A War Against Worms: Evaluating Appropriate Preservation Methods of At Risk Underwater Cultural Heritage Sites

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When a ship falls into the realm of the underwater environment, a new variable of destruction begins to take hold of the vessel. While a ship might have succumbed to the rigors of wind, currents, foul weather, and perilous rocks, microorganisms and bacteria lay in waiting for a ship once it unfortunately reaches touches the bottom. As scientific analysis and collection procedures become increasingly easier and more affordable--largely in part to technological innovations-- researchers are able to learn more about the hazardous marine environment elements which facilitate the biodegradation of UCH and oppose preservation efforts. However, the marine environment is not constant and various oceans, seas, lakes, rivers and other bodies of waters have differing chemical properties. In addition to the marine environment themselves, the actual physical components of shipwrecks are affected differently; for example: wooden wrecks found off of the southern coast of England are subject to wood boring and fouling organisms while deep sea steel and iron shipwrecks are prone to corrosion intensified by metal-consuming bacteria (Knight et al., 2019, 854; Fox-Skelly). With the recent investigations into biodegradation of shipwrecks we can better analyze the optimal methods for not only preserving the wrecks, but understanding the extent to which the physical properties and location of the shipwrecks themselves determine the feasibility of conservation efforts.

In the recent 2019 publication, *A Comparison of Biodegredation by Teredinidae…*, a team of researchers took the approach of studying the deterioration rates of four different wooden shipwrecks in the English Channel. Their methodology included placing test panels of wood on each site for 4-5 months to determine the problematic environmental factors as well as the biodegradation rates of various UCH sites (Knight et al*.,* 2019, 855-56). The data analysis lends a great deal of understanding to not only the environmental variables--such as location, sediment, and currents—but also the endurance of various wooden materials when exposed to marine organisms which consume or use the sites as housing. This study opted to use three different materials to investigate how hypothetical vessels would fare in each shipwreck location; researchers chose to use the wood most common in 19th century shipbuilding: pine, oak, and elm. However, it must be noted the preparation of the test panels was incongruent to 19th century shipbuilding methods where in which panels were constructed with axes, adzes, and hand saws and then radially split or tangentially sawn depending the type (Childs, 2009).

An integral aspect in developing efficient marine preservation methods is to understand what contributes to the biodegradation of UCH sites; not only are these sites intellectual nourishment for the starved archaeologist, but also a source of sustenance and housing for the numerous organisms of the site's surrounding eco-system. The wrecks in the English Channel create an ideal environment for the wood burrowing and ingesting organisms within the Amphipoda, Isopoda, and Myoida order (Borges, 2014). Teredinidae, *i.e.* shipworms, are a robust family of 68 species of wood boring, consuming, and colonizing creatures include: *Teredo navalis*, *Lyrodus pedicellatus*, and *Chelura terbans* (Voight, 2015). Following a larvae metamorphose, these creatures develop serrated teeth on their shells which allow them to bore into wood and create tunnels (Quayle, 1992; Lippert et al.,). Their survival is dependent on the availability of wood, and as their number increase the colony deteriorates the wood in which they reside, ergo shipworms are a significant obstacle in the preservation of shipwrecks. As a result of their dependency on wood as a source of sustenance, these organisms are often the prominent source of destruction to shipwrecks.

Each species of shipworms have evolved differing characteristics which leads to various species having particular environments in which they can survive. For example, *T. navalis* swim well and can survive in the water column for an extended period of 17-34 days; this longevity enables it to travel large distances and occupy various sites, whereas *L. pedicellatus'* limited swimming abilities forces to colonize in the same location also in part to its shortened life span in the water column of 24-48 hours (Knight et al., 2019: 854).

Limnoria, a genus of the Isopoda family, are found internationally and the *species L. Lignorum, L. quadripunctata, and L. tripunctata* are found in the English waters. *Limnoria* are also poor swimmers, like *L. pedicellatus,* they face habitation limitation and colonize close to their birth place. Aided by live birth and parental care, *Limnoria* boast a low mortality rate and thus can grow their numbers in a short amount of time. These creatures aggressively attack wood in large numbers and their existence is made more damaging by the semi-symbiotic creature: *Chelura terebans*. While *C. terebans* relies on wood for shelter rather than nutrition, they exacerbate the damage done to shipwrecks by *Limnoria* by enlarging burrows created by by *Limnoria.* These two species are often found in similar environments and their coupling can amount for catastrophic damage to underwater sites (Mohr, 1959).

Seeing as the aforementioned creatures are a leading obstacle against preservation, it is important to note the environmental conditions in which these destructive creatures thrive and their effects to underwater sites. Temperature and salinity are the most determining factors which affect growth, distribution, and reproduction of marine wood borers (Knight et al.; 2019, 855). As *Limnoria, C. terebans, and T. navalis* are most active in shallower and warmer waters, the majority of protected wreck sites in the South coast of England, such as *The London,* HMS *Invincible,* Poole Cannon Site, and the West Bay Wreck in Figure 1, are at high risk for biodegradation (Historic England, 2018).

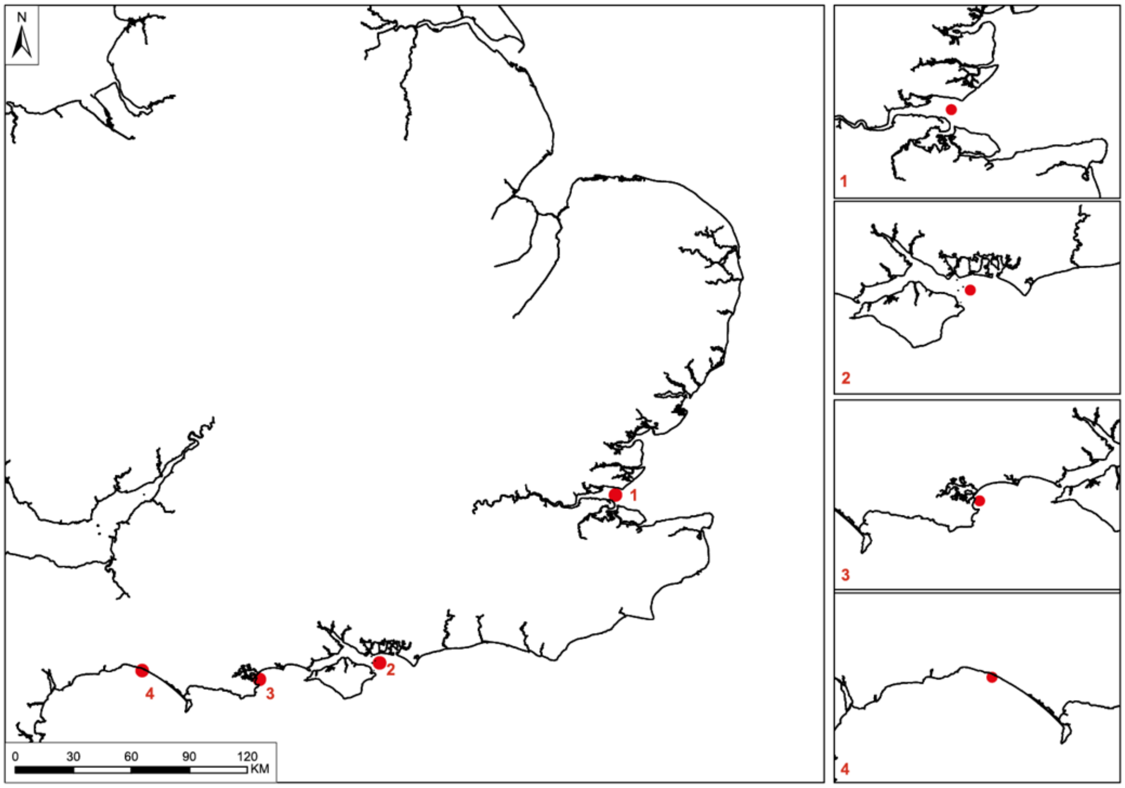

Fig. 1. The locations of the four shipwreck sites in the English Channel. (1) The *London* in the Thames Estuary (2) HMS *Invincible* in the Solent (3) Poole Cannon Site outside of Poole Harbour (4) West Bay Wreck in West Bay, West Dorset.

While the test panels in Knight's research demonstrated the biodegradation of various woods, pine was subject to highest levels of biodegradation in all tests. *Limnoria* and *C. terebans* "were responsible for the highest percentage of mean surface area loss on pine test panels (excluding West Bay)" (Knight *et al.* 2019, 860). West Bay's abnormal results were attributed to its adjacent location to a well-developed reef which hosted fouling species, thus biodegradation was attributed to Teridinade rather than to *Limnoria* or *C. terebans*.. The location of the West Bay's site lends support to the environmental factors which play into biodegradation levels; currents, swells, depth, salinity levels, termperatures, reefs and sediment have strong effects on the risk of exposure and biodegradation of UCH.

While salinity levels and depth can affect the prominence of destructive creatures, Muckelroy argues sediment "was the main determining factor in the survival of archaeological matter" (1977, 164). The results from Knight's research solidified this point when the collected data demonstrated that anoxic sediment, such as compacted silt, enabled the best environmental protection in the preservation of these sites. Simply put, compact sediments inhibit the development of wood boring and fouling creatures by creating an anoxic environment in which oxygen can not flow through the fine granules, thus without oxygen the destructive creatures can not survive. Gravel sediment allows for the flow of oxygen and provides less protection, however "dissolved oxygen is a dominant factor in the survival of wood boring and fouling species and subsequently, the survival of archaeological material. As a result, the reburial of UCH is considered an effective means of *in situ* protection" (Knight et al., 2019 864).

Whereas UCH sites with complete exposure to the physical elements of the water as well as destructive organisms face the greatest levels of biodegradation, sites, such as the WASA, which were covered in soft sediment demonstrated the greatest resistance to deterioration caused by both environmental elements and organisms. Due to limited funds alotted to the preservation of UCH, it is of great value to not only recognize the environmental factors which lead to the deterioration of sites, but also then most effective means of preservation, which according to Knight's study is creating anoxic environments via sediment burial of at risk sites. In addition to using soft sediment to cover the sites and prevent wood-boring and fouling colonization the recovery of artefacts and excavation are a viable, but more cost intensive than *in situ* preservation. Through the analysis of the causes of biodegradation, researchers can hope to better identify at risk heritage sites and choose appropriate paths of preservation. In the hopes of understanding what creates an at risk environment, preservationists and archaeologists can make an informed choice of methodology. If the funds are not readily available to excavate a UCH, it is the realistic suggestion to bury UCH sites in soft sediment until a time when the site can be excavated. By covering a site, an anoxic environment is created—exposed items are protected from the destruction of organisms as well as the effects of the physical elements. Financial feasibility is the largest factor when it comes to preservation work, in fact it is much more difficult to battle bureaucracy than it is to wage a war against worms.

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