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GEOPHYSICAL SURVEY OF A CHOLERIC MASS GRAVE IN SAN JUAN, PUERTO RICO

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Introduction

Cholera is an acute gastrointestinal tract disease caused by the vibrio cholerae bacteria that causes watery diarrhea and overall loss of bodily fluids, leading to extreme dehydration that can be fatal (Kaper, Morris, and Levine 1995). This disease spreads mostly from exposure to contaminated water, which made historical cities with lack of sewer systems extremely vulnerable to cholera epidemics. In 1855, Puerto Rico was struck by the second global wave of cholera, killing over 20,000 individuals – over 4% of the total population at the time (Kiple 1985). Due to the high volume of corpses piling up and fear of the disease's further spreading, a cemetery outside of the walls of Maria Magdalena de Pazzi's cemetery and the San Felipe del Morro Fort was established (Sifres-Fernandez 2015). Little is known about the cemetery's conception and use, as the area was officially closed in 1856 after the epidemic ended. The cemetery has remained untouched since.

Today, however, this cemetery is in danger of being destroyed, as tourists in San Juan have now access to this section of the fort through National Parks Service's El Morro Scenic Trail. Thousands of people are walking on top of the cemetery, uncovering human bones as they walk and erode the landscape (**Fig. 1** and **Fig. 2**). This grave contains critical information regarding the late Spanish colonial period in Puerto Rico as well as the health and lives of the residents of San Juan. Therefore, we have developed a rescue bioarchaeological investigation with the main objectives of collecting, analyzing, preserving, and repatriating the human remains buried here before erosion and intrusion destroy or further compromises the site and its contents. Using these findings to continue with this community-informed rescue project will allow us to reintroduce the lives of these individuals - that were once forgotten - into our present and future.

Materials and Methods

The site was mapped using a Sokkia SET 530r3 Total Station and Trimble GeoXH GPS. Vegetation, path, features, fort wall, city cemetery wall, significant finds, and grids were mapped (**Fig. 3**). GPS was also used to map the extent of the skeletal fragments beyond the site area as well as USGS datums in throughout the San Juan National Historic Site. This data was processed using QGIS.

13 contiguous grids were laid out for the surface collection of the skeletal fragments (Fig 3). The collection was done in a systematic way, each grid being surveyed twice.

A Bartington Grad601-2 Fluxgate Magnetometer was used to survey 7 contiguous grids of the site. The data was processed using the Terrasurveyor software.

Finally, GSSI SIR 3000 GPR was used to survey 5 overlapping grids throughout the site with a 400Mhz antenna. Grids 1-3 were surveyed in two directions (e.g., East to West and North to South), while Grid 4 and 5 were surveyed in one direction. GPR data was analyzed using the open-source RGPR package (Huber and Hans 2018) in the R software, using default settings for the processing and the interpolation of the data.



Figure 1. Birds eye view of the surveyed area. Picture taken from El Morro Fort wall, looking East. Santa Maria Magdalena de Pazzi Cemetery is visible on the top right of the image.



Figure 2. View of the site after the identification of skeletal fragments on the surface. Each flag represents a human bone fragment. On the background, El Morro Fort is visible. To the left, the city cemetery's wall.

Results

Bone Density Analysis

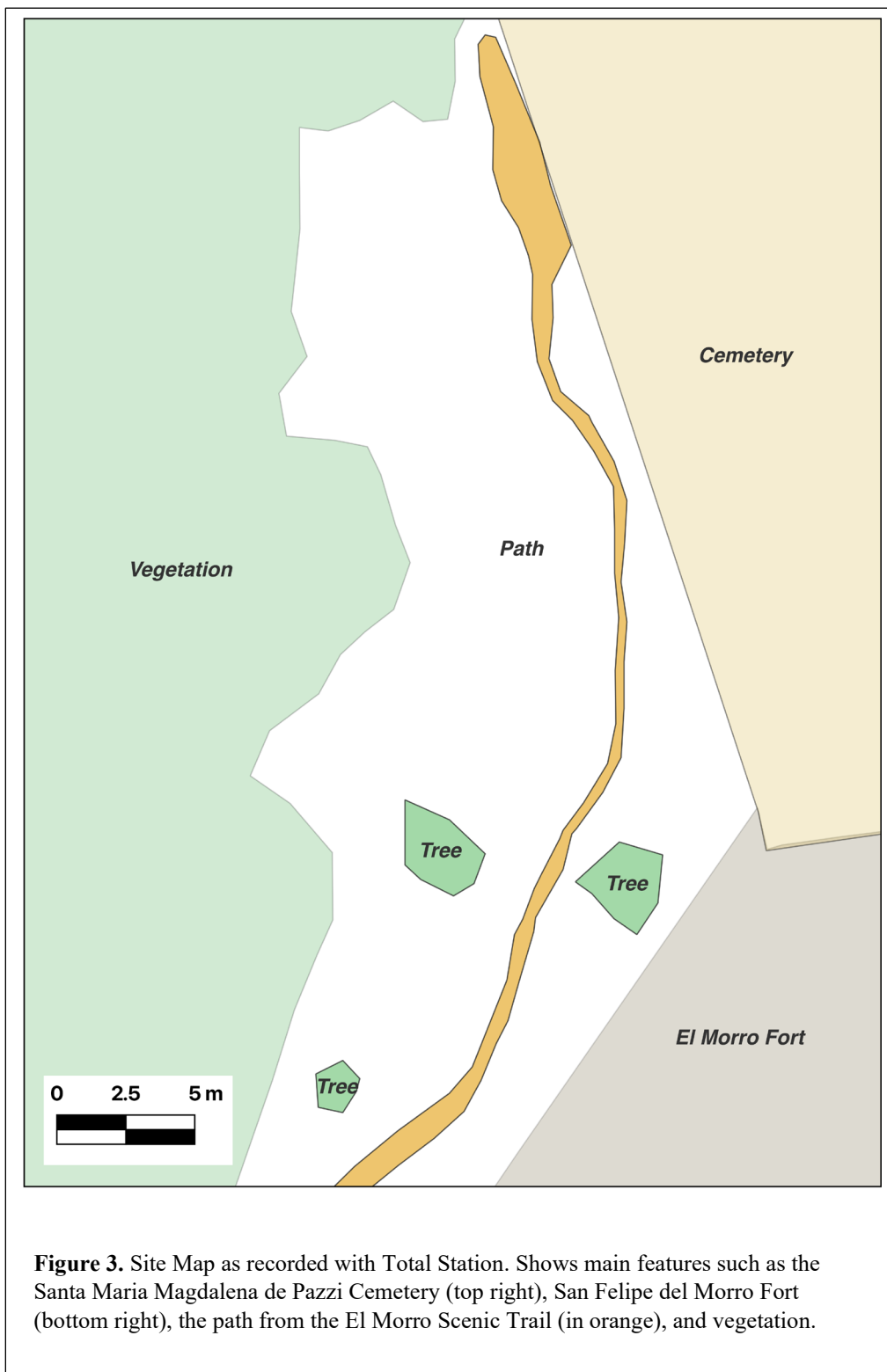
Figure 4 shows the bone density analysis from the surface collection of skeletal remains. Only bone fragments that were exposed were marked and later collected. No bones were identified in Grid 1 due to short grass covering the entire grid. From these data, we see a stark difference in the bone density across the 13 grids. Grid 6 contained the largest number of human bone fragments in the site, with a total of 150 fragments recovered, yielding a density of 7.5 bone fragments per m². The grid with the second highest bone density, Grid 8, yielded a bone density of 3 bone fragments per m² with a total of 60 fragments, less than half of Grid 6.

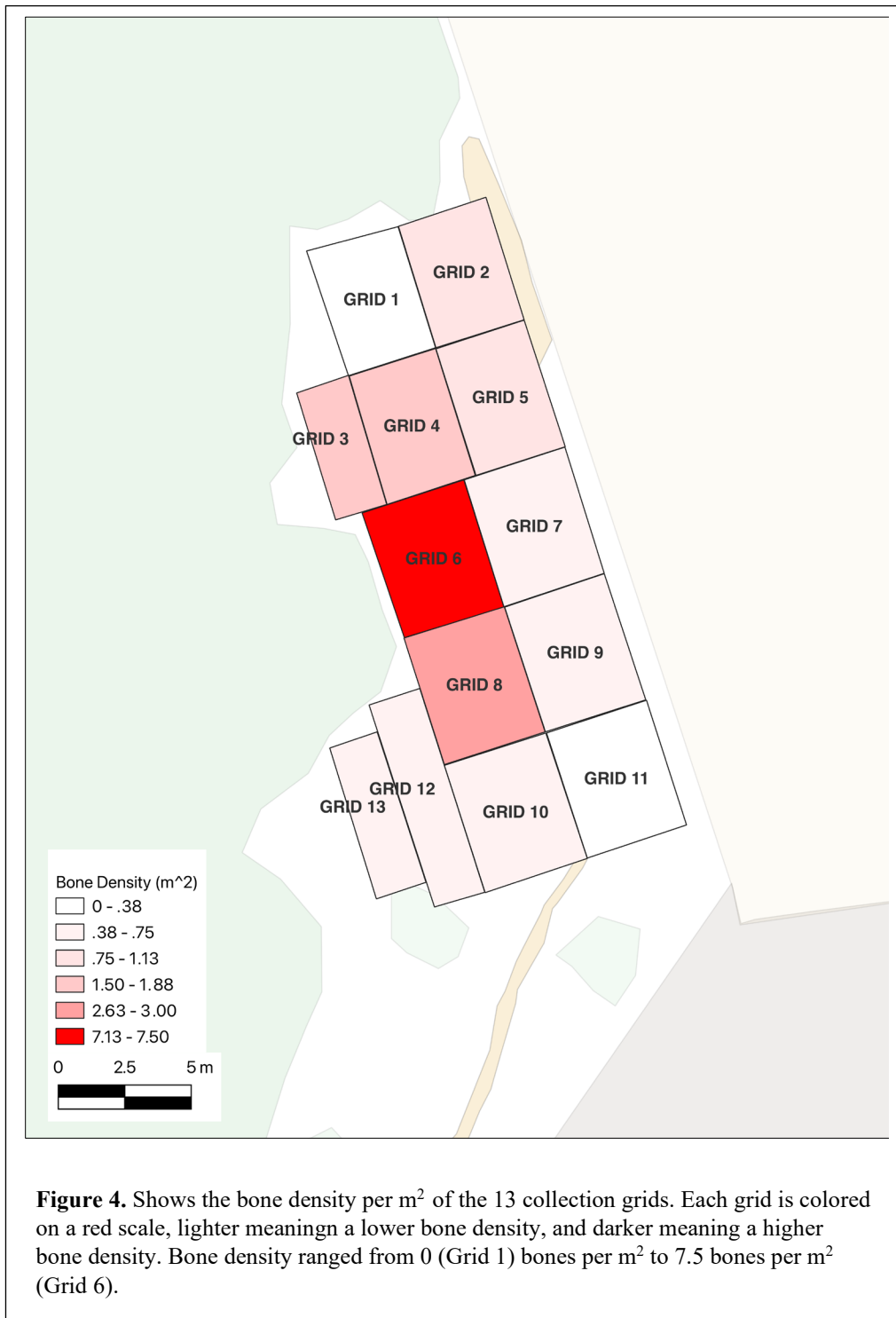
Magnetometer

In **Figure 5** we see the data obtained with the magnetometer. In the top right we observe an area with strong electromagnetic signal that covers almost the entirety of the Grid. Although not shown in Figure 1, the area of this top right grid encompasses an artificial mound. Furthermore, all other grids show evidence of material across the landscape.

GPR

Using the RGPR package in R, we interpolated the GPR data with all the lines of the 5 grids at once. **Figure 6** shows the interpolated image at depth of 9.95ns. Right away we see what looks like a semi-circle stretching throughout most of the surveyed area. This signal was also observed at contiguous depths in the interpolation. Apart from this semi-circle, we also observe a strong signal next to this semi-circle, towards the bottom right of the image.





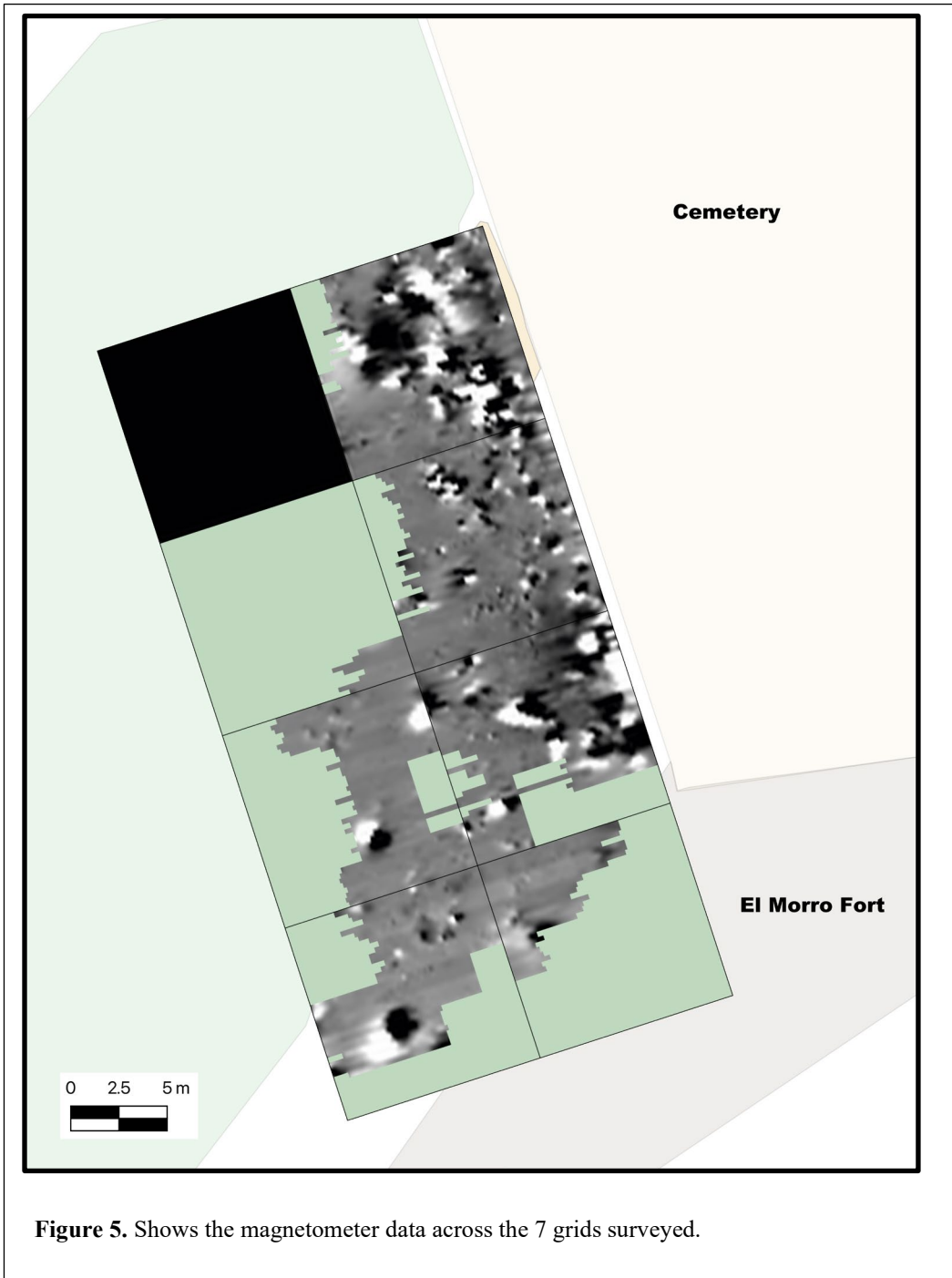


Figure 5. Shows the magnetometer data across the 7 grids surveyed.

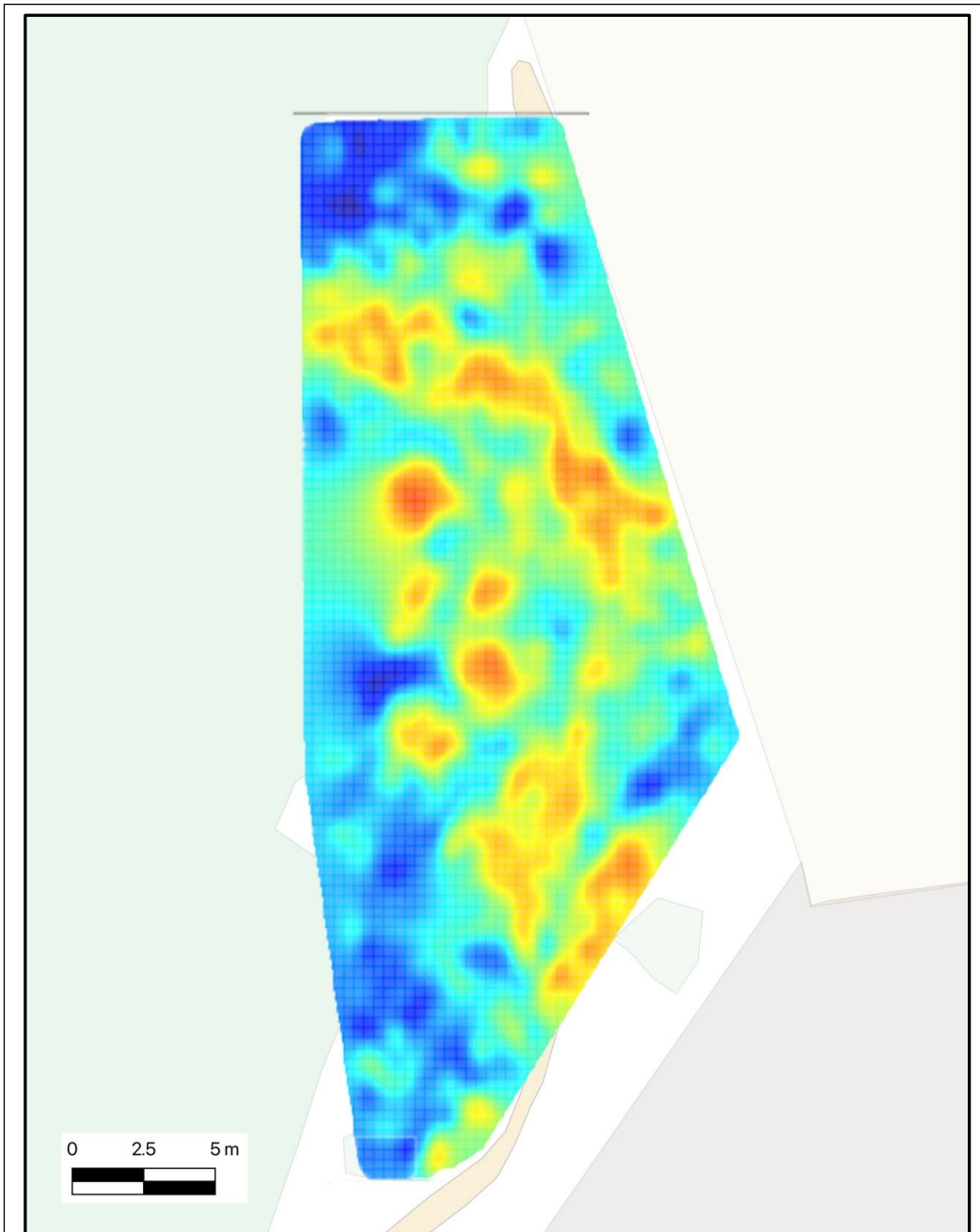


Figure 6. GPR data interpolation of the 5 grids surveyed. Image shows interpolation slice at 4.95ns.

Discussion

Bone Density: two main takeaways can be concluded from the bone density data. First, and most importantly, that the site is actively being eroded. In total, over 500 hundred human bone fragments were identified in the systematic collection, with one particular grid having 150 bone fragments within it. This further highlights the need for this rescue project. The second point pertains to the stark difference in the bone density across grids. This stark difference could be explained by a higher erosion on this grid or by the location of the grid with regards to the delimitations of the mass grave.

Magnetometer: one of the main findings is that of human activity in the area after the creation of the mass burial. Given that there is no particular concentration of electromagnetic signal that may indicate the presence of concentrated mortuary artifacts, the signals seen are likely from the trash and debris left behind by visitors. The 3rd grid on the right from the top-down, furthermore, likely shows what is a high concentration of rocks and tombstones found on an artificial mound close to the city cemetery wall. The top right grid, similarly, likely shows the signal of whatever is inside an artificial mound in that corner of the site, which is also likely debris from the city cemetery.

GPR: provides one of the most important findings of the geophysical survey. As seen in **Figure 6**, the semicircle that is seen across most of the surveyed area is potentially the choleric mass grave. This strong signal does not align with the path in **Figure 3**, or any of the electromagnetic signals seen in **Figure 5**, further suggesting this could be the mass grave. If true, this would also highlight the importance of geophysical surveying before any archaeological excavation, as in this case, the data broke our biased preconception that we were looking for a large rectangular mass grave cut. This survey, therefore, will better inform future work at the site.

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Ethics Statement: This project has been conducted after careful discussions with local agencies and stakeholders. The Instituto de Cultura Puertorriqueña (ICP), Department of Health of Puerto Rico (DoH), the City of San Juan, and National Parks Service (NPS) have all closely worked with the authors during the project development and the initial surveys. The local community of La Perla has also been consulted, and we proceeded with the project only after getting positive feedback from them.

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