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Exploring the Intersection of Art, Science, and Marine Conservation Using Algal Biomass Waste

ACTIVITIES AND PROGRAM MODEL

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ABSTRACT

Algal Turf Scrubbers (ATS) are designed to remediate polluted waters where wastewater and agricultural runoff have caused eutrophication and the non-point source of excess nutrients cannot be determined. These ATS systems improve water quality by encouraging algal growth on flow-way surfaces rather than forming harmful blooms in open waters. Excessive nutrients from the water accumulate in the flow-way's lawn of algae, and unless the algal biomass is repurposed, it is discarded in landfills as waste. In this article, we outline a simple methodology to utilize waste algal biomass as a novel source of clay. Raw algal waste contains minerals which can be used as a sustainable and more environmentally-friendly alternative to industrially-mined clays. When algae-based clay sculptures are kiln fired, they resemble terracotta brick in their color, durability, and porosity. In addition to the aesthetic and artistic potential of algae-based clay, this medium provides an excellent opportunity for educators to engage students with hands-on crafting activities while learning about eutrophication and environmental restoration of aquatic habitats.

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INTRODUCTION

As anyone who has kept a fish tank knows, algae buildup on the aquarium glass is a frequent problem and must routinely be scraped clean. Without regular water changes, the aquarium can turn green and a layer of slime will cover submerged surfaces. These same algal blooms occur in larger bodies of water, such as ponds, lakes, rivers, and estuaries, when excessive nutrients such as nitrogen and phosphorus build up in aquatic ecosystems. While these elements are essential for primary producers such as plants and algae, an influx of this nutrient pollution, known as eutrophication, can be problematic. Eutrophication has been linked to the occurrence of harmful algal blooms in coastal regions where wastewater and agricultural runoff from land empties into nearshore environments (Anderson et al., 2008). Harmful algal blooms can lead to degraded water quality (Smith, 2003), depletion of oxygen levels (Breitburg et al., 2018), and biodiversity loss (Diaz & Rosenberg, 2008). Algal turf scrubber (ATS) technology is used to remedy eutrophic wetlands when a single, non-point source of the pollution cannot be located. Large-scale ATS units have been installed throughout wetlands of South Florida to remediate waters of Lake Okeechobee and the Everglades (Adey et al., 2013). An ATS system works by continuously pumping water over an inclined runway where algae and other organisms can colonize. The lawn or "turf" of periphyton (Figure 1) serves as a biological filter as nutrients are cleaned from the water and taken up by the living matrix of biomass. Home aquarists and fish hobbyists use similar, scaled-down systems for display tanks. Commercial turf scrubbers are available, but their demand is limited by the prohibitive cost. As on-line tutorials for assembling inexpensive units are now readily available, at-home use of ATS systems is gaining popularity.

Figure 1 Growth of algae on the flow-ways of an algal turf scrubber (ATS) system operating during summer 2022 at a pier on the Skidaway River in Savannah, GA.

Regardless of the scale and size of the ATS system, algal productivity in nutrient-rich waters is excessive, and the resulting lawn must be periodically removed to allow new biomass to continue nutrient uptake. Disposal or reuse of this algal biomass can be problematic. For large-scale ATS systems, harvested biomass can be converted into animal feedstock (Sandefur, Matlock, & Costello, 2011), fertilizer (Khan et al., 2019), or biofuel (Kumar & Singh, 2019). Yet, the relatively high amount of inorganic ash in harvested algal turf poses a challenge for biorefinery and limits its secondary use (Aston et al., 2018). The added salt in algal biomass from marine ATS systems further limits its secondary use and, instead of being recycled, is sent to landfills where it is added to the accumulation of discarded trash.

In this article, we provide the methodology to utilize algal biomass waste as a clay body for ceramic products (Figure 2). Here, we also provide suggestions for potential uses of clay sculptures in marine conservation and STEAM (Science, Technology, Engineering, Art and Mathematics) education.

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Figure 2 Hand-sculpted horseshoe crabs using clay made entirely from algal biomass. These clay figures have not dried and are still pliable.

HOW ALGAE IS SIMILAR TO CLAY

Clay is composed of silica, aluminum, calcium, iron and other materials which, once fired to a high enough temperature, become ceramics that no longer dissolve in water. These same minerals are also found in ATS algal biomass (Tables 1 and 2). Regardless of the water source, the bulk of collected biomass will likely consist of diatoms, cyanobacteria and green algae though environmental factors such as water temperature and sunlight will influence the relative abundance of these primary producers (Adey et al., 2013). Once the organic material is heated and all carbon is burned off in the ceramic firing process, only inorganic minerals remain. Like other organic materials such as wood and straw, algal biomass will produce inorganic ash residue after heating. Ironically, while ash limits the recycling potential of ATS waste (Aston et al., 2018), that component contributes to the viability of its use for ceramic sculptures. The ash from harvested biomass from an ATS system is relatively high (~75 wt%) with nearly half of that total weight coming from silica (Aston et al., 2018). In addition to the silica found in the cell walls of diatoms, the gelatinous mucilage of periphytic algae will trap inorganic particulates from suspended silt adding to the clay's ash content. This silica-based ash in the matrix of periphytic algae provides the unique potential for use as clay for ceramics by promoting porosity, water absorption, and strength.

	PERCENT COMPOSITION					
	Ca	K	Mg	P	N	S
Mean	1.2	0.6	1.0	0.1	0.4	1.1
SD	0.04	0.03	0.07	0.00	0.01	0.05

Table 1 Percent composition of mineral elements (Ca - Calcium, K - Potassium, Mg - Magnesium, P-Phosphorus, N-Nitrogen, S-Sulfur) from ATS algal biomass from four flow-way samples from scrubbers at the Skidaway River. Samples were analyzed by the University of Georgia Extension Agricultural & Environmental Services Laboratories. The mean percentage and standard deviation (SD) for the four samples are included.

SOURCES OF ALGAE

Algal biomass for clay use can be sourced from any marine or brackish waterway. Clay from freshwater algae can be used but we have found that marine biomass produces better ceramics. We believe that the marine ATS has higher ash from an abundance of diatoms and sediment-trapping mucilage of marine algae. In addition to using algal biomass from an ATS system at the Skidaway River in Savannah, Georgia, we collected marine algae from two other sources to determine if different types of periphytic growth could be utilized. We collected algal scum growing at the waterline on the walls of a marine aquaponics tank and we scraped biofilm from the slick part of a concrete boat ramp at low tide. For all three sources, we removed abrasive

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barnacle and mollusk shells, and poured the raw, unprocessed algal biomass into resealable plastic bags. This bulk storage of algae was frozen (–18°C) until ready to defrost and use as a source of clay.

	PARTS PER MILLION (PPM)										
	AL	B	Cd	Cr	Cu	Fe	Mn	Na	Ni	Pb	Zn
Mean	37681.8	73.0	1.3	54.4	13.1	28100.0	849.5	35533.0	14.3	42.6	82.7
SD	5411.7	8.8	0.2	4.5	0.6	2008.2	17.7	4387.9	1.01	4.47	7.72

Table 2 Quantity (parts per million) of mineral elements (Al -Aluminum, B -Boron, Cd -Cadmium, Cr-Chromium, Cu-Copper, Fe-Iron, Mn-Manganese, Na-Sodium, Ni-Nickel, Pb-Lead, Zn-Zinc) from four samples collected from four algal turf scrubber flow-ways at the Skidaway River in Savannah Ga. Samples were analyzed by the University of Georgia Extension Agricultural & Environmental Services Laboratories. The mean ppm and standard deviation (SD) for the four samples are included.

PROCESSING ALGAE INTO CLAY

Unprocessed, raw ATS biomass will have a consistency of liquified clay, known as slip, Algal slip can be poured into plaster or silicone molds and allowed to air dry (Figure 3). Using this method, ceramic products will have a standardized shape and can be replicated with minimal processing. However, by using unprocessed algal slip, the finished ceramic products will likely have remnants of shells and other particulates that will surface during firing and will appear as white specks (Figure 3). To create a clay body similar to what is used in a regular ceramic practice with commercially available clays, the slurry must be further processed. To create a clay with a smooth consistency, the raw algal slip can be filtered through a mesh such as a metal screen colander or a cheesecloth to remove shell particles. The slurry can also be ground in a common household blender to homogenize the algae while reducing any remaining shell fragments into smaller, non-abrasive particles. This wet slurry can be poured onto plaster slabs or left in the sun to remove excess moisture to get a workable clay body.

Figure 3 Unprocessed raw algal biomass in the form of clay slip was poured in silicone molds (left image) ready to air dry, and the resulting ceramic tiles (right image) kiln-fired to a bisque temperature around 1830°F/999°C. Remnants of mollusk and barnacle shells appear as white specks in the finished red ceramic tiles.

For long-term dry storage, we processed the algal slurry into a dried powder until ready to rehydrate and use as clay (Figure 4). To powderize the biomass, the algae was poured into aluminum cooking trays and allowed to either air dry over several days or heated in an oven at 105°C for 72 hours. Dried algae can be ground manually with a mortar and pestle, but we used a blender to turn the biomass into fine powder. To minimize the wear on the blender, we manually crumbled dried algae and re-hydrated rock-hard algal chunks that can wedge underneath the blades. Once fully powderized, the collection of dried algae was stored at room temperature in sealed plastic bags or containers and reconstituted with water until a moldable consistency was reached. Because algae-based clay largely consists of organic material, it usually has an odor similar to a coastal saltmarsh. If handling algae-based clay is a concern, general safety precautions used when working with commercially available clays can be followed. As such, natural clays purchased in a store likewise contain organic living components such as fungi, mold, and bacteria. Similarly, when working with any dry ceramic product such as commercial ball clay or fireclay, a respirator such as an N-95 mask should, likewise, be worn when working with powderize algae. Although not necessary, people working with these dry materials can wear additional personal protective equipment like gloves and eye protection.

Figure 4 Algal biomass scraped from the surface of a concrete boat-ramp was dried and then broken into smaller fragments (Figure A), ground in a blender (Figure B), turned into a fine powder (Figure C) and then rehydrated to form a moldable clay (Figure D).

PRODUCING FINISHED SCULPTURES

Like commercially available clay, sculptures made from algal biomass can be air dried and will stay preserved indefinitely as greenware (Figure 5) unless rehydrated. When greenware sculptures are heated to at least 1100°F/593°C (cone 022), the ceramic products are porous but no longer dissolve in water. Desktop electric kilns are a relatively affordable option and are commonly purchased for at-home use by novice and experienced artists. Alternative firing methods such as pit or barrel firings can be used to reach high enough temperatures. All of our sculptures were fired in an electric oxidizing kiln at temperatures up to a bisque 1830°F/999°C (cone 06). Although there was some variation in the general appearance of the finished products (Figure 5), sculptures made from algae from the three different sources (i.e., edges of a marine tank, ATS flow-way and concrete boat dock) resulted in brick-like, low-fire ceramics similar to terracotta. We found that by incrementally elevating firing temperatures up to glazing levels, the color of the ceramic products changed from red to a rich brown color (Figure 6). For larger projects that required an abundance of clay, we mixed equal amounts of algae clay with commercially purchased Lizella Georgia clay (Figure 7).

Figure 5 Hand sculpted horseshoe crabs using clay made from algal biomass. The closest figure is air dried (greenware) and the other three are bisque fired 1830°F/999°C (cone 06). The closest fired crab was made from clay scraped from the side of a marine tank, the next was from algae from an ATS system, and the last was crafted from clay made from algae growing a concrete boat ramp. Notice that for the ceramic crab from the marine tank, the evaporated salts and calcium particulates surfaced in the firing process giving the sculpture a mottled appearance.

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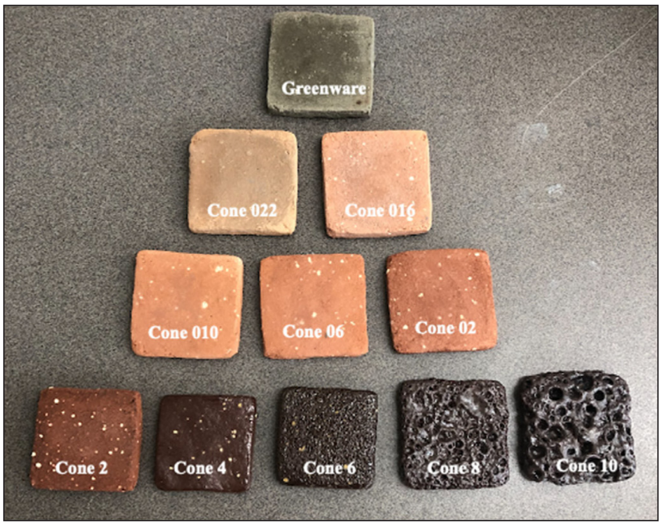

Figure 6 Ceramic test tiles crafted from ATS algae displaying the range of firing temperatures from raw greenware (top) to bisque 1830°F/999°C (cone 06) to glaze 2280°F/ 1249°C (cone 10).

Figure 7 A horseshoe crab shell (left) was used by faculty member Casey Schachner to create a plaster mold to create an algae-Lizella clay ceramic press (right) that was bisque fired to 1830°F/999°C.

APPLICATION AND RELEVANCE

Converting algal biomass into ceramics provides a novel approach to tackling four needs: 1) Recycling algal biomass waste from ATS systems by converting it into ceramic products, 2) Reducing the demand for finite industrially mined clay bodies and materials, 3) Providing a potential substrate for reef-dwelling marine organisms such as oysters and corals, 4) Educating children and adults about arts and sciences in an understandable and visually enjoyable way.

Small and large-scale ATS and other periphyton nutrient removal systems are currently in operation in the U.S., so an abundance of waste algal biomass can be kept out of landfills by reclaiming its mineral-rich content (Tables 1 and 2) while simultaneously serving as an alternative source of mined clays. Because periphyton acts as a natural aquatic filter, trace minerals captured from the water are incorporated by living algae and stored in their biomass. Bioaccumulation of elements in periphytic growth should be explored as a more sustainable and renewable alternative to extracting minerals from finite clay mines. For example, the United States is a key global exporter of kaolin clay mined in Georgia (Schroeder, 2018); however, these finite mineral deposits that formed millions of years ago will eventually be exhausted. In addition, the industrial processes (Figure 8) used to harvest these mined minerals are taxing on the environment and landscape restoration is a costly endeavor. Other common sources of clay are exclusively mined from regions experiencing war and other conflicts that can affect global supplies and create widespread shortages (O'Driscoll, 2022). Once the non-renewable products of clay mines are exhausted, the need will arise for innovative and comparatively less environmentally harmful alternative sources.

We have found that ceramics made from algal biomass are aesthetically and structurally similar to that of terracotta clay sculptures and can similarly have a variety of uses. Using ceramics made from 100% algal biomass to serve as an alternative substrate for reef restoration is especially appealing as it represents a return to its marine source. Although natural oyster shells are the preferred substrate in constructing oyster reef habitat, the demand for shell exceeds the availability so alternative substrates are utilized. Concrete is the most commonly-

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used reef shell substitute but others include porcelain, limestone, and granite (Goelz, Vogt, & Hartley, 2020). Ceramic reefs constructed from algal biomass might provide an alternative solution that yields the same physical results. Through the Georgia Sea Grant's Artists, Writers and Scholars program, algae-based ceramic pieces were created and submerged in oyster spat tanks where larva colonized the artwork (Figure 9). While these spat-colonized pieces were created as an artistic showcase, ongoing studies include testing the suitability of algae-based ceramics as an alternative option for oyster recruitment and reef restoration.

Figure 8 Street view of the Imerys kaolin mine in Sandersville Georgia.

Figure 9 (left) Artwork created by Georgia Southern University's faculty member Casey Schachner. The pieces showcase oyster larvae also known as spat, growing on the surface of the algal ceramics. (right) detail image of oyster spat growing on surface of piece made by student Nina Samuels.

Through the support of the Georgia Sea Grant, we have used this algae-based clay to create sculptures for an exhibition at the University of Georgia Marine Extension Center & Aquarium at Skidaway Island in Savannah, Georgia. In June 2023, Submerged: An Underwater Exhibition of Bioceramic Artwork went on display and showcased selected works of faculty and undergraduate students who processed algae, created clay, and designed artwork that also functioned as interactive pieces to enrich the environment for the fish, turtle, octopus, and crustacean inhabitants (Figure 10). The artworks were primarily created through hand building and slip casting methods which are traditional techniques in ceramics.

In addition to the aesthetic and artistic potential of algae-based clay, this media provides an excellent opportunity for educators to provide hands-on student crafting activities to learn about eutrophication and environmental restoration. Using algae as the raw material to craft ceramics is an excellent tool to provide experiential learning opportunities to increase awareness of Ocean Literacy Principles (OLP) to educate students of all ages in a cross-disciplinary approach combining art with science (NOAA, 2024). As a part of the *Submerged* exhibition, an infographic (Figure 11) outlining the process was instrumental in accompanying the artwork display. Importantly, this public exhibit highlights that the ocean is a diverse complexity of life living in a multitude of ecosystems (OLP #5) and that with risks of eutrophication, humans impact the oceans but can also play a role in its preservation and restoration (OLP #6).

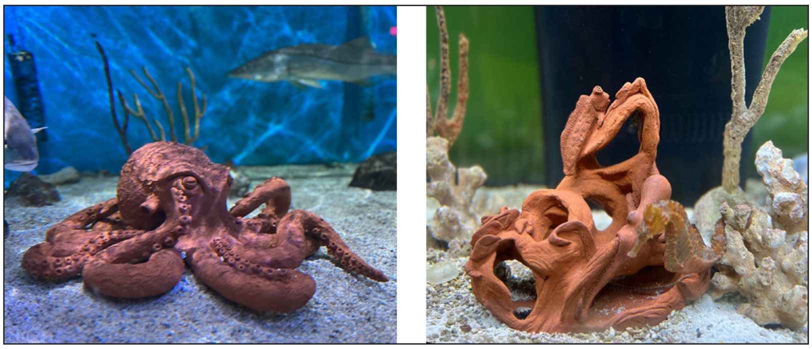

Figure 10 (left) student Nina Samuel's large sculpture "Octopus" made of algal waste and ceramic submerged in the UGA Aquarium tanks with snook and drum fishes. (right) seahorse and pipefish interacting with the algae ceramic piece made by faculty member Jennifer Zettler.

Figure 11 Infographic depicting how algae waste can become oyster reef restoration via ceramic artwork.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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