Chapter 4
Quantification of Bottom Trawl Damage to Ancient Shipwrecks: A Case Study from the Coastal Waters of Turkey

Michael L. Brennan

Ancient shipwrecks in the Mediterranean region are particularly susceptible to damage by bottom trawl fishing activities because of their low relief on the seabed. Shipwrecks from the Greek and Roman periods typically consist of mounds of amphora cargoes, which slump onto the seabed in the shape of the vessel outline once the wooden hulls deteriorate following consumption by wood boring organisms. These low relief mounds do not snag trawl nets the way steel-hulled shipwrecks do in which fishers lose gear and could avoid those locations later. Instead, the fragile ceramic artefacts that comprise ancient wrecks are exposed to repeated strikes by trawls until they are broken and scattered across the seabed, potentially to the extent that they can no longer be found. Expeditions from 2008 through 2013 by Ocean Exploration Trust (OET) and the Exploration Vessel *Nautilus* documented numerous ancient shipwrecks in the Black and Aegean Sea coastal waters of Turkey that exhibited a range of damage from trawls, and which allowed for quantification of some of this damage.

Understanding the effects of bottom trawling on ancient wrecks, and assessing the threat posed to them, requires finding the wrecks, documenting their current state of preservation, and finally quantifying the amount of damage already inflicted, prior to the implementation of any protection measures. Hard bottom substrate, which the amphora cargoes of these wrecks provide, are important habitat for juvenile fish and other organisms as artificial reefs, and trawl activities cause severe impacts to the benthos. The drastic effects of continued trawl activities also include the smoothing over of seabed substrates and erasure of seabed structures such as ripples and other bedforms, soft reef substrate like carbonate outcrops, and other structures such as wrecks (Vigo et al., 2023; Puig et al., 2012). Efforts to protect shipwreck sites specifically from trawling have been minimal. For shipwrecks in

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M. L. Brennan (✉)
SEARCH Inc., Jacksonville, FL, USA
e-mail: mike@brennanexploration.com

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deep water, and unobservable to researchers and resource managers, the essential component missing in reducing the damage inflicted by bottom trawling is thorough documentation of threatened sites by return visits and repeated surveys (Brennan et al., 2016).

4.1 Trawling in the Mediterranean

The Mediterranean Sea is home to the oldest – and some of the most overexploited – trawling grounds in the world. The deep-sea fishery was historically centred on the deep-water red shrimp species, *Aristeus antennatus* and *Aristaeomorpha foliacea*, originating in the western and central Mediterranean. When the eastern Mediterranean countries, namely Greece and Turkey, began to exploit their own deep-water resources in the early 2000s, the fishing grounds were determined as non-virginal seabed, since Italian trawlers had already been exploiting them (Pulcinella et al., 2023; Pinello et al., 2018). Over the last two decades, the coastal resources of the Mediterranean have become overexploited due to the increasing power of trawling vessels and the expansion of benthic fisheries deeper onto the continental shelf down to depths of 1000 m. Recent work has investigated the 'spatiotemporal patterns of trawling pressure and impact… particularly towards commercial species and unwanted catches, but also as trawling extent and intensity on European wide habitats' (Smith et al., 2023, p. 2). This chapter builds upon previous history of Turkish fisheries, specifically, presented in Brennan et al. (2012), to update the discussion with recent scholarship.

European Union guidance has begun to further regulate the fishing industry with the objective of assuring that the marine waters of the Mediterranean Sea are in 'Good Environmental Status (GES)' (Smith et al., 2023, p. 1) to help determine, and improve, the pressures and impacts of fisheries on the marine ecosystem and provide better ecosystem management. Other major efforts in Europe in recent years have included the BENTHIS project[1] which conducts mapping of the seabed for the purposes of identifying trawling impacts (Eigaard et al., 2017). Such work has produced a series of scientific papers that discuss large areas of the Mediterranean and document trawling impacts across the entire sea 'for benthic status in relation to trawling intensity, landings and value' for habitats at varying depths (Smith et al., 2023, p. 2). In 2019, the European Commission implemented 'a global management strategy for the whole western Mediterranean' although each country still manages its own waters and governs in which areas or seasons bottom fishing is restricted (Vigo et al., 2023, p. 2).

Bottom trawling has been active throughout the Mediterranean for more than 80 years, and most fishery stocks are being captured at their maximum yield or above, putting them at unsustainable levels (Vigo et al., 2023; FAO, 2022). In

[1] http://www.benthis.eu

addition to overfishing and the indiscriminate nature of trawl nets, bottom trawling is also a highly destructive force that flattens and damages the benthic ecosystem on and within the seabed. This repetitive action changes the morphology of the seabed, smoothing over bedforms and other bathymetric features, as well as causes the resuspension and removal of sediment through the impacts of the wires, nets, and otter doors (Vigo et al., 2023; Puig et al., 2012). Areas of intense commercial trawling, therefore, act as an anthropogenic geological force that changes the bathymetry and benthic ecology, often scraping down far enough to expose hard substrate. Large swaths of continental shelf substrate have been damaged in this way, particularly in the Straits of Sicily, the northern Aegean Sea, and areas of the Adriatic Sea (Pulcinella et al., 2023; Ferrà et al., 2020). A recent study established a no-take area and observed the recovery of the benthos, which showed that ecological recovery following the cessation of trawling occurred in a relatively short time (Vigo et al., 2023). This is positive information for resource managers and fishery biologists. However, ancient shipwrecks cannot recover from the impacts of trawling like a benthic ecosystem can; damage to these historic sites is permanent.

A recent development in maritime shipping is the introduction of the Automatic Identification System (AIS), which was developed to avoid collisions between ships, and has been required on all vessels greater than 15 m in length since 2014 for the monitoring and management of a number of maritime activities, including fishing (Ferrà et al., 2020). The implementation of AIS on fishing vessels allows for the tracking of their mobility and operations, resulting in 'consistent data to observe large deep-sea trawlers' (Pulcinella et al., 2023, p. 810). This tracking system also shows instances where there are data gaps stemming from captains switching off the system for short periods and allowing 'hidden fishing' or unobserved bottom trawling in prohibited areas (Ferrà et al., 2020). Bottom trawling is often focused on prime bathymetric areas that contain morphologic features conducive to both the habitat necessary for the targeted catch species and ease of towing gear. However, trawling is generally prohibited within 3 miles of the coast in the Mediterranean or within the 50 m isobath as well as below 1000 m (Smith et al., 2023). Illegal trawling operations may target areas within these parameters that are otherwise prohibited, and vessels operate for short periods with their AIS transponder switched off to avoid it being reported.

4.2 Nautilus *Expeditions 2008–2012*

4.2.1 Yalıkavak

Ocean Exploration Trust began operations in the coastal waters of Turkey in 2008 while E/V *Nautilus* was in drydock near Istanbul being made ready for use the following year. A small dive boat was used to tow a side-scan sonar along survey lines around the northwestern side of the Bodrum peninsula in southwest Turkey around the town of Yalıkavak. Two late Hellenistic wrecks were already known by the Institute for Nautical Archaeology, one in the Yalıkavak harbour and the other just outside, and another four were located. Two of these consisted of rock ballast piles, likely from the nearby island of Çavuş Adasi as, historically they brought rock around from the back side to build a breakwater on the eastern side and ceramics among the rock indicated these were shipwrecks and from the Byzantine period. Another wreck, lying just outside the entrance to the natural harbour, consisted almost entirely of terra cotta pipes (Brennan, 2009).

During the sonar survey of the areas west and northwest of Yalıkavak harbour, the survey team noted significant trawl scars across the submarine landscape, particularly to the northwest. A line on the nautical chart denoted a 2.5 km boundary within which trawling operations were prohibited. The sonar indicated that the visible trawl scars on the seabed disappeared consistently at this demarcation on the chart, and even showed curves to the west as fishers began veering away while they recovered their towed gear. This indicated that the trawlers in this coastal area abided local regulations (Brennan et al., 2012a).

4.2.2 Knidos

One of the first expeditions with E/V *Nautilus* in 2009 continued the surveys off Yalıkavak and continued south of Bodrum to the northern, western, and southern coastal areas around the Datça peninsula where the ancient site of Knidos lies. Twenty-six shipwrecks were located and documented in these areas between 2009 and 2012, ranging in age from Classical Greek to Ottoman (Brennan et al., 2012a, b; Brennan & Ballard, 2013). This set of shipwrecks also ranges in impacts from trawling gear. Like those off Yalıkavak to the north, trawlers off Knidos appear to adhere to the 2.5 km from shore restriction. While none of the Knidos wrecks found are within that range, we did note that, likely due to this prohibition, trawl damage increased with distance from shore (Brennan et al., 2012a, b). The bathymetry south of Knidos is a flat, gentle southward slope, allowing for easy trawling operations parallel to the peninsula in an east-west direction.

Four other wrecks were found to the east off the coast of Marmaris, one of which that was carrying Late Roman Amphora (LRA) style amphora, in particular, showed significant trawl damage (Fig. 4.1). This wreck, Marmaris B, is easily comparable with two other LRA wrecks off Knidos (A and C), which have both been damaged by trawls, but not to the extent that Marmaris B has. These wrecks illustrate just how destructive repeated strikes from bottom trawls are to ancient shipwrecks (Brennan et al., 2020).

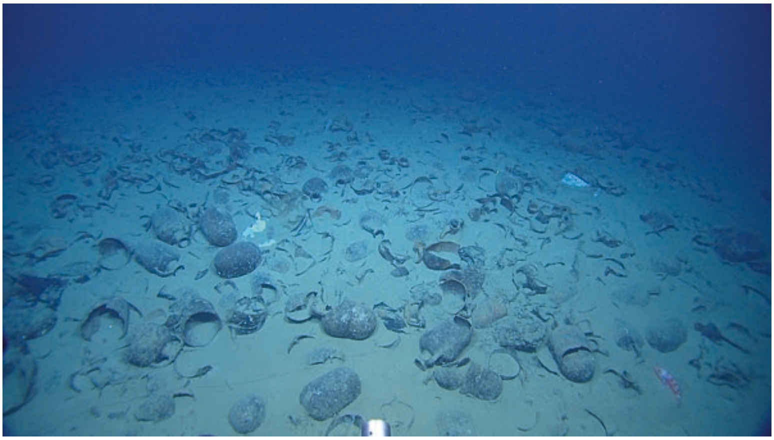

Fig. 4.1 ROV image of Marmaris B shipwreck (Ocean Exploration Trust)

4.2.3 Sinop

Exploration in the Black Sea along the northern Turkish coast was initiated in 1999 by Robert Ballard and the Institute for Exploration to investigate the isolated sea for preserved paleoshorelines and potentially well-preserved ancient shipwrecks lying in the anoxic waters below 155 m. Through 2003, the expeditions located and identified four shipwrecks off the coast of the Sinop peninsula. Three of these were mounds of ‘carrot’ shaped amphora on the continental shelf dating to the early Byzantine period, and the fourth was deeper at 325 m, well into the anoxic zone, and with wooden elements, including the mast, that were perfectly preserved (Ballard et al., 2001; Ward & Ballard, 2004; Ward & Horlings, 2008; Brennan et al., 2011). This latter shipwreck proved the theory put forth in 1976 by Willard Bascom that shipwrecks could be found well preserved in the anoxic depths of the Black Sea (Bascom, 1976).

E/V *Nautilus* returned to the southern Black Sea in 2011 to continue mapping the area off Sinop to further characterise the dynamics of the suboxic zone between the oxygenated surface waters and the anoxic layer below, and to see what the shipwrecks in the area could reveal about these processes. While exploration located an additional four ancient wrecks in various states of preservation, this work also documented significant trawl damage to wrecks along the shelf, particularly those found during the expeditions in the early 2000s (Brennan et al., 2013). Sinop A, in particular, showed significant changes to the site over a decade. More artefacts were exposed, with some clearly removed from the site, and wooden elements of the wreck were dug up out of the sediment during the decade between visits.

4.2.4 Ereğli

The 2011 and 2012 expeditions also conducted survey in a new area of the southern Black Sea, off the coast of Ereğli, Turkey, formerly Heraclea Pontica, where a flat shelf, like that off Sinop, lies off the coast above the continental shelf where the suboxic zone transitions to the anoxic deep waters. The main objective of these expeditions was to document internal waves between the oxic and anoxic waters moving across these shelves, and the varying levels of preservation of shipwrecks from different time periods illustrated these dynamics (Brennan et al., 2013). In addition, newly discovered wrecks in this area showed evidence of trawl damage. Ereğli A, B, and C are wooden wrecks with much of the timber still preserved but they were jumbled, with timbers pulled off site, by trawling. These wrecks with wooden elements preserved exhibit trawl damage differently than the amphora-mound wrecks in the Aegean Sea.

One wreck found in 2011, Ereğli E, is a Hellenistic era vessel that primarily consists of an artefact mound with some preserved wood, and it showed clear evidence of trawl damage (Davis et al., 2018). The standard protocol for newly discovered shipwrecks during these expeditions was to conduct a photomosaic and multibeam microbathymetry survey with sensors on the *Hercules* ROV, and this was done for Ereğli E. The 2012 *Nautilus* expedition returned to the site about 11 months later and upon visual inspection, it was clear that the site had sustained heavy trawl impacts since we first documented it. A repeated sonar survey allowed a direct comparison of the site between 2011 and 2012 and showed significant material had been removed from the wreck, including specific artefacts, both ceramic and timber, that were identified in 2011 (Brennan et al., 2016). Some artefacts were traceable to other parts of the wreck, while most were entirely missing. These sort of return visits and repeated surveys are essential in documenting and quantifying bottom trawl damage to shipwrecks.

4.3 Quantification

Quantifying the amount of damage to a shipwreck site is difficult, especially wrecks in deep water that are hard to access with any frequency or consistency. This work off Turkey implemented two ways to look at trawl damage quantitatively that allow for comparison between wrecks and establish baselines for future documentation.

The first attempt was done for ten amphora wrecks off Knidos and Marmaris. The high-resolution photomosaics from surveys of the wrecks allowed for visual analysis of the sites following the expeditions. Broken and unbroken amphoras were counted, estimating when a group of sherds likely represented 'one' amphora, to develop a total number in order to derive a percentage of those that were broken on the site. This percentage reflected the level of damage from trawls and allowed for comparison between sites in these areas. This was also plotted against distance from shore and showed that trawl damage increased farther offshore from the 2.5 km boundary where trawling was prohibited (Fig. 4.2). The most heavily trawled site, Marmaris B, exhibited 62.5% of its amphoras broken, and is also the farthest shipwreck from shore among those analysed (Brennan et al., 2012b).

The comparative analysis mentioned above of the two bathymetric surveys of Ereğli E 11 months apart was the 'first detailed documentation of how an ancient shipwreck site changes morphologically due to repeated strikes by bottom trawl gear' (Brennan et al., 2016, p. 87). The calculated difference between these two surveys is shown in Fig. 4.3. White colour indicates no change, while red shows negative change, or material removed from the site, and blue is positive change where artefacts or sediment were deposited. The greatest indicator of negative change is at the wreck itself, while some areas around the wreck show positive change due to material from the wreck being moved to the surrounding area by trawls. This shows how trawl gear scrapes shipwrecks away over time because they are bathymetric highs on a flat seabed. We estimated that about 15 m^3 was removed across an area 184 m^2 (Brennan et al., 2016). This method of return visits and repeated surveys allowed for the opportunity to truly quantify change to a shipwreck site over time by bottom trawling, and more work like this is needed to illustrate the threat posed to shipwrecks.

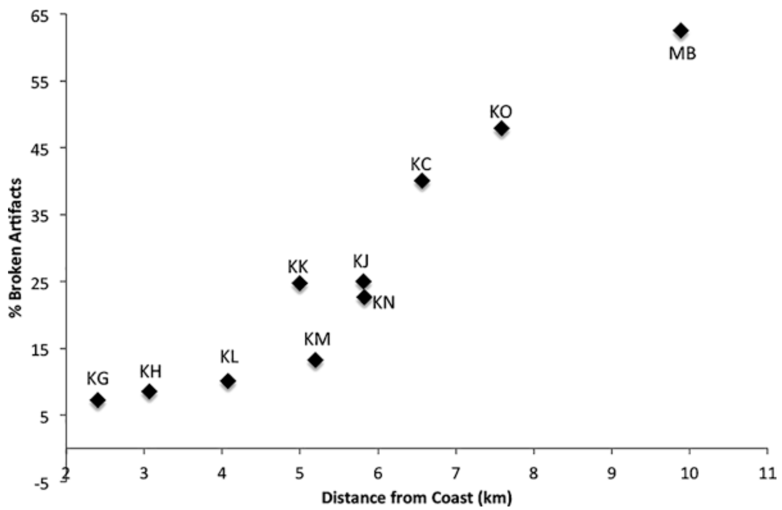

Fig. 4.2 Graph showing extent of trawl damage by distance from shore in terms of % broken amphoras. (From Brennan et al. 2012b)

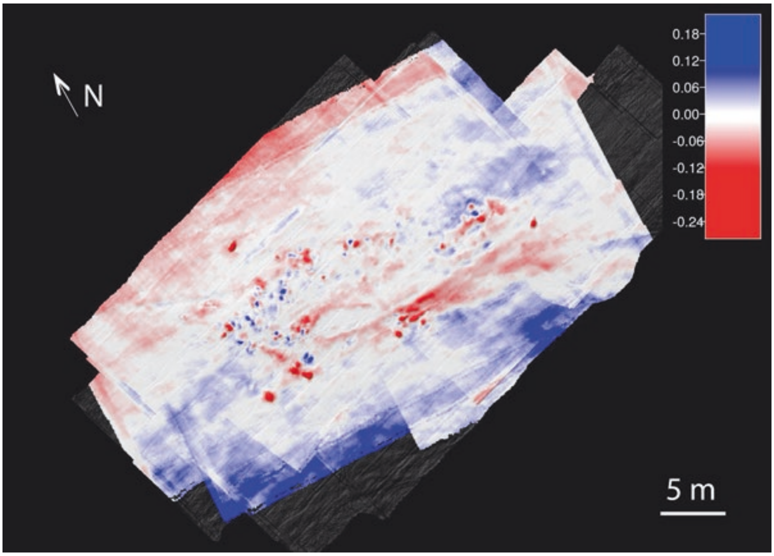

Fig. 4.3 Two sonar surveys of Eregli E conducted 11 months apart and the difference between them illustrating the material moved by trawling. (From Brennan et al., 2016).

4.4 Updated Work

While no further *Nautilus* expeditions have been conducted in Turkish waters, preventing the opportunity to revisit additional deep-water shipwrecks located between 2009 and 2012, some additional work has been undertaken since by other researchers. Exploration and documentation of ancient shipwrecks has continued in Turkey, along the eastern Aegean and northern Mediterranean coasts (Kızıldağ, 2022; Özdaş et al., 2022) as well as along the Bulgarian coast of the Black Sea (Pacheco-Ruiz et al., 2019, Prahov et al., 2021). While none of these studies looked at trawl damage directly, they made some observations to that effect.

Numerous remote sensing and photomosaic surveys were conducted by the Shipwreck Inventory Project of Turkey (SHIPT), including off the Aegean coast at Çanakkale and Yalıkavak (Kızıldağ, 2022). Five shipwrecks are reported from surveys in 2016 and 2018, three of which are amphora cargo wrecks of different ages; one of these was located by the Institute of Nautical Archaeology in 1990 in Yalıkavak harbour and denoted Yalıkavak II and is also among the wrecks documented during the *Nautilus* expeditions (Kızıldağ, 2022, Brennan et al., 2012b). Due to its location in the harbour, it is not damaged by trawls. Two amphora wrecks were found near Çanakkale, one Hellenistic and one Late Roman, and are generally in good condition—likely due to their location near the shore and within that exclusion zone discussed previously. A shipwreck consisting of a cargo of flat stones from the eighteenth century was located off the Gallipoli peninsula near Çanakkale. This wreck is located 2 km offshore and exhibited trawl damage, trawl scars in the sediment nearby, and fishing nets covering parts of the wreck. The last wreck reported by these recent surveys for SHIPT is a warship from the Ottoman period located off Bozcaada about 2.5 km from shore and was found to be heavily damaged by trawls, particularly one deep furrow that damaged the eastern side of the site (Kızıldağ, 2022). The study also notes that the use of side-scan sonar allows for the imaging of the seabed surrounding the shipwrecks and the trawl marks running through the sites, assisting with the interpretation of the damage (Kızıldağ, 2022, p. 340).

SHIPT also reports on a 2018 survey in the near-shore and coastal waters along the southern coast of Turkey around the island of Kekova Adası (Özdaş et al., 2022). This survey documented more than 25 sites along the near-shore area, many consisting of scattered and mixed assemblages due to the overlapping of activities and well-travelled routes as well as disturbance by waves action, as these sites are in shallow water. The authors note that disturbance of underwater sites, in both shallow water by coastal processes and deep water by anthropogenic activities such as fishing, 'presents a major challenge to preservation and study' (Özdaş et al., 2022, p. 14). Instead of fishing at these shallow areas, however, sites around Kekova Adası were often disturbed by 'casual collection before its declaration as a Specially Protected Area in 1990' (Özdaş et al., 2022, p. 5).

The Black Sea Maritime Archaeology Project (Black Sea MAP) was conducted in Bulgarian waters of the Black Sea from 2015 to 2017 and located 65 shipwrecks ranging from the fourth century BC to the nineteenth century AD in depths ranging from 40 to 2200 m. This survey employed deep-sea robotics for detailed photogrammetry of each shipwreck (Pacheco-Ruiz et al., 2019). Many of the wrecks discovered during this work were in the anoxic waters below 155 m depth and well preserved, but also out of the reach of trawling vessels, which do not trawl anoxic waters where fish do not live. The authors note a large difference between the wrecks located on the shelf and those in the anoxic waters due to disarticulation by trawling. For this project, however, most of the wrecks discovered were fortunately in the anoxic waters (Pacheco-Ruiz et al., 2019).

Analysis of the shipwrecks discovered during the Black Sea MAP project is ongoing. Bulgarian archaeologists have analysed their waters for litter and other anthropogenic debris, and this includes deep-water shipwrecks as additional impacts aside from trawling (Prahov et al., 2021). Bulgaria has yet to regulate bottom trawl fishing and the activity has impacted most of the continental shelf in Bulgarian waters down to depths of 100 m. As noted above, some of the Black Sea MAP wrecks were impacted by trawls, but the larger results of this project have yet to be published. However, policy and regulations are clearly needed for Bulgarian waters, for both ecological and archaeological reasons.

4.5 Marine Protected Areas

A colleague and I reviewed the species of fish visible on the numerous wrecks located during *Nautilus* expeditions in Turkish coastal waters through the ROV imagery. This led to a discussion about how shipwrecks act as hard substrate and artificial reefs and habitat for benthic ecosystems and fish to congregate at, particularly juveniles. If shipwreck sites – or in the case of areas like Sinop or Knidos, certain areas containing multiple shipwrecks – were protected in established Marine Protected Areas (MPAs), juvenile fish populations could thrive and 'spillover' into areas where fishing remained allowed, thereby both protecting the shipwreck sites and helping to increase the fishery (Krumholz & Brennan, 2015). This is a common topic in fishery sustainability research, but here applied to ancient shipwrecks. Recent research of seabed recovery from trawling continues to put forth this argument: 'The establishment of Marine Protected Areas, such as legally recognized no-take reserves where fishing activity is prohibited, could be a useful management measure… the benefits obtained from MPAs could also be observed in adjacent areas, as a result of the spillover of adults and juveniles from the protected area' (Vigo et al., 2023, p. 2).

The development of modern satellite technology now offers new options for resource management in remote areas. All vessels now carry AIS and active trawlers can be monitored (Pulcinella et al., 2023). Such use can provide the resources necessary so deep-water shipwrecks are no longer out of sight and out of mind. An option for resource managers and regulatory agencies could be to set up a type of EZPass (used for tolls on the highways in the United States) implementing trawlers' AIS. Geofences can be set up so when a trawler crosses into certain protected areas, such as areas of high numbers of shipwrecks like that off Knidos, a fine is deducted from their account. A fine can also be deducted if the AIS is turned off, indicating hidden fishing in illegal areas (Ferrà et al., 2020). This new technology can allow for real-time monitoring and protection of shipwreck sites, assuming they are first located and documented.

4.6 Conclusions

The shipwrecks located in Turkish waters during the *Nautilus* expeditions have not been revisited in the last decade, but nothing has changed in terms of trawling regulations for these waters, so it is likely that these wrecks are continuing to be dismantled by active trawling operations. The European Union and UNESCO are making headway in regulating trawling for environmental reasons, and cultural resources could be added to the discussion moving forward. European Member States are obligated to ensure that their fisheries are sustainable and that their waters are in Good Environmental Status (GES) (Smith et al., 2023). Shipwrecks can be added to this, if more support is provided to ocean exploration for documentation and return visits to these sites and repeat surveys to document damage.

Implementing modern satellite technology and improving upon AIS systems already in place can provide management options that would only require infrastructure to be developed, which regulatory agencies could do. The need, therefore, is for expanded deep-water exploration and documentation of shipwrecks worldwide that are within the depths that can be trawled. We cannot protect a resource we do not know about. Pulcinella et al. (2023) show that the Turkish fishers' exploitation off Knidos is not intense. Ancient shipwrecks that sank in more heavily trawled areas, such as the Straits of Sicily, may have been trawled to the point that they no longer exist, but those in Turkish waters may yet still be preserved.

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