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Article

# Mapping essential fish 'hardbottom' habitat using sonar techniques: A local reef off Masonboro Island, North Carolina, USA

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**Abstract:** This study investigates an outcropping submarine reef, known as John Creek Hardbottom, located on the shoreface off Masonboro Island, North Carolina. The exposure is likely associated with the high-relief Pleistocene coquina calcarenite hardbottom reefs, which are prevalent off southeastern North Carolina. The reefs provide essential ecosystem services, which include habitat for a wide range of biological communities, in addition to acting as an important sand source for local beaches and providing substantial recreational fishing and diving opportunities. Due to their local importance, the National Oceanic and Atmospheric Administration (NOAA) has classified the reefs as Essential Fish Habitat (EFH). In this study, a range of different hydrographic survey techniques, including sidescan sonar and single-beam echosounding, were collected to produce a geo-referenced mosaic and bathymetric grid of the reef. The reef's various morphological features are classified based on terminology from previous studies, and upon further examination, a new term for local hardbottom reef morphology, known as 'boulder fields' is presented. John Creek's unique morphology differs from other nearby hardbottoms, allowing this study to provide a wider understanding of local hardbottom characteristics. Due to their protected status, in addition to natural and anthropogenic threats they face, mapping and monitoring southeastern North Carolina's reefs provides critical information for all stakeholders involved in sustainable coastal management decision-making.

**Keywords:** coquina; limestone; pavement; boulder fields; seafloor mapping; North Carolina; reef; sidescan sonar

## 1. Introduction

Southern Onslow Bay off North Carolina is classified as a sediment-poor inner shelf system, in many cases dominated by hardbottom, or reef, environments [1–4]. There are generally two different types of recognized hardbottoms: low-relief (< 0.5 m) pavement and mixed hardbottom, and high-relief (> 0.5 m) hardbottom [5]. Low-relief hardbottoms within the region are often composed of Oligocene siltstone (Oligocene dolosilt) and Plio-Pleistocene moldic limestone, whereas high-relief hardbottoms are predominantly comprised of Pleistocene *coquina* calcarenite [3,6–8].

*Coquina* limestone outcrops are presumed to be formed in the late Pleistocene between 75 to 55 ka BP, during Isotope Stage 3 [5,9]. *Coquina* is classified as a partially- to well-indurated calcarenite facies of the Neuse formation [2,7,9]. The reefs were formed through post-depositional diagenesis of shell bearing shoreface sands during a sea-level high, where aragonite produced by the shell hash cemented and calcified the sediment at or near the paleo-water table [9]. A second dissolution episode occurred when sea level was lower and aerial exposure caused meteoric waters to erode the *coquina*, producing unlithified, generally reddish, non-fossiliferous sands we generally see blanketing the area [9]. At present, physical erosion occurs on the *coquina*, providing new sediment to the shoreface and beaches in response to wave energy, tidal and longshore currents [5,10,11].

Low-relief hardbottoms tend to support little to no life, while high-relief hardbottoms have been described as ecosystems with diverse biological communities [3]. The term hardbottom is generally used to describe an indurated surface with no growth of reef-building organisms, therefore a lot of high-relief hardbottoms tend to fall under the category of livebottoms: a hardbottom that provides substrate for a persistent biological community [5,12]. Livebottoms found in Onslow Bay host a variety of organisms that contribute to the bio-aggradation and bio-erosion of the livebottoms, classifying them even further as reefs [3,12]. Through the process of bio-erosion, organisms erode the *coquina*, providing more sediment to the surrounding environment [1,4,5].

The sediment eroded from the hardbottoms forms a sand sheet that often envelops rock outcrops [4,5]. The sand sheet produces sediment for the shoreface and inner shelf, which is subsequently transported to the adjacent beaches through a process known as shoreface bypassing [2,10,12]. Past studies in the vicinity of the Kure Beach shoreface, a few kilometers to the south of the present study, have suggested that up to 50% of its sands are derived from the biological and geological reworking of hardbottom units [7,8].

Livebottom reefs in Onslow Bay are highly valued by the community as a sand source, and also as diverse ecosystems and hotspots for fishing and diving. NOAA has designated them as Essential Fish Habitat (EFH) under the *Magnuson-Stevens Fisheries Conservation and Management Act 1976* [13] and the *MSA Reauthorization Act 2007* [14], 16 U.S.C. §§1801 et seq. The establishment of livebottoms as EFH assists in the protection and conservation of habitats used by managed species during different life stages [15]. This requires councils to monitor and evaluate potential adverse effects of fishing activities on EFH [15]. Other federal statutes assist in protecting livebottoms, including the Endangered Species Act, the Modernizing Recreational Fisheries Management Act and the National Marine Sanctuaries Act).

Currently, the reefs are mostly under-studied and under-mapped, with their most extensive research published between the late 1970s and early 2000s [2,5–8,12,16]. In this study, a range of marine geophysical and sedimentological survey methods were used to produce maps and an overview of John Creek Hardbottom, located on the shoreface off Masonboro Island, North Carolina. External pressures such as warming ocean temperatures and increased tropical storm activity, in addition to anthropogenic effects like coastal development, increased recreational and commercial fishing activities, and possible large-scale infrastructure projects such as dredging for sand, further deepening of shipping channels and offshore wind development, will undoubtedly have impacts on these critical, natural local ecosystems [17]. As a result, monitoring and mapping of these local hardbottom reefs needs to be a priority when it comes to effective and sustainable coastal-management decision making.

## 2. Study area

### 2.1. Southern Onslow Bay, North Carolina

Onslow Bay is a recessed coastal compartment located between North Carolina's east facing Capes Lookout and Cape Fear (**Figure 1**, inset). The bay is a moderate to high-energy environment where the offshore region is dominated by hardbottoms. Their age, lithology, and distribution are associated with the regional outcrop pattern of Tertiary depositional geological sequences that dip gently to the southeast [4,6,12]. The modern sediment produced by the reworking of older outcropping stratigraphic units and carbonate sediments produced by benthic biota creates a surface sediment veneer that is often less than a meter thick and is easily stripped from Plio-Pleistocene and Oligocene-aged strata during storm events [2,8,18]. The limited sediment thickness is indicative of low fluvial input, entrapment of sediments in estuarine systems, and insufficient sediment exchange between shelf embayments [2,10,19]. The transgressive barrier islands located within Onslow Bay are typically bi-modal when it comes to surface sediment cover, often comprising either fine quartz sand with little to no shell hash or a mixture of medium to coarse sands with shell hash, shell fragments and whole shells derived from the bio-eroded hardbottom reefs [7,8,10,18,19].


**Figure 1.** Study area. John Creek Hardbottom (blue star) is located approximately 1 km off Masonboro Island, a protected coastal and estuarine reserve and barrier island in southeastern North Carolina. Red line C-C' represents a bathymetric cross-sectional profile.

### 2.2. Masonboro Island, North Carolina

John Creek Hardbottom, also known as John Creek Rock, is a reef located on the shoreface off the southern end of Masonboro Island, North Carolina, comprising a 5653-acre, 13 km long, low-lying undeveloped transgressive barrier island (**Figure 1**). It was selected in 1991 to become part of the National Estuarine Research Reserve System (NERRS) managed by NOAA and the N.C. Division of Coastal Management, designated to protect and study estuarine systems [20]. Long-term erosion of Masonboro Island's southern section has been estimated at approximately 3 m/year, in contrast to its relatively stable to accreting north end, adjacent to Masonboro Inlet [11,20].

## 2.3. John Creek Hardbottom

Little is known about the origin of the name "John Creek", however, local magazines suggest it is associated with John Creek inlet, which is the remains of a creek channel that once extended through a now-closed inlet. John Creek is located 1.1 km east of Masonboro Island at a water depth of ~10.45 m (~34 feet), although the shallowest part of the reef comes up to within 4.0 m of the sea surface. The main section of the reef, which is approximately 60 m long and 40 m wide, is located at approximately 34°06′ N, 77°50′ W. The reef is a well-known recreational fishing spot. Another well known (and charted) comparable high-relief hardbottom reef is Sheephead Rock off Fort Fisher, several km further south. *Coquina* rock is also subaerially exposed at the beach off Ft. Fisher (**Figure 2**), representing only a few locations where rock is directly exposed along southeast North Carolina's barrier beaches.

**Figure 2.** Aerial drone image of Fort Fisher coquina outcrop. Note person in bottom left. Image by Whittington.

## 2.4. Biological and physical characteristics

Organisms which reside on or near the hardbottom reefs in Onslow Bay are dependent on a range of variables, including water depth, temperature, salinity, light attenuation, and outcrop surface area [21]. Flora and fauna that use the reef as habitat include brown algae, sponges, a wide variety of fish species and various encrusted bivalves [3,7]. Macroalgae which inhabit sandy hardbottom areas tend to only colonize outcrops above the sediment or on large shells or lithoclasts; storm events can also strip sediment and create more surface for meadows to form [18]. The erosion of encrusted bivalves forms the shell hash that is common within Onslow Bay's barrier islands. The mean aragonite saturation rate for these organisms is 3.8 Ω, which is indicative of healthy growth.

According to the US National Oceanic and Atmospheric Association (NOAA), tides in the area are semidiurnal, with a mean tidal range of 1.2 m (NOAA Tide Station #8658163). Dominant sediment transport direction is primarily from north to south, although northward transport takes place during summer tropical cyclones and during episodic nor'easters during the winter. Results from 10 years of local buoy observations (www.CORMP.org/ILM2), show that average significant wave heights are 0.93 m, and average dominant wave periods are 7.7 s, respectively [22]. Based on 2023 metocean buoy data, mean wind direction is from the south with an average velocity of 4 m/s.

## 3. Materials and methods

Sediment sampling and geophysical survey data were collected between 9:30 a.m. and 12:30 p.m. (EST) on 10 November 2023 aboard UNC Wilmington's RV Seahawk (**Figure 3**). Standard 'lawn mowing' techniques were used to record eight survey lines (five lines orientated SE/NW approximately 250 m in length and three lines orientated NE/SW approximately 150 m in length) of bathymetric and sidescan sonar data while sediment and sound velocity profile data were recorded at deployed points over and near the reef. Underwater photos of John Creek Hardbottom from April 2005 were also available. All maps were created in ESRI ArcGISPro v.3.2 software, projected in WGS 84 World Mercator/UTM Zone 18N. Vertical datum for the bathymetry data was based on North American Vertical Datum (NAVD 88), using Mean Lower Low Water (MLLW).

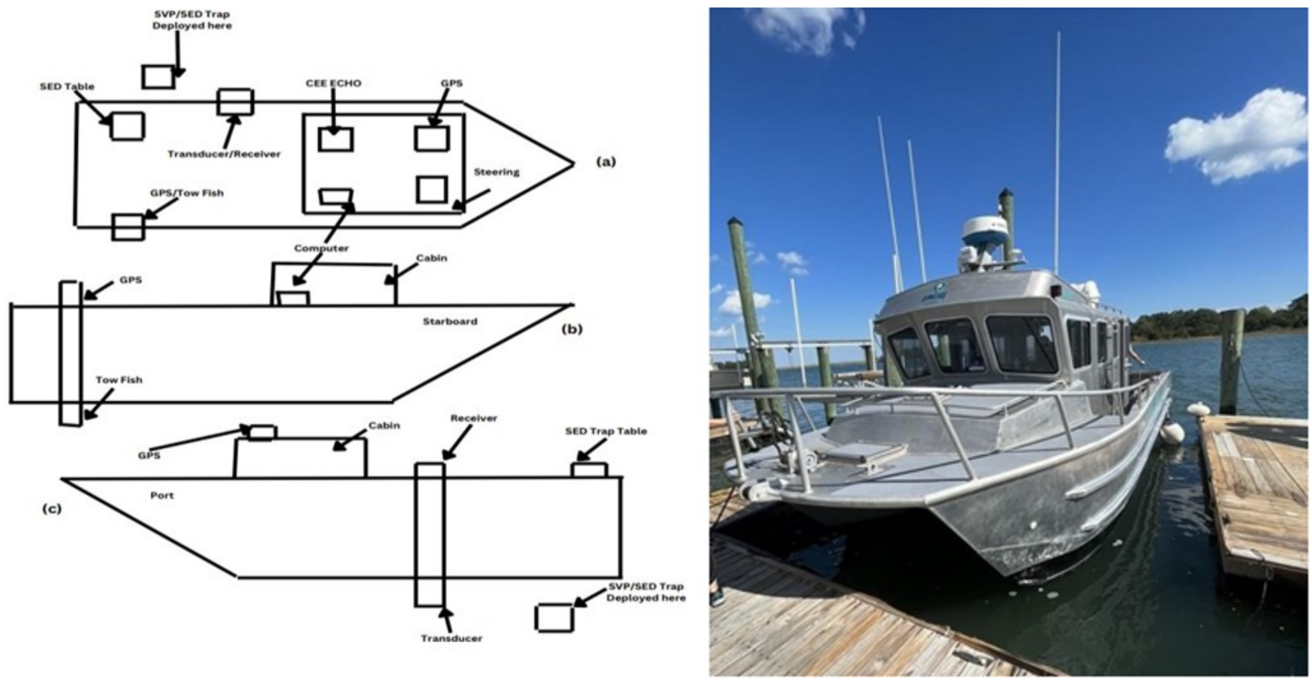



**Figure 3.** Left: **(a)** diagram of equipment setup through aerial view; **(b)** starboard view; **(c)** port view. Right: photo of the RV Seahawk survey vessel.

### 3.1. Sidescan sonar

Sidescan sonar was used to produce acoustic images and a geo-referenced mosaic of the study area, collected using a 990 kHz Tritech Starfish (1 MHz 'chirped' pulses with a 0.3-degree horizontal beam width). The georeferenced mosaic was exported as a geotif image at 0.25 m resolution. The system also included a US Global Sat BU-352 GPS, with accuracies of ± 3–5 m. A custom pole-mounted sidescan sonar, with the transducer set 0.5 m below the water surface, was designed to allow access to shallow water and to decrease risk of obstructions while also avoiding the need for positional layback corrections.

The sidescan sonar data was post-processed in SonarWiz7 v.7.08.01 (Chesapeake Technologies, Inc.) using standard industry techniques, and visually analyzed in DeepView v.1.0.0.1 (DeepVision AB). The raw imported xtf data was processed using common digital methods (e.g., bottom tracking, file trimming, range adjustments and applying different filters) following Sonar Wiz guidelines. The final georeferenced mosaic was imported to ArcGISPro. DeepView was used for detailed visual imaging, figure production and for object (e.g., scarps, boulders, sandwaves) length and height measurements.

### 3.2. Bathymetry

A pole-mounted 200 kHz CEE-ECHO single-beam echosounder, with a ping rate of 20 Hz and resolution of 0.01 m (**Figure 4**), was used to produce a bathymetric grid and profiles of the reef and surrounding area. The transducer was located 0.80 m below the sea surface. Position was recorded with a Trimble R8s GNSS receiver, mounted directly above the transducer.

Data from the echo sounder were post-processed in SonarWiz7 by importing the raw single-beam echosounder files, removing any spikes and subsequently applying tide, heave and sound velocity corrections to produce a geo-referenced bathymetric grid of the study area. The grid was interpolated using the nearest neighbor algorithm with a grid resolution of 1.0 m.

**Figure 4.** Echosounder acquisition survey setup, including pole-mounted Trimble R8s GPS receiver.

### 3.3. Sediment data

Two seabed sediment samples were collected using a standard Ponar sediment grab sampler. Sample locations were recorded with a US Global Sat BU-353 receiver attached at the helm of the vessel. On return from the field, the samples were oven dried and analyzed using traditional sieving techniques. Sediment data were processed using GRADISTAT v.9.1 (Kenneth Pye Associates Ltd.).

## 4. Results and discussion

Based on observations from the sidescan sonar, bathymetry, sediment samples and previous studies, John Creek was classified into five main geomorphological units: high-relief scarp, rubble mound, rubble ramp, rubble field, and boulder fields (**Figure 5**). These are discussed in turn below.

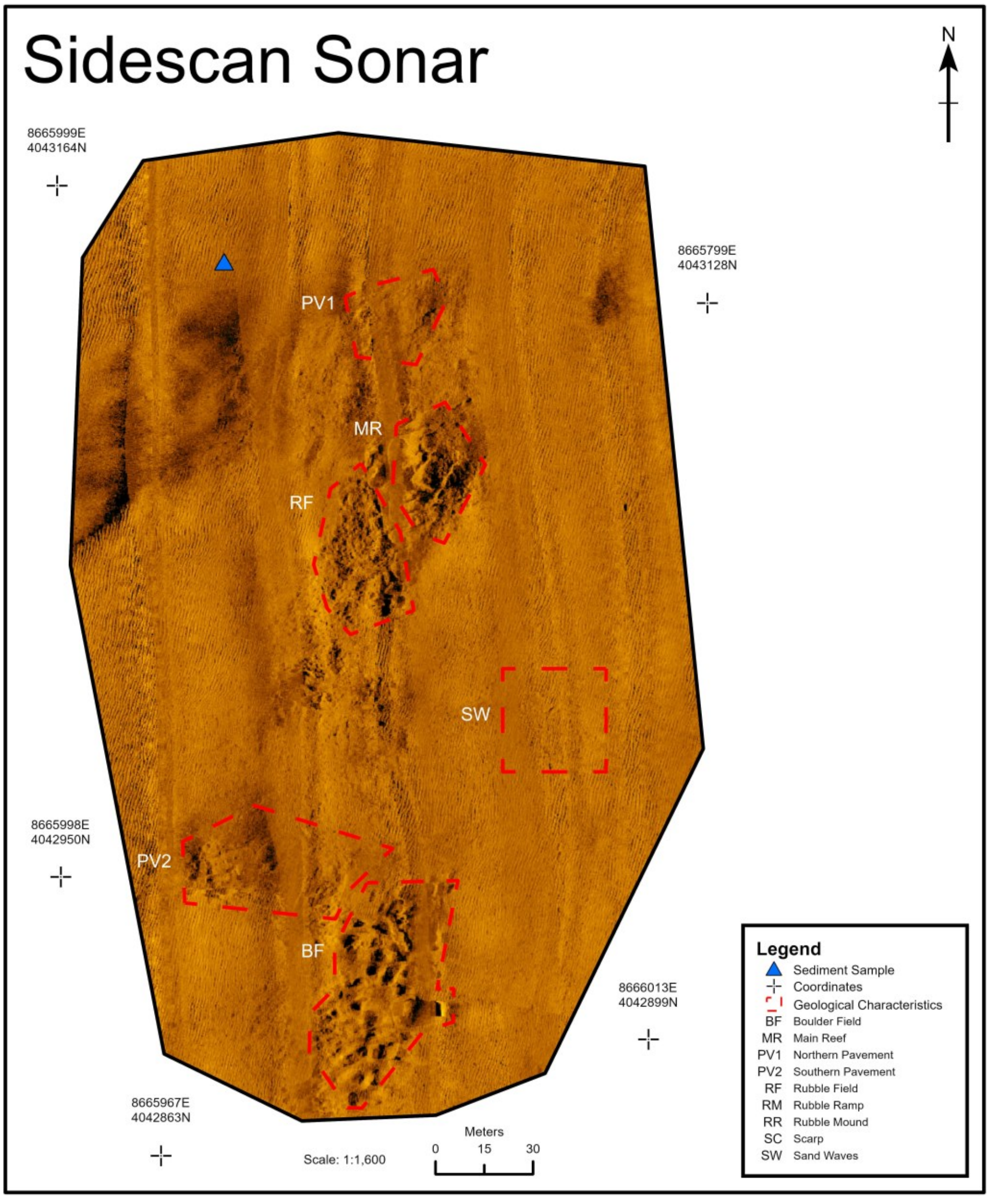



**Figure 5.** Geo-referenced sidescan sonar mosaic of John Creek Hardbottom showing main morphological characteristics.

### 4.1. Sidescan sonar feature classifications

High-relief scarp: The main body of the reef is classified as a high-relief scarp (**Figure 5**). Scarp morphology has been further classified into three different categories: vertical cliffs, sloped cliffs and undercut with associated overhangs [12].

Out of the three categories, based on sidescan results, the main reef is presumably undercut with an associated overhang scarp. This term is defined as the upper part of the scarp's lithology which is more indurated than the lower part of the scarp, causing overhangs as the softer lithology is undercut via bioerosion [12]. This particular scarp faces towards the southwest, which is commonly seen in other hardbottom scarps in the region [1]. The impact of surficial sediment burying the zone of relief is minimal due to the scarp's height above the seafloor, which allows for diverse sessile benthos and reef-fish communities to concentrate on or near it. Many high-relief scarped hardbottoms have been known to correlate with shallow subsurface fluvial channels, where eroding margins often terminate against channel walls [6]. This suggests that there may be a link between groundwater discharge through these channels, secondary cementation, and induration of the carbonate sediment [12].

Rubble mound—The rubble mounds produced on and around the main reef are formed from the overhangs of the scarp breaking off due to erosional processes. John Creek Hardbottom's rubble mounds (**Figures 5** and **6A,B**) are found on and adjacent to the main reef and measure around 3–6 m in length. Other studies have shown that they can be up to 10 m wide and 30 m long, and can extend 80 m away from the main reef [12]. Based on sidescan survey data, there appear to be four main rubble mounds (**Figures 5** and **6**). The mounds continue to erode, and large boulder-sized fragments break off, creating rubble ramps and rubble fields.

Rubble ramp—John Creek's rubble ramp extends approximately 7 m away from the reef's main scarp into the adjacent rubble field (**Figures 5** and **6A,B**). The erosion and accumulation of rubble mounds produce boulder-sized fragments that create a rubble ramp. Some studies from nearby reefs have shown that the bottom extension of the ramps tend to be buried beneath varying thicknesses of highly mobile sediment [5]. Storms, however, have been known to strip the surficial sands away from hardbottoms, leaving more lithoclasts to be exposed. The upper extension of ramps are known to host infauna and epibenthic communities with low species diversity [5,23].

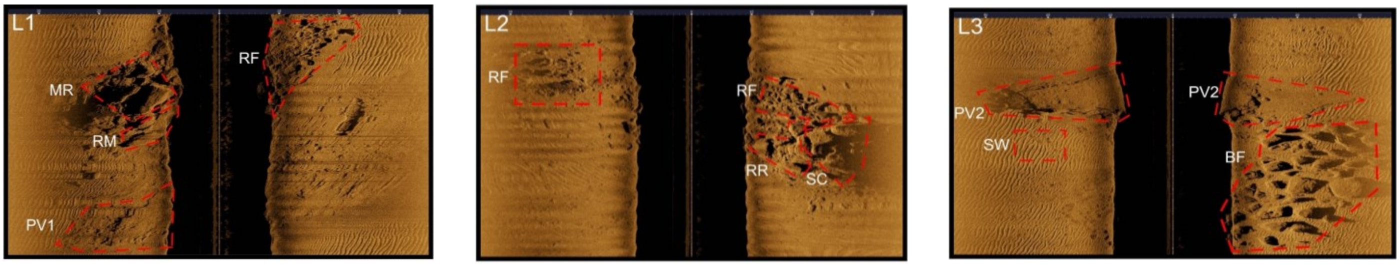
Rubble field—The rubble field off John Creek, which is approximately 35 m long, extends towards the southwest from the main reef (**Figures 5** and **6A,B**). Formed from rubble mounds, rubble fields produce resistant quartz, pelecypod fragments, and gravel-sized lithoclasts as part of the sand sheet enveloping high-relief hardbottoms [5]. Coarse sediment adjacent to the *coquina* hardbottoms generally contains a higher percentage of gravel in its sediment compared to other hardbottom lithologies, likely due to the '*coquina*' being composed of erosion-resistant cement and clastic components [5,18].

Pavement—There are two pavement surfaces to the north and south of the main reef which are easily visible in the sidescan sonar data (**Figures 5** and **6C**). The northernmost pavement measures almost 20 m long and 11 m wide, with 0.4 m of relief. The southernmost pavement measures almost 41 m long and 18 m wide, with relief between 0.4 and 1 m. Studies have shown that coarse gravelly sands from adjacent sand flats form a lag pavement [12,24]. Pavement has been known to be associated with high-relief hardbottoms, but are not known to occur on top of hardbottoms. Benthic invertebrates identified on pavement include sponges, tunicates, bryozoans, octocorals, and macroalgae [3]. Fish use high-relief scarps as habitat during the day and pavement to feed in the evening [3].

Boulder field—Boulder fields have not been identified from other published hardbottom studies in Onslow Bay, and are added here as a new classification (**Figures 5** and **6C**). The boulder field, comprising more than 20 individual boulders (**Table 1**), is located ~80 m south of the main reef and is ~53 m long and ~29 m wide. The largest boulder in the field measures 5 m long and 6.8 m wide, with a relief of 2.1 m (**Table 1**). Circular indents on top of some of the boulders (**Figure 6**) suggests that they may have existed in a period of sub-aerial exposure. The acidity in rainwater causes limestone to dissolve, forming 'pools' or moulins. The presence of ancient pools may indicate that these boulders were much larger when they were impacted by erosion and dissolution, decreasing their volume. The lower elevation of the boulder field, especially compared to the main reef, suggests that the boulders may originate from an older stratigraphic unit than that of the main reef, possibly underlying Oligocene siltstone. Additional field studies would be required to confirm this.

**Table 1.** Length and height (in meters) of twenty representative boulders identified within John Creek's boulder field.

| Length | Height | Length | Height | Length | Height | Length | Height |
|---|---|---|---|---|---|---|---|
| 5.0 | 2.1 | 3.4 | 2.4 | 2.4 | 2.3 | 1.6 | 2.8 |
| 4.6 | 2.3 | 1.3 | 1.7 | 2.8 | 2.2 | 2.0 | 1.1 |
| 5.0 | 1.9 | 3.8 | 2.6 | 2.3 | 2.6 | 4.6 | 2.0 |
| 3.4 | 3.5 | 3.5 | 4.6 | 2.5 | 2.3 | 0.9 | 1.6 |
| 3.5 | 3.0 | 2.6 | 2.0 | 2.1 | 2.3 | 3.0 | 2.0 |




(a) (b) (c)

**Figure 6.** Unprocessed sidescan sonograph images of John Creek's main geomorphological units including: (L1) the main reef, rubble fields and rubble mounds, (L2) scarp, rubble mounds and rubble fields, and (L3) pavement, sand waves and boulder field. Scale (on top of images) is in meters.

## 4.2. Bathymetry

A bathymetric grid and representative depth profiles of John Creek and surrounding areas are presented in **Figure 7**. The main reef is clearly visible (in red) within the central northern section, where it comes to within 6.5 m of the sea surface from a depth of approximately 10 m (**Figure 7A**). Other shallow (orange/yellow) sections include two smaller areas located to the north and southwest of the main reef, which represent the pavement discussed earlier. Shallower depths are mostly centered around the main reef, while areas west and south correspond to deeper water (shown in blue). Representative N-S and E-W profiles clearly illustrate the presence of the main reef and the two areas of pavement (**Figure 7B**). The boulder field's relief is not apparent in the profile, indicating that it is in deeper water compared to the other features, which may suggest that it is composed of an older geological unit than that of the main reef and pavement. A bathy-topo profile, collected by the US Army Corps of Engineers in 2020, which extends from Masonboro Island to 500 m seaward beyond John Creek is presented in **Figure 7C**. The exact location of the profile is shown in **Figure 1**.

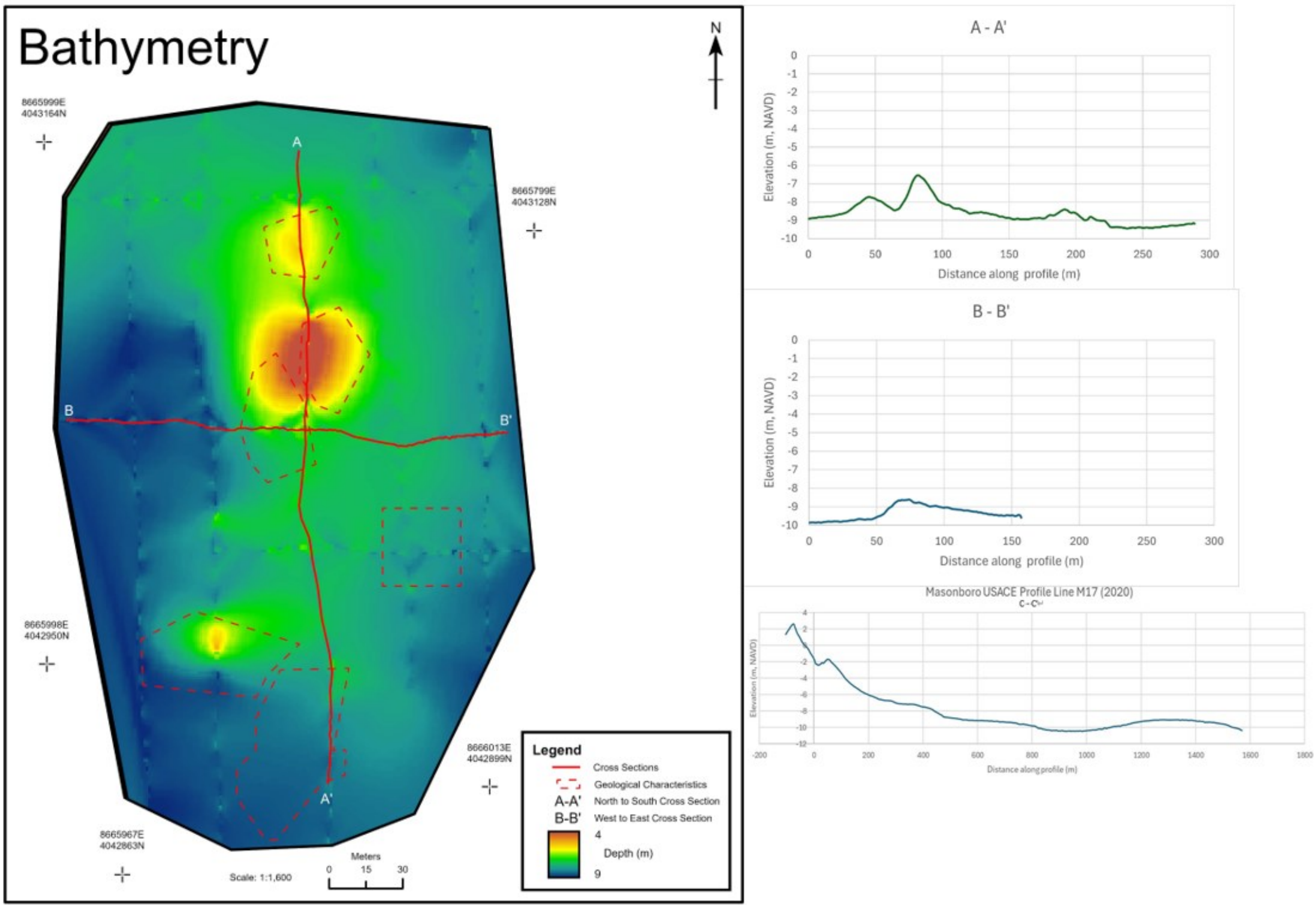



**Figure 7. (A)** Bathymetric grid of study area generated from single-beam echosounding; **(B)** north-south and east-west bathymetric profiles of John Creek Hardbottom; **(C)** bathymetric cross sectional profile extending from Masonboro Island to offshore and seaward of John Creek. Profile location for C is presented in **Figure 1.**

### 4.3. Surficial sediment and bedform characteristics

Two surface sediment samples were collected from within (Sample 2), and just outside (Sample 1), the study area (**Figure 8**). Sample 1 was located seaward of the northern area of pavement. Sample 2 was collected to the southeast of the rubble field (RF). Both samples comprised a mixture of fine quartz sand, shell hash, shell fragments and whole shells. Both samples are classified as poorly sorted gravelly sand according to the Wentworth classification scale. Gravel ranged from 8%–16%, sand from 83%–91% and mud was 0.2% or less for both samples.

Sand waves are common across the study area, some of which are present ~2 m from the main reef and rubble field (**Figure 6**, L3). Bedform wavelengths ranged between 4 to 10 m and heights ranged between 0.4 to 1.0 m. Granules, shell gravel, and coarse sand compose the sand wave troughs, while fine quartz sand forms a 10–

20 cm thick veneer over gravel on wave crests [2].

Representative diver observations and photographs from 2005, which highlight some of the diversity of organisms found at John Creek, are shown in **Figure 9**. These include species of *mollusca*, *tunicata*, *echinodermata*, *actiniaria*, *octocorallia*, and *blenniodei*, in addition to numerous fish species. Habitat type is indicative of preferred locations in which biota resides. A preliminary offshore wind study off the coast southeastern North Carolina by Taylor et al. [3] showed that hardbottom morphology often defined habitat type and residing organisms. For example, sand waves supported little to no life while pavement and rubble field habitat included sponges, soft corals, gorgonians and algae. Mixed hardbottom habitat hosted the most biodiversity compared to pavement, ledge, and artificial habitat.

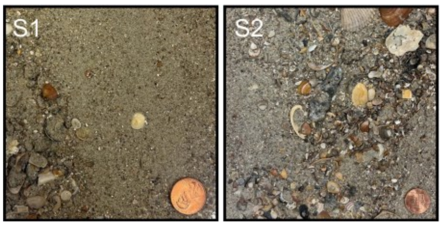



**Figure 8.** Seabed sediment samples collected from within (S2) and just outside (S1) the survey area. Both samples are classified as poorly sorted gravelly sand, comprising a mixture of fine sand, shell hash, shell fragments and whole shells. Penny on bottom right is provided as a scale.

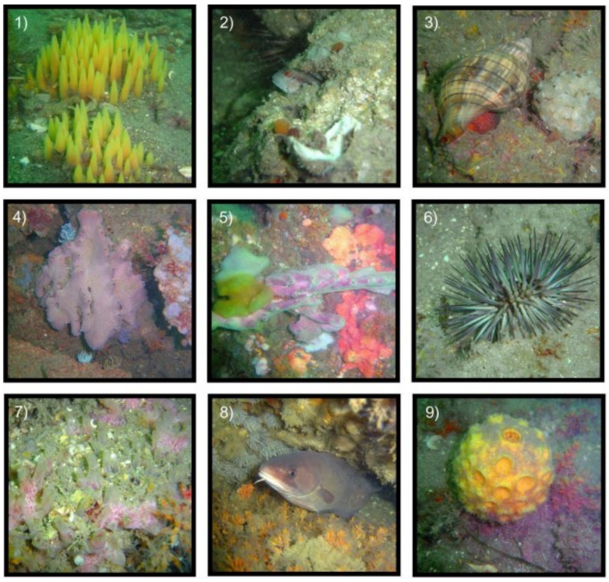



**Figure 9.** John Creek Hardbottom photos from 2005 including: (1) Sponge (*Raspailia spp.*); (2) Seaweed blenny (*Parablennius marmoreus*); (3) Tulip snail with eggs (*Fasciolaria tulipa*); (4) Red algae (*Peyssonnelia spp.*) and white sponge (*Ircinia felix*); (5) Colonial tunicates (*Didemnum sp.*), sea pork (*Aplidium stellatum*), and white sponge (*Ircinia felix*); (6) Atlantic purple sea urchin (*Arbacia punctulata*); (7) Tunicates (*Clavelina Oblonga*), yellow sulfur sponge (*Cliona spp.*), and octocoral (*Telesto fruticulosa*); (8) Carolina hake (*Urophycis earllii*) and anemones (*Exaiptasia sp.*); (9) Yellow golf ball sponge (*Cinachyrella alloclada*). Photos courtesy of Jason Souza and species identification by Jared Oviatt.

### 4.4. Biological characteristics

Underwater photos of John Creek (**Figure 9**, collected in 2005) illustrate the high biodiversity of the area, with a range of organisms and habitats, including sponges, tunicates, macroalgae, fish, sponges and anemones. Sediment movement is also an indication of biodiversity. Outcrops with higher relief become an obstacle for sediment transport and cause sediment to accumulate along one side of the outcrop, creating less surface area for sessile invertebrate distribution [3,12,18]. Large storms have been known to clear sediment buildup, creating more surface area for organism colonization [18]. Taylor et al. [3] also suggest that benthic communities have adapted in areas where burial and abrasion is more common.

## 5. Conclusions

Hardbottom reefs, classified as Essential Fish Habitat by NOAA, provide essential ecosystem services to the coastal and marine environment. This includes, for example, habitat to numerous fish and invertebrates, a source of sand to local beaches and recreational fishing and diving opportunities. The biodiversity residing on or near these reefs play an important role in Onslow Bay’s food web for many migratory species, including fish and seabirds. They are also remarkable since numerous organisms have adapted to existing in this high-energy and high turbidity environment. Although they are well-known and prevalent off the coast of southeastern North Carolina, they remain relatively understudied and warrant further investigation. With tropical coral reefs in decline worldwide, it is important to increase studies associated with local hardbottom reefs as they provide critically similar ecosystem services comparable to coral reefs.

This study used a combination of geophysical and sedimentological surveys to characterize John Creek Hardbottom, located only 1.0 km off the coast of Masonboro Island. Results of the study revealed a number of classic hardbottom geomorphological units, including e.g., the main outcropping reef, in addition to smaller units like rubble ramps, rubble fields and pavement. The study also identified a boulder field, which has not been identified at other hardbottom reefs within the wider region. The temporal evolution of hardbottom reefs, especially when impacted by high-magnitude storms such as hurricanes and nor’easters, is presently not well understood and should be incorporated into future studies. In addition, the reefs currently face a number of threats, including warming oceans, increased tropical storm activity, coastal development, pollution and proposed large scale offshore marine projects (energy, sand resources). Future long-term field studies, especially rock and sediment ground-truthing, fisheries distribution and physical oceanographic investigations (e.g., currents, sediment transport, groundwater distribution) will be required to obtain an improved understanding of the environmental characteristics of John Creek Hardbottom, in addition to other hardbottom reefs within the region. It is hoped that studies like this one and others will ultimately aid in establishing the reefs as Marine Protected Areas (MPAs) and/or protected reserves across southeastern North Carolina.

**Author contributions:** Conceptualization, PJW and JTB; methodology, PJW and JTB; software, PJW, PJC and JTB; validation, PJW, PH and JTB; formal analysis, PJW and JTB; investigation, PJW and JTB; resources, PJW and JTB; data curation, PJW, PJC and JTB; writing—original draft preparation, PJW and JTB; writing—review and editing, PJW, PJC, PH and JTB; visualization, PJW, PJC and JTB; supervision, JTB. All authors have read and agreed to the published version of the manuscript.

**Conflict of interest:** The authors declare no conflict of interest.

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