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Two-Eyed Seeing into shipwrecks: maritime microscopy in the South Carolina Lowcountry

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By enhancing methods for how archaeology can contribute to the study of multi-species shipwrecks (or shipwreck ecology), this paper reconsiders the function of non-functioning ships and boats from anti-colonial and Native American perspectives. In partnership with the Waccamaw Indian People and the Indigenize SC Education Task Force, wood samples from several submerged wreck sites in a blackwater tidal river in the Lowcountry of South Carolina (USA) were analyzed for their archaeological potentials and for their potential to disclose the performance of individual sites within the underwater ecosystems of which they are a part. In turn, this information offers the opportunity to inform the public about the ecological roles of wreckage, thereby expanding the typical archaeological research questions into ones pertaining to sovereignty: namely, Indigenous and water. Following a thorough review of relevant literature and theory, the results of microscopic analyses of submerged sites are presented, along with an introduction to the interactive museum exhibit derived from the data and the questions they raise. In these ways, the paper moves between archaeological theory, scientific methodology, and the practice of public pedagogy.

KEYWORDS
anti-colonial science, Indigenous sovereignty, nautical architecture, necrobiome, place-based research, shipwreck microbial ecology, water sovereignty

1 On coming to terms with lively wreckage

Maritime archaeologists often consider wrecked ships as "dead ships" in that they are failed works of architecture, swallowed by deadly oceanic forces. Scottish archaeologist Keith Muckelroy, in his esteemed book *Maritime Archaeology*, summarizes this view with the statement that shipwrecks are no more than the disorganized, static seabed remains of a once dynamic and organized machine (Muckelroy, 1978, p. 157). Antony Firth, in the policy document, *Managing Shipwrecks*, echoes Muckelroy's position with the statement, "Ships that now lie wrecked and static were once dynamic" (Firth, 2018, p. 18). And closer to home in the coastal Carolinas of America, a recent paper on the Pappy Lane wreck refers to shipwrecks in general as "irreplaceable artifacts that have fallen victim to Earth's watery depths" (Price et al., 2020, p. 10).

At first thought, these remarks may seem common-sensical; however, they are also suggestive of a uniquely Christological perspective that remains pervasive in maritime archaeology. Watery depths are equated with the death, or even martyrdom, of the ship, and its only redemption is through archaeological resurrection. Termed the "savior-scholar model" of nautical archaeology, the dead, deposed, and decomposing ship is removed (physically and/or digitally) from where it has spent the majority of its existence

(Rich, 2021). It is then displaced into a new and sterile environment (museum and/or internet) for the purposes of research, outreach, or commodification. In these cases, interventionists operate under terracentric assumptions of the rightful place for wreckage and a pretense of control over the artifact that, for decades or millennia, had been yielding to the various ecological forces of submersion.

Additional to the pretenses of univocality among such resurrective recourses, shipwreck removal is also an extractive practice that seems eerily familiar to mining and petrochemical industries, where seemingly inert objects are removed from their positions—often beneath ocean sediments—and subjected to a transmutation process that alters them through refinement (Yin Han, 2024). Yet, at the same time, for many Indigenous North American thinkers, immediate conformation to the "industry standard" of shipwreck preservation is not only colonial but oddly self-defeating (cf. Rich et al., 2022, which details this argument). All things come from Land, and in time, all things return to her—including boats and ships, even those plasticized with polyethylene glycol (PEG, itself a petrochemical byproduct). Following the most common conservation practice of "impregnation" with PEG, the wrecked but sterilized ship goes to a museum for perpetual public display, which in some cases, only serves to reinforce colonial power dynamics (Rich et al., 2022). In this way, the industry standard is what Jicarilla Apache/Hispanic philosopher Viola Cordova would have called a "Euroman's" practice, arcing from "Euroman's" culture (Cordova, 2007, p. xiii). Acting instead on an Indigenous understanding that all knowledge is ecological (Little Bear, 2000), wrecks are presented here, in contrast to static ruins on the seafloor awaiting human intervention, as persistent works of architecture whose architects are more-than-human ecosystem engineers.

This paper builds on recent research by archaeologists and adjacent scholars who have begun to explore the liveliness of the "dead ship": e.g., by instead characterizing shipwrecks in a tongue-in-cheek manner as "vibrant corpses" (Rich, 2021), or by utilizing the methods of marine biologist Leila Hamdan's "shipwreck microbial ecology" (e.g., Hamdan et al., 2018, 2021) as an avenue for questioning some dominant anthropo- and eurocentric paradigms in nautical archaeology. For example, given the near-constant cycles of construction and conversion throughout the "working life" of a ship, it would be inaccurate to conclude that nautical (re)engineering ends with the sinking of the ship; instead, "from nautical architecture to naufragic architecture, upon sinking, extrahuman engineers take over the processes of construction and conversion that had been dominated by humans" (Rich et al., 2023, p. 187). Along these same lines, Australian maritime archaeologist Pearson (2023b) characterizes "the multi-species shipwreck" as she observes the mechanics and biologics of marine concretions on materials from the Belitung shipwreck in Indonesia. Sparking interdisciplinary interest, literary scholar Quigley (2023) contemplates what the indeterminate concretions of marine animal remains and shipwreck artifacts (called "sea sculptures") from the Ca Mau wreck could mean for the way wreckage is interpreted within the humanities and social sciences. Likewise, art historian Presutti (2025) sees in geochemical and artifactual "agglomerations" among the wreckage of *Astrolabe* and *La Boussole* a metaphor for the effects of European imperialism. A new highly interdisciplinary, multi-authored paper in *BioScience* goes so far as to introduce "shipwreck ecology" as a new scientific subdiscipline (Paxton et al., 2024). Surprisingly though, while the paper claims a postcolonial positionality, its articulations remain reliant on colonial constructs such as an arbitrary divide between the natural and artificial, and an insistence upon framing shipwrecks with capitalistic concepts such as "resources" that can be "harnessed." These characterizations rest uneasily outside a modern Euro-American framework; elsewhere, the entirety of existence is not bifurcated into "cultural" or "natural," and non-human entities are understood as having intrinsic value, autonomy, and agency unto themselves, regardless of potential interactions with globalized human economies (e.g., Aikenhead and Ogawa, 2007; Cajete, 2000; Little Bear, 2000).

In keeping with the propositions that archaeology does not require antiquity (Nativ and Lucas, 2020; Campbell, 2021) and that ecology is the Western science that most closely approximates Indigenous scientific practices (Aikenhead and Ogawa, 2007), we continue these conversations on "shipwreck ecology" from more explicitly anti-colonial and Indigenous standpoints. This first section details the rationale shaping our research methods; the second section turns to the scientific methods, results, and discussion; the third section summarizes how the results are being used to help indigenize public education on the wreckage in our rivers; and the fourth section offers brief concluding remarks. In so doing, this paper offers preliminary, place-based research rooted in the ancestral lands and waterways of the Waccamaw Indian People and other East Siouan tribal nations (cf. Rich, 2025; on place-based and anti-colonial research methods, see Liboiron, 2021; Tuck and McKenzie, 2015a,b; Watts, 2013). The authors (a Waccamaw citizen and maritime archaeologist, a Catholic Caucasian biologist, and an Italian-American environmental humanist) are all long-time residents of this Land and its many waters. Our research is located in the northern section of what is now called the South Carolina Lowcountry, where five centuries of wrecked settler ships have become architectural necromasses. To be clear, calling these wrecks "necromasses" is not the same as thinking of them as "dead ships." In biological terms, a necromass refers to the concentration of non-living organic matter that composes any given ecosystem. Wooden ships are constructed of sturdy, non-living organic material, and when they sink, that wood forms the firmament that fosters a *microbial* necromass. As microbial communities grow and expand, they form biofilms over wooden hull remains, which, in turn, attract macrofauna, from sponges and corals to fish and alligators, eventually forming a necrobiome. The effect is a unique ecosystem, connected to others by the watery matrix in which they thrive. In this research, we attune ourselves and attend to the underwater ecosystems that each shipwreck affords: who grows where and which materials they prefer, and how saltwater ingress and industrial pollution may be disrupting those patterns.

The research presented here is focused on shipwrecks in the West Branch of the Cooper River (known to the ancestors as the Wando), a blackwater tidal river that empties into Charleston Harbor and the Atlantic Ocean. As will be detailed in the following section, microscopic investigations of subsampled pine and oak ship timbers, which were originally sampled for tree-ring analysis

(Rich, 2025), reveal that wooden wreckage in the Cooper River is anything but dead. As ships, they may be ruined, but their architectural designs continue to be shaped by floral, faunal, fungal, microbial, and mineral engineers (Rich et al., 2023). Autogenic (e.g., corals and cyanobacteria) and allogenic (e.g., sponges and zooplanktons) organisms work the wreckage metabolically within and against increasingly polluted river water to build settler wreckage into thriving ecosystems (Jones et al., 1994).

Locally, resurrective efforts are usually made to engage the public with maritime history and vernacular boatbuilding, albeit often glossing over the role of enslaved Black and Native individuals in maritime economies. Formal requests to surface once-submerged hulls are also approved by state authorities when they are intended to prevent further degradation to the broken vessel's architecture. However, research demonstrates that in shallow-water environments such as the ones holding the wrecks under consideration here, "the biofilm, upon reaching a certain thickness, may act as a protective layer by restricting the amount of oxygen that can access the surface of the wreck, possibly inhibiting degradation and corrosion" occurring in anaerobic environments (BOEM, n.d.). In these cases, the wreckage is preserved by those living on it; underwater ruins are further ruined by mechanical action, which includes water erosion, sediment scour, and anthropogenic activities; indeed, our own local experts have lamented that they have seen these submerged sites diminish more in the last 10 years than in the 40 years previous: hence, the urgency to "resurrect" wrecks such as the nineteenth-century Biggin Creek rowboat, whose timbers have been removed from the bed of the Cooper River and are, at the time of writing, being prepared for conservation. But if mechanical action is the primary threat to the river's wrecks, it seems that it would be more advantageous in the long term to work toward a more holistic solution that minimizes the sources of degradation deemed untimely, whether those sources are greenhouse gas-fueled superstorms or policies that permit more direct anthropogenic damage. Even these degradatory sources, unwieldy as they already are, operate within broader scientific and theo-philosophical value systems, and these too can be sources of further ruination to rivers and all that they keep inside themselves.

Offering alternatives to prevailing norms, Viola Cordova composes a "matrix" of culturally opposite values and assumptions: for example, the Western habit of being "unaware of other living things" is at odds with the Indigenous self-interrogation of "What other life forms am I disturbing?" (Cordova, 2007, p. 66). She claims further that the Western habit of being "unaware of a living Earth" is at odds with the Indigenous dictum that "One ought not take the world for granted." Applying this logic, when North American archaeologists conceive of shipwrecks as "dead ships," or rivers as fundamentally destructive agents, we align ourselves with scientific and philosophical positions that differ diametrically from those of this Land's First Peoples.

Along the same lines, when practitioners of science and philosophy seek universal answers to complicated problems, there is an underlying assumption that a single solution can and will work for all places and peoples, despite their various and divergent needs. But our shared world is a complex place, full of change and motion, shaped by innumerable agents each with its own ecological agenda. As was reinforced through the processes of this research, the world is so vibrant that microorganisms thrive in dark, dirty water; they keep thriving inside Ziplock bags and microscope slides; and they zip off screen before they can be identified, never really "caught" or "captured" even by the camera. Things can never quite be pinned down when they're constantly in motion.

Although only one of us is a tribal member, all this microscopic motion and silent commotion raises a series of related ethical questions that should be considered by any responsible investigator working on Native Land and in Native Water (Cordova, 2007; Whyte, 2018; Kovach, 2021): Is this work being done in a good way? Are we breaching the original covenant with these creatures by using a microscope to peer into their lives? And does being watched bother them?

This third question issues some epistemological quandaries too: Do they know they are being watched, and does their behavior change accordingly? Once in the spotlight of the microscope's illuminator, do they perform for the viewer on the other side of the lenses? Or do they zip out of view because of what we might call "stage" fright?

These questions are important to consider carefully despite their complexity, as they interrogate the nature of consensual relationships between human beings and micro-beings, along with the nature of consciousness itself. In keeping with Vanessa Watts's (2013) "place-thought," we err on the side of consciousness among all, even if it varies in kind and scale. Equally relevant to these questions is Deloria's (1999) assessment that because humans are such a young species, we learn best by observing all the other kinds. In turn, this data informs the ways that we ought to conduct ourselves, how we become the best kind human possible, and how best to reciprocate all that Land and Water give us. Although new kinds come into being all the time, generally speaking, microorganisms are the most ancient lifeforms, so following Deloria's logic, maybe we are obligated to use the sensory instruments available to us to form respectful relations with our smallest of relatives so that we can learn some of what they have to teach us. Even with all the limitations of the English language, it is clear how closely connected are the nouns *ken* (knowledge) and *kin* (family).

In this respect, binocular microscopy might even literalize the concept of "Two-Eyed Seeing" proposed by Mi'kmaq elders Murdena and Albert Marshall (Bartlett et al., 2007; Hatcher et al., 2009; Bartlett et al., 2012; Wright et al., 2019). As an epistemological process and guiding principle, Two-Eyed Seeing integrates the best practices of Indigenous and European sciences. While many Native American thinkers have commented on the incompatibility of these different methods and motives of knowledge production and transmission (e.g., Deloria, 1999; Cajete, 2000; Little Bear, 2000; Cordova, 2007; Wilson, 2008), advocates for Two-Eyed Seeing find common ground in shared practices, such as seeking patterns and drawing conclusions from close observation, while recognizing that each "eye" is distinct: one eye sees mereologically, and the other sees holistically. Conscious reflection (ceremony) is crucial to Two-Eyed Seeing, so in contrast to the relative atheism of anti-colonial science (cf. Liboiron, 2021), the integrative mechanisms of Two-Eyed Seeing can lead to ecological knowledge that is grounded by an acute sense of spiritual ethics. In this and other ways, Leroy Little Bear's (2000) "jagged world views" slide together, or rotate in and out as different lenses on a microscope; the principle, and the metaphor, are especially helpful for personal scientific reconciliation processes among tribal members of mixed ethnicity, and for tribes whose pre-contact epistemic traditions have been heavily diluted through centuries of assimilation (in our case, both are true).

One of the most important aspects of Two-Eyed Seeing is that it is a Land-based practice. Like the shipwrecks where these microorganisms live, each ecosystem is unique, requiring a unique set of customs and cosmologies to understand how to behave within it so that a covenant is maintained between all Land's constituents in that particular place (cf. Deloria, 1999; Wilson, 2008; Kovach, 2021). To fulfill part of our covenant with the river, dried sage was sent downstream in an act of exchange or reciprocity for each sample removed from the wreck site, as per the guidance of Waccamaw tribal leaders. The samples, now that their *data* (meaning, their *gifts*) have been graciously received, have also been rematriated to the river (Figure 1). Despite the role of ceremony in the rematriation process, letting go of these samples was, for a scholar trained in the Western tradition, more difficult than anticipated. Even though billions of tiny lives were liberated by sending the wood back to the currents, while obligations were met and relations strengthened, it is difficult to release things that have given so much, and who might, if held onto long enough, give even more. But they are not our property.

Putting Two-Eyed Seeing into practice requires that the practitioner becomes attuned to each eye's tendencies and strengths and learns to remain cognizant of baseline assumptions. Cordova summarizes the differences between Western and Indigenous thinking in a way that perfectly befits the subject matter of this paper, as she uses analogies of water and wood:

> The goal of the Native American, deriving from a different set of assumptions altogether, is to create an island of stabile motion in a sea of random, but predictable, motion. An example of "random but predictable motion" would be the pattern of wood grain: there is always such a pattern (the *predictable*) but what that pattern will be is dependent on the numerous incalculable factors—this is the random element. "Stability," for the Native American, unlike its connotation for the Western thinker, is not synonymous with a static, unchanging state. "Stability" requires action for its maintenance. "Stability" denotes, for the Native American, a balancing act (Cordova, 2007, pp. 70–71, original emphasis).

This paragraph is cited here in its entirety not only for its apt nautical analogies, but because of how Cordova frames the "static" in relation to the "stable." As this paper hopes to make readily apparent, wrecks on a riverbed or a seafloor may be *stable*, but they are not *static*. Our desires as knowledge seekers must be balanced with the river's own desires to secure life for everyone who relies on her, whether nematode, mollusk, or man.

To further consider Cordova's "balancing act," and what that might entail for sunken ships as works of living architecture, it may be worthwhile to consider briefly the nature of *data* themselves. As Deloria (1999) explains, Native science does not exclude data that may seem errant, anecdotal, or circumstantial; *data* come from all directions and from unexpected sources, so to exclude them would be to deny the gifts that they offer. With this in mind, the microorganisms analyzed below must be understood along with the unexpected but unsurprising prevalence of microplastics. On the one hand, this means that organisms within each shipwreck ecosystem are contending with one of the most pervasive and least understood problems of our era. On the other hand, we have frequently found microbes willfully interacting with the microplastics sharing their biofilm habitat. Perhaps this too is unsurprising. Again, all things come from Land—not just the plants and the protozoa—but also the tar sands and oil fields and the plastics produced from them (Todd, 2017). It is not that these things are inherently bad; rather, their power has been misunderstood and downplayed into something controllable by "Euroman" interlocuters.

Cree scholar Shawn Wilson shares the wisdom of an Elder musing over his computer, made from petrochemicals and more: "This machine here is made from mother earth. It has a spirit of its own. This spirit probably hasn't been recognized and given the right respect that it should" (Wilson, 2008, p. 90). While few would argue with Métis scientist Liboiron (2021) that "pollution is colonialism," if the spirit of things were more respected, if the things we make were done so with intention and care, there would be far fewer toxins and toxicants flooding our waterways. Only by respecting things and their unique tendencies can we know which of them should be "refused" (à la Simpson, 2014).

There has been considerable discussion among archaeologists who work with beach plastics and shipwrecks as to the applicability of the term "afterlife" when considering anthropogenic objects in their phases of ruination and decomposition. On one hand, "afterlife" presupposes that anthropogenesis and the "working life" is the key feature of an object's being, even though its interactions with humans often compose only a small fraction of its earliest phases of existence (Pétursdóttir, 2017). On the other hand, given water's deep-seated associations with eternality and oblivion (Bachelard, 1983), marine microbial hauntings (Schrader, 2019), and the wooden wreck as a *necromass*, that word "afterlife" becomes a seductive way to think with shipwrecks (Pearson, 2023a; cf. Rich, 2021), not to mention the plastics and "forever chemicals" embedded in their biofilms. That said, Métis scholar Michelle Murphy offers an alternative term, *alterlife*, which may describe more comprehensively the ways of shipwrecks in polluted rivers, as well as the modern wrecks whose hulls and cargoes contribute further to the pollution:

> In orienting toward decolonial futures, I have tried to work with the concept of *alterlife* as a prompt. Alterlife names life already altered, which is also life open to alteration. It indexes collectivities of life recomposed by the molecular productions of capitalism in our own pasts and the pasts of our ancestors, as well as into the future. It is a figure of life entangled within community, ecological, colonial, racial, gendered, military, and infrastructural histories that have profoundly shaped the susceptibilities and potentials of future life. [...] Studying alterlife requires bursting open categories of organism, individual, and body to acknowledge a shared, entangling, and extensive condition of being with capitalism and its racist colonial manifestations. It asks that we situate

FIGURE 1
Rematriation of timber samples to the Cooper River on 16 January 2025. Courtesy of Rich (2025).

> life as a kind of varied enmeshment and enfleshment in infrastructures—as well as in water as a distributed being (Murphy, 2017, pp. 497–498).

Each of the Cooper River wreck sites whose ecosystems have been studied thus far are located within the general vicinity of the Dupont Cooper River Plant, on the former site of the Dean Hall Plantation (Figure 2, white building just north of DHST). The proximity and overlapping of Plant and Plantation crystallize the relationship between colonialism and pollution on a local scale. The Lowcountry is coursed by tidal rivers, wetlands, and swamps, each of which has been subject to that same relationship over the last five centuries (e.g., Harris, 2014). The Waccamaw Indian People live near the river named after them, north of the Cooper, while the Great Pee Dee and the Little Pee Dee Rivers, named after our neighboring East Siouan nation, flow between these two, joining the Waccamaw before emptying into Winyah Bay north of Charleston. In April 2024, the non-profit advocacy group American Rivers (2024) announced that the Little Pee Dee, which has earned Scenic River status from the South Carolina Department of Natural Resources and which several East Siouan nations consider sacred, has been rated number 5 of the top 10 most-threatened rivers in the country because of worsening pollution and infrastructural threats.

2 On indebtedness to *data*

In the first paper published on Two-Eyed Seeing, the authors offer a 3-part, iterative process to the intentional integration of sciences: recognition, transformation, and expression (Bartlett et al., 2007, p. 16). While the first section of our paper can be identified as "recognition" in that it sees patterns in shipwreck studies and seeks to act on them ecologically, this section can be identified as "transformation," as it explains our processes of *data* collection and offers some preliminary interpretations. The following section will present the "expression" or communication of our findings to the general public.

Following protocols in Rich et al. (2018) and Domínguez-Delmás et al. (2019), wood samples were removed from four

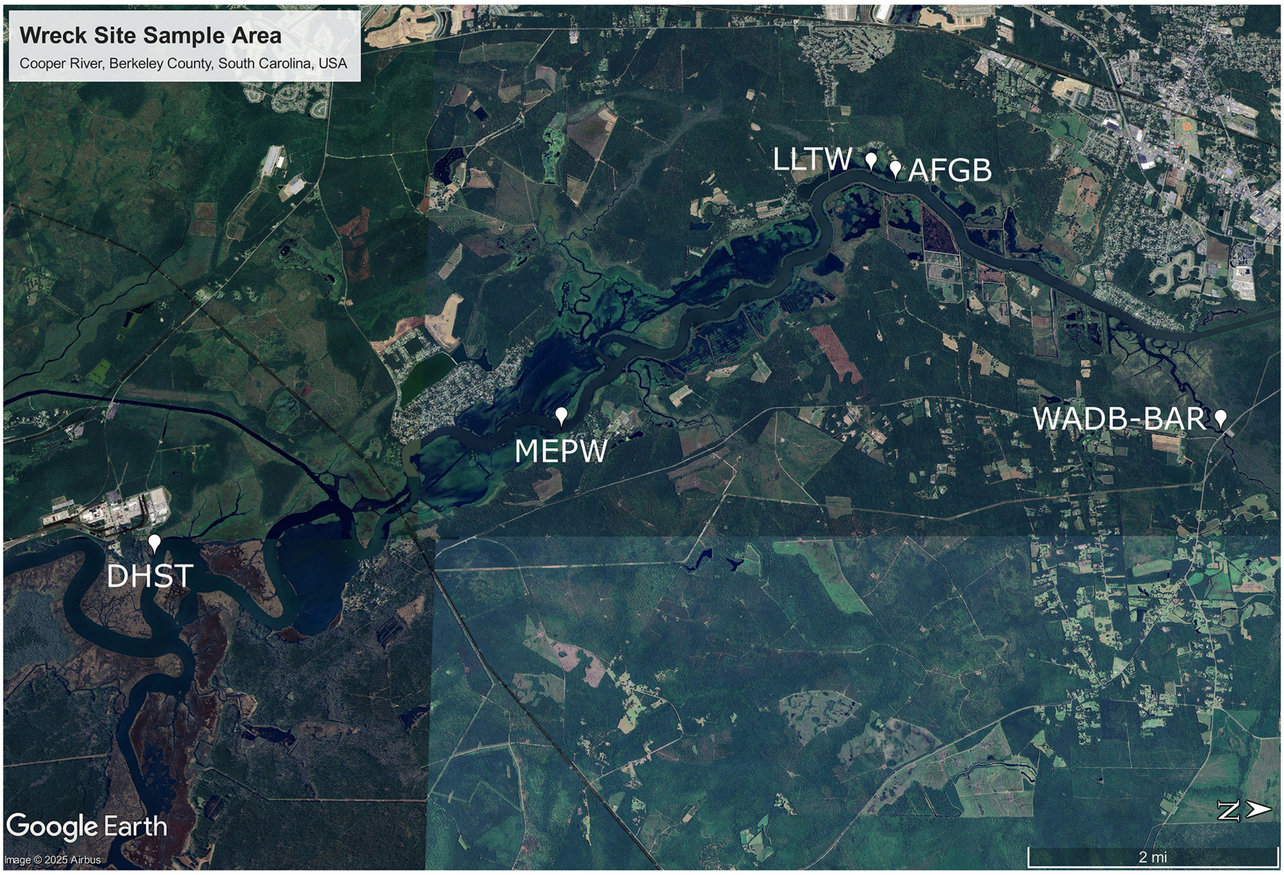

FIGURE 2
Map of the study area in the Cooper River, South Carolina, with locations of sampled wrecks.

historic shipwrecks in the Cooper River's West Branch: a Revolutionary War wreck (known as "LL2") near the former Lewisfield Plantation; a mid-nineteenth century steam vessel near the former Dean Hall Plantation (now the site of the Dupont Cooper Plant); an early- to mid-nineteenth-century sailing ship (known as the Mepkin Abbey wreck) near the former Mepkin Plantation; and an early twentieth-century barge in Wadboo Creek, a tributary of the Cooper River (Figure 3). Additionally, wood samples were removed from two submerged or semi-submerged historic installations: the dock at Mepkin Abbey and plank decking a few meters upstream from the barge. And for comparison, we also examined samples of wood from a fallen log in Wadboo Creek; a wrecked fiberglass houseboat upstream from LL2; and a 1980s vintage Pepsi bottle that was removed from the site of the late 19th-century wooden rowboat at the intersection of Biggin Creek and Tailrace Canal, so that its water could be analyzed as a substitute for timbers that we were, at the time, not permitted to sample.

As part of the Lowcountry Tree-Ring Project, the primary purpose of the removal of most samples was for dendrochronological analysis (Rich, 2025), but the shipwreck samples also offered a way to learn from the river herself. In this way, the riparian ecological component of the project allowed us to maximize the knowledge value of each sample by subsampling the surfaces that were not cut during removal: i.e., the surfaces longest exposed to the water (Table 1). Furthermore, subsampling increased the scientific value of the samples unsuitable for dendrochronological or dendroprovenance research, while demonstrating a fuller appreciation for materials removed, or borrowed, from the wreckage and the river. Our primary research questions included the following:

1. What kinds of microorganisms compose the biofilms of wreckage in the Cooper River?
2. What are the rates of marine colonization of these sites, and how are they affected by construction materials (wood vs. fiberglass, pine vs. oak, etc.)?
3. How do depth, salinity, and pH factor into the biodiversity and biomass of each site?
4. How does marine pollution impact biodiversity and biomass on submerged sites?

Macro-organisms were noted during sampling and subsequent dives on each submerged site, and they were recorded in divers' logbooks. This information is accounted for when considering the site's contribution to the overall river ecosystem (Table 1).

Wood samples were removed from seven submerged sites and were identified to the genus or species level using methods in (Hoadley, 1990 from Table 1). All samples were kept refrigerated

FIGURE 3
Touchscreen kiosk and accompanying signage at the South Carolina Maritime Museum in Georgetown, South Carolina. Courtesy of Rich (2024).

in sealed containers with river water to preserve the integrity of microbial communities at each site. After deliberating as to whether DNA analyses should be conducted in response to question 1, we decided that this method did not correspond well to the kind of spiritual ethics that we propose in the previous section, as any organisms present would be killed in the process of analysis. Instead we opted to use morphological features to identify organisms visually, using a compound microscope with digital recording lens and software. Provisional microscopic identifications were verified using the citizen science app iNaturalist, which enabled some organisms to be identified to the genus level (Table 1). Microplastics were observed, measured, and recorded during this same process. We used a 3-point scale for biodiversity, biomass, and microplastic accumulation; for the latter two categories, each level was determined on an impressionistic or intuitive basis relative to other samples, rather than relying on an arbitrary threshold (cf. Liboiron, 2021). However, biodiversity proved more difficult to rate without set ranges into which all subsamples fell, so these ratings were determined by the number of distinct Linnaean families identified in each subsample.

Not surprisingly, higher rates of biomass and biodiversity correspond with sites that have been submerged longer, and which are made of organic materials. The samples from fiberglass and glass surfaces were the only ones ranked "low" in biomass, although the biodiversity inside the glass bottle was "high" despite having only been submerged for some 40 years. Of the three tree genera sampled, southern yellow pine (*Pinus elliotti*, *P. taeda*, *P. palustrus*, *P. serotina*, or *P. brevifolia*; those designated with a "y" in the Table are likely *P. palustrus*) is most represented due to its common use in historic maritime architecture, and because this was the genus targeted for dendrochronological sampling. Pine timbers have the most "high" rankings in biodiversity, although the only bald cypress (*Taxodium distichum*) sample was also given a 3 in biodiversity, and one among the red oak (likely *Quercus coccinea*, *Q. falcata*, *Q. palustrus*, or *Q. velutina*) samples was ranked 3 in biomass and biodiversity; it may be significant that of the oak timbers sampled, this one had been the longest submerged. More diverse wood samples would be needed to determine if pine substrates are more conducive to micro-biodiversity, especially interesting given conifers' reputation for resistance to rot in marine environments.

TABLE 1 Marine colonization of sampled submerged heritage sites in the Cooper River, Berkeley County, South Carolina (USA).

Site name	Submerged since (cal. year)*	Timber No.	Wood type	Timber depth range (m)	Salinity (ppt)	pH	Sample date	Analysis date(s)	Biofilm micro-organisms (with genera when known)	Bio-diversity	Bio-mass	Biofilm micro-plastics (magnification)	Micro-plastic mass	Macro-organisms and *in-situ* conditions
Dean Hall Steam Vessel (DHST)	ca. 1860	1	*Pinus* sp. (southern yellow pine group)	5–7	0.47	6.58	20 Aug 2022	2 Feb 2023, 22 Mar 2024	nematodes, ciliates (*Paramecium* sp.), diatoms (*Chaetoceros* sp.), sponge spicules, water fleas (*Chydorus* sp.)	2	2	Red and purple (40×, 100×)	3	Timbers charred; erosional damage but little evidence of damage from marine borers; site is too dark for photosynthesis; several species of fish noted among the wreckage; bull sharks seen nearby
		2[†]	*Pinus* sp. (southern yellow pine group)	5–7	0.45	6.42	20 Aug 2022	15 Apr 2024	Rotifers (*Philodina* sp.), annelid worms (*Aeolosoma* sp.), nematodes, ciliates (*Spirostomum* sp.), sponge spicules	2	2	Various (40×, 100×)	2	
		3[†]	*Pinus* sp. (southern yellow pine group)	5–7	0.46	6.70	20 Aug 2022	12 Apr 2024	Ciliates (*Spirostomum* sp., *Urostylida* sp., *Paramecium* sp.), fungi, annelid worms (*Aeolosoma* sp.), nematodes, diatoms, sponge spicules	3	3	Red and blue (100×)	2	
		3b	*Pinus* sp. (southern yellow pine group)	5–7	nd	nd	5 Jun 2024	7 Jun 2024	Fungi, sponge spicules, ciliates (*Paramecium* sp.), diatoms, algae (*Spirogyra* sp.)	2	3	Red (40×)	1	
		4[†]	*Pinus* sp. (southern yellow pine group)	5–7	0.42	6.27	20 Aug 2022	15 Apr 2024	Ciliates (*Paramecium* sp., *Spirostomum* sp.), fungi, diatoms (*Nitzschia* sp.), sponge spicules	2	2	Red and transparent (40×)	2	
		5[†]	*Pinus* sp. (southern yellow pine group)	5–7	0.43	6.25	20 Aug 2022	12 Apr 2024	Nematodes, ciliates (*Spirostomum* sp.), diatoms, sponge spicules	2	2	Multiple red and purple (100×)	3	

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TABLE 1 (Continued)

Site name	Sub-merged since (cal. year)*	Timber No.	Wood type	Timber depth range (m)	Salinity (ppt)	pH	Sample date	Analysis date(s)	Biofilm micro-organisms (with genera when known)	Bio-diversity	Bio-mass	Biofilm micro-plastics (magnification)	Micro-plastic mass	Macro-organisms and *in-situ* conditions
		6†	*Pinus* sp. (southern yellow pine group)	5–7	0.48	6.51	20 Aug 2022	15 Apr 2024	Nematodes, ciliates (*Paramecium* sp.), diatoms (*Gyrosigma* sp., *Chaetoceros* sp., Thalassiosiraceae), water fleas (*Chydorus* sp.), fungi, water mites (Hydrachnidia), sponge spicules	3	3	None observed	1	
Lewisfield plantation "Little Landing" Wreck 2 (LLTW)	ca. 1781	7†	*Pinus* sp. (southern yellow pine group)	3–5	0.43	5.92	18 Jul 2023	21 Jul 2023, 17 Apr 2024	Ciliates (*Paramecium* sp.), diatoms (*Gyrosigma* sp.), nematodes, fungi, rotifers (*Adineta* sp.)	2	2	Red (40×, 100×)	2	Timbers mostly buried under silt, some charred; small crustaceans and a pod of dolphins seen on site
		8	*Quercus* sp. (red oak group)	3–5	0.44	5.74	18 Jul 2023	9 Feb 2024	Fungi, cyanobacteria (*Oscillatoria* sp.), ciliates (*Paramecium* sp.)	1	3	None observed (40×, 100×)	1	
		10	*Quercus* sp. (red oak group)	3–5	0.42	4.34	18 Jul 2023	9 Feb 2024	Ciliates (*Paramecium* sp.), algae (*Spirogyra* sp.), nematodes, fungi, rotifers (*Adineta* sp.)	2	2	Red and light blue (40× and 100×)	2	
Mepkin Abbey Dock (MEPD)	ca. 1850	1	*Pinus* sp. (southern yellow pine group)	3–5	0.49	6.28	2 Aug 2023	8 Sep 2023	Algae (*Spirogyra* sp.), ciliates (*Paramecium* sp.), diatoms (*Gyrosigma* sp., *Cymbella* sp.), nematodes, rotifers (*Adineta* sp.), sponge spicules	3	2	Teal and green (40×)	2	Prevalent sponge growth on timbers; thick *Hydrilla* sp. growth throughout site
		2	*Pinus* sp. (southern yellow pine group)	3–5	0.51	6.19	2 Aug 2023	8 Sep 2023	Ciliates (*Stentor* sp., *Paramecium* sp.), nematodes, diatoms (*Gyrosigma* sp.)	1	2	Red (40×)	2	

(Continued)

TABLE 1 (Continued)

Site name	Sub-merged since (cal. year)*	Timber No.	Wood type	Timber depth range (m)	Salinity (ppt)	pH	Sample date	Analysis date(s)	Biofilm micro-organisms (with genera when known)	Bio-diversity	Bio-mass	Biofilm micro-plastics (magnification)	Micro-plastic mass	Macro-organisms and *in-situ* conditions
		3	*Pinus* sp. (southern yellow pine group)	3–5	0.49	5.88	2 Aug 2023	8 Sep 2023	Diatoms (*Gyrosigma* sp.), ciliates (*Paramecium* sp.), rotifers (*Adineta* sp.), sponge spicules	2	3	Purple, green and yellow (40×)	3	
Mepkin Abbey Wreck (MEPW)	ca. 1830	11	*Quercus* sp. (red oak group)	6–8	0.47	6.21	2 Aug 2023	25 Sep 2023	Ciliates (*Paramecium* sp.), algae (*Spirogyra* sp.), nematodes, sponge spicules	2	2	Few observed (40×, 100×)	1	Sponge growth on timbers and several species of fish and crustaceans noted on site; some *Hydrilla* sp. growth despite mostly dark conditions; site is exposed on clay marl
		12[†]	*Pinus* sp. (southern yellow pine group)	6–8	0.48	6.43	2 Aug 2023	17 Apr 2024	Fungi, ciliates (*Paramecium* sp.), nematodes, sponge spicules	2	3	Red (40×)	2	
		13	*Pinus* sp. (southern yellow pine group)	6–8	0.49	6.18	2 Aug 2023	17 Apr 2024	Fungi, diatoms, ciliates	1	3	None observed	1	
		14	*Pinus* sp. (southern yellow pine group)	6–8	0.52	6.45	2 Aug 2023	25 Sep 2023	Nematodes, ciliates (*Paramecium* sp.), fungi, sponge spicules	2	2	Sparse red (100×)	1	
		15	*Pinus* sp. (southern yellow pine group)	6–8	0.48	6.30	2 Aug 2023	17 Apr 2024	Nematodes, fungi, sponge spicules	1	3	None observed	1	
		15b[†]	*Pinus* sp. (southern yellow pine group)	6–8	nd	nd	5 Jun 2024	7 June 2024	sponge spicules, ciliates (*Paramecium* sp.), nematodes, algae (*Spirogyra* sp.)	2	2	None observed	1	
		16	*Taxodium distichum*	6–8	0.49	6.54	2 Aug 2023	25 Sep 2023	Nematodes, ciliates (*Paramecium* sp.), algae (*Spirogyra* sp.), sponge spicules	2	3	None observed	1	

(Continued)

TABLE 1 (Continued)

Site name	Submerged since (cal. year)*	Timber No.	Wood type	Timber depth range (m)	Salinity (ppt)	pH	Sample date	Analysis date(s)	Biofilm microorganisms (with genera when known)	Biodiversity	Biomass	Biofilm microplastics (magnification)	Microplastic mass	Macro-organisms and *in-situ* conditions
Biggin Creek Rowboat (BCRB)	ca. 1880; glass bottle vintage 1980s	1	n/a—glass bottle	2–5	nd	nd	18 July 2023	7 Jun 2024	Ciliates, water flea (*Daphnia* sp.), diatoms (*Chaetoceros* sp.), algae (*Volvox* sp., *Klebsormidium* sp., *Draparnaldia* sp.)	3	1	None observed	1	No wood samples were removed at this time; analyses were conducted with water retained inside a 1980s glass Pepsi bottle recovered from the site, which had visible algae growing inside it.
Wadboo Creek Barge (WADB-BAR)	ca. 1920	1	*Pinus* sp. (southern yellow pine group)	1–3	0.50	5.66	27 Jul 2023	27 Oct 2023	Limpets (*Ferrissia* sp.), ciliates (*Stentor* sp.), diatoms, fungi	2	2	Red and blue (100×)	2	Mollusk damage on timber no. 1; *Hydrilla* sp. growth on top side of timber no. 2 and throughout site
		2	*Pinus* sp. (southern yellow pine group)	1–3	0.48	6.19	27 Jul 2023	22 Jan 2024	Nematodes, ciliate (*Stentor* sp.), diatoms (Thalassiosiraceae), fungi	2	2	Red and purple (40×)	2	
Wadboo Creek Deck (WADB-DEC)	ca. 1920	1	*Pinus* sp. (southern yellow pine group)	0–1	0.47	6.14	27 Jul 2023	27 Oct 2023	Algae, ciliates (*Paramecium* sp.)	1	2	Teal (40×)	2	Intertidal platform on clay creek bank; *Hydrilla* sp. growth on top side of timber sampled
Wadboo Creek Log (WADB-LOG)	ca. 2020	1	*Quercus* sp. (red oak group)	3–5	0.51	6.34	19 Oct 2023	22 Jan 2024	Fungi, ciliates, nematodes, water fleas (*Chydorus* sp.)	2	2	None observed	1	Sample removed from submerged portion of fallen tree; no macro species noted
Abandoned Fiberglass Houseboat (AFHB)	2022–2023	1	n/a—fiberglass hull	0	na	na	5 June 2024	7 Jun 2024	Ciliates (*Paramecium* sp.), nematodes, diatoms (*Nitzschia* sp.)	1	1	Purple, red, blue, and green (40×, 100×)	2	Observations made at and above surface level; plentiful lichen growth at water line

Biodiversity, biomass, and microplastics mass are rated on a 3-point scale (minimal, moderate, high). Biodiversity: 1 (minimal) = 2–3 families, 2 (moderate) = 4–5 families, 3 (high) = 6 or more families. Biomass and microplastics ratings are approximations based on visual density relative to other samples. na, not applicable; nd, no data.

*Historical records provide exact time submerged for only one site, while typological features from the ship construction and/or cargo provide estimates for the other sites.

† Sample is also under analysis for dendrochronology, which will provide a more accurate estimate of time submerged for the sites for which there are no historical records.

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Salinity (0.42–0.52 ppt) does not appear to be a significant variable in predicting biomass or biodiversity at these sites, which is unsurprising given the tidal nature of the river, with twice-daily saltwater ingress from the Atlantic Ocean. Most samples were taken during incoming high tides, which create a slack effect that facilitates better underwater visibility, lower currents, and overall more favorable river diving conditions. Therefore, the salinity measured with these samples is slightly higher than what it would be on average. However, as sea levels continue to rise, future research could monitor changes in salinity and possible effects on biomass and biodiversity levels.

Measured pH levels (4.34–6.70) are lower than typical for freshwater due to the acidity of tannins from pine and cypress leaves in blackwater rivers in the Southeast (compare Okefenokee Swamp in north Florida at pH 3.8–4.1; Flotemersch, 2023). Given that we generally sampled during incoming tides, these values may be somewhat higher than average for this part of the river. While pH values indicate that the aquatic species identified are adapted to higher acidity, they also indicate that acidity is not variable enough in the Cooper River to predict rates of biodiversity or biomass; neither does acidity seem to be a function of depth, at least not in the depth ranges of this river. And while depth itself does not seem to be a predictor of biomass or biodiversity, sites sampled at or near the surface of the water trend toward lower measurements in both categories, regardless of time submerged.

Surprisingly, the site ranked highest in biomass and biodiversity [Dean Hall shipwreck (DHST); see Table 1] is also the site with the least amount of light and, correspondingly, the lowest water temperatures. Although the cause is unclear (and cannot be explained by the relative duration of submersion alone), the results are all the more confounding given the site's proximity to the Dupont Cooper River Plant and its associated chemical runoff, alongside the relatively high concentration of microplastics observed in subsampled timbers (Figure 2). Fascinatingly, only in the recently submerged sites does there appear to be a direct correlation between microplastics concentration and biomass or biodiversity: the fiberglass boat had "moderate" concentrations of microplastics and the lowest ranked biomass and biodiversity of all sampled sites; inversely, there were no microplastics observed in the fallen tree sample, but it ranked "moderate" in both biomass and biodiversity.

For other sites, it seems that other factors (especially greater depth combined with a longer time submerged) are more conducive to higher biomass and biodiversity than is a decreased presence of microplastics; or put differently, a higher concentration of microplastics on sites submerged deeper and for a longer period does not appear to impede biomass or biodiversity. Further sampling at these and the many other sites in the Cooper and surrounding rivers could augment these preliminary interpretations. To expand this study into future research, a "site" need not necessarily be a shipwreck or any other type that is usually meant by "submerged heritage sites." In the Southeast, wooden wreckage of a different sort could also include "sinker wood": i.e., trunks of pines and cypresses that were felled in the nineteenth century and sank while floated downstream to one of the many lumber mills that lined these rivers. Inorganic comparisons could include the bottles, jars, and cans that litter the riverbeds, some of which are several hundred years old.

3 On community offerings

A community focus is another pillar of Two-Eyed Seeing as a guiding principle in scientific practice. The findings presented in the table and section above offer new ways to help the general public come to a more holistic understanding of the polluted waterworld that we have co-created yet often feel powerless to "fix." Young people in particular find themselves dropped into an *alterlife* wherein a healthy future is difficult to imagine. However, the *data* shared above demonstrate how other organisms are coping with, and even thriving among, pollutive forces, and while that certainly doesn't justify their continued profusion, witnessing small-scale "survivance" (Vizenor, 1999) may help community members to better understand our own responsibilities and obligations to those with whom we share an ecosystem, while at the same time addressing the crippling anxieties that can come along with a heightened awareness of anthropogenic ecological crises. By partnering with the Indigenize SC Education Task Force, a state-wide, intertribal non-profit organization affiliated with the South Carolina Indian Affairs Commission, we took the opportunity to develop these results and their implications for a broader multi-species ecology, littered with wreckage, into an interactive digital exhibit for display at the South Carolina Maritime Museum in Georgetown (Figure 3).

Built using Prezi, the Web-based exhibit guides participating audiences through the shipwreck sites as they "paddle down the river" by advancing to the next slide.[1] Each wreck has a cluster of slides that introduce the site with a relevant fact and key terms, one or two orienting photographs, and a video (hosted on YouTube) of representative microorganisms in action. Wreck sites are linked by transitional questions for class or family discussion, or personal reflection. These range from "What do you picture when you imagine a shipwreck?" at the beginning of the exhibit to "How can we think about water pollution in a way that accounts for the marine organisms who turn pollutants into a new home?" toward the end. Some transitional questions are variations of our own research questions: "Would you expect there to be more life on wrecks in dark or sunlit waters?", "How do you think the construction materials affect what (or who) can safely live on a wreck?", and "If you were a microorganism, how would you feel about having to live with microplastics?" The exhibit concludes with a series of questions to prompt deeper thinking about the broader implications of the exhibit's lessons:

- "What would removing a shipwreck from the river do to the lifeforms on the wreck?"
- "Many of these wrecks have been in the river for hundreds of years. So do humans have a right to remove them from the river? To whom, or what, do abandoned shipwrecks really belong?"

1 The interactive display can be found here: https://prezi.com/view/4Fj2whwRoynvPa4n6XFa/.

- "South Carolina tribes, like the Waccamaw Indian People, tend to believe that because all things come from land, all things are related—even humans and microplastics! Most people have a family member who misbehaves (not you, of course!). For Native Americans, microplastics are one such family member. How could humans ensure a future with fewer 'misbehaving' relatives?"

The exhibit's final slide features a QR code inviting teachers and home-schooling parents to download free lesson plans derived from the exhibit. The lesson plans are also linked on Indigenize SC Education's Native-Centered Educational Resources Database, with one each in the categories for Elementary, Middle, and High School developmental groups. Each lesson plan fulfills several science education standards as currently defined by the South Carolina Department of Education so that instructors have turnkey resources for introducing the material and maximizing its educational potentials in their own classrooms, while also being able to adapt them to their particular pedagogical context.

Inclusive corresponding signage was developed in color schemes, fonts, and contrast accessible for the vision-impaired, and to help draw audiences of all ages toward the 11-inch (28-cm) touchscreen kiosk where the exhibit is displayed (Figure 3). The signage offers a brief overview of the exhibit's key themes, instructions to pre-empt technological impediments to interacting with the display, and a list of the "bonus features" to encourage participants to complete their journey through the river.

4 On fluvial architects

The methods introduced here can easily be replicated elsewhere, in partnership with the communities indigenous to the lands and waters where wreckage is found. In the meantime, we hope that these *data*, in the true sense of "gifts," offer further reasons for nautical archaeologists and other marine scientists to leave wooden shipwrecks *in situ*. These wrecks' construction is ongoing: the architects in charge now are microscopic organisms, fish and crustaceans, dolphins and alligators, bodies of water, lunar phases, superstorms, and even pollutants, along with the occasional human investigator. Although it is too late for the Biggin Creek Rowboat, which has been removed from the riverbed and awaits conservation, other sites can be respected for their ability to provide habitats—even micro-habitats—inside conditions that are becoming increasingly hostile to ecosystem health. While it is possible that some of these wreck sites harbor introduced organisms, as it is suspected that the aquatic plant waterthyme (*Hydrilla verticillata*) along with alligator gars (*Atractosteus spatula*) are not endemic to the river, these displaced relatives can still have or assume important ecosystem functions.

While our findings on the abundance of microplastics is disconcerting if unsurprising, we also find in these underwater architectural necrobiomes a certain optimism that confronts the hard realities of ecocide on all fronts with an adaptive spirit—one of resilience and resourcefulness that is not unlike the descendant communities of First Peoples who remain along these rivers despite generations of ongoing dislocation, dispossession, and forced assimilation. Metaphorically, the resistance and liveliness among fluvial settler wreckage—and within the river as a whole despite microplastics, PFAS, PCBs, and the actions of well-meaning archaeologists—mirror the resistance and liveliness of the traditions of the Waccamaw and other surviving East Siouan nations indigenous to these waters, in the wake of the ancestral apocalypse (cf. Whyte, 2017; Leonard et al., 2023).

The accretion of marine organisms on maritime infrastructure and architecture is often framed in terms of "colonization," so given the heightened rate of wreckage and seafloor sprawl beginning with transoceanic colonizing expeditions, perhaps these processes could more appropriately be termed "meta-colonization." If so, the meta-colonizers are doing the rivers' work. These rivers have been coursing through the land since before ancestral times, and the wrecks, abandoned and sunken and teeming with *alterlives*, belong to the water now. In their actions and their knowing, the small, ancient relatives who worm and whip, squirm and swim, make clear that Land and all she encompasses is not just alive, but also willful, and that like so many other deposited, yet powerful, layers, broken boats and ships are usually best left in the river's ground.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SR: Writing – review & editing, Writing – original draft. KR: Writing – review & editing. HH: Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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