeves A (2009) Vision: light and dark adaptation. In: Squire LR (ed) Encyclopedia of neuroscience. Academic Press, Cambridge (Massachusetts), pp 211–216. https://doi.org/10.1016/B978-008045046-9.00926-8
Rouge J (1981) Ships and fleets of the Ancient Mediterranean (trans. S. Frazer). Wesleyan University Press, Middletown (Connecticut)
Roussos I, Chalmers A (2003) High fidelity lighting of Knossos. In: Arnold D, Chalmers A, Niccolucci F (eds) 4th international symposium on virtual reality, archaeology and intelligent cultural heritage (VAST). Eurographics Association, Goslar, pp 47–56
Safadi C, Sturt F (2019) The warped sea of sailing: maritime topographies of space and time for the Bronze Age eastern Mediterranean. J Archaeol Sci 103:1–15. https://doi.org/10.1016/j.jas.2019.01.001
Schüle G (1970) Navegación primitiva y visibilidad de la tierra en el Mediterráneo. In: IX Congreso Nacional de Arqueología de Mérida 1968. Secretaría General de los Congresos Arqueológicos Nacionales, Mérida, pp 449–462
Sherratt ES (1990) "Reading the texts": archaeology and the Homeric question. Antiquity 64(245):807–824. https://doi.org/10.1017/s0003598x00078893
Sliney DH (2016) What is light? The visible spectrum and beyond. Eye 30(2016):222–229. https://doi.org/10.1038/eye.2015.252
Śmielak MK (2023) Biologically meaningful moonlight measures and their application in ecological research. Behav Ecol Sociobiol 77(2):21. https://doi.org/10.1007/s00265-022-03287-2
Stager LE (2003) Phoenician shipwreck in the deep sea. In: Stampolidis NC, Karageorghis V (eds) Ploes—sea routes. Interconnections in the Mediterranean. 16th–6th c. BC. Proceedings of the International Symposium, held at Rethymnon, Crete, in September 29th–October 2nd 2002. University of Crete and the A.G. Leventis Foundation, Nicosia, pp 233–247
Stager LE (2005) Dos pecios fenicios en alta mar de la costa norte del Sinai. In: Mederos Martín A, Peña V, Wagner C (eds) La navegación fenicia: tecnología naval y derroteros: encuentro entre marinos, arqueólogos e historiadores. Universidad Complutense de Madrid, Madrid, pp 176–196
Taylor EGR (1956) The haven-finding art. Hollis and Carter, London
Trapero Fernández P, Aragón E (2022) Modelling cabotage. Coastal navigation in the western Mediterranean Sea during the Early Iron Age. J Archaeol Sci Rep 41:103270. https://doi.org/10.1016/j.jasrep.2021.103270
Walters BH (1905). History of ancient pottery: Greek, Etruscan and Roman, vol. I. Charles Scribner's Sons, New York
Wandell BA (1995) Foundations of vision. Sinauer Associates, Sunderland Mass
Whitewright J (2011) The potential performance of ancient mediterranean sailing rigs. Int J Naut Archaeol 40(1):2–17. https://doi.org/10.1111/j.1095-9270.2010.00276.x
World Meteorological Organization (2021) Guide to meteorological instruments and methods of observation, vol 1. WMO-NO.8 (2021)
Zamora Merchán M (2012) La altura de los faros de época romana en relación con su visibilidad marítima: El Faro de Brigantium y el posible Faro de las Campa Torres (Gijón). Cuadernos De Prehistoria y Arqueología 38:705–721. https://doi.org/10.15366/cupauam2012.38.039