Using 3D Micro-Geomorphometry to Quantify Interstitial Spaces of an Oyster Cluster

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Abstract— **In ecology, it is assumed that the characteristics (e.g. shape, size) of interstitial spaces found in a variety of habitats affect the colonization of species, species interactions, and species composition. However, those characteristics have traditionally been difficult to measure due to technological limitations. In this study,we used the Structure-from-Motion (SfM) photogrammetry technique to measure the physical characteristics of interstitial spaces in a small oyster cluster. The point cloud (and mesh) of the oyster cluster derived from SfM photogrammetry was found to be accurate enough (mean error of 0.654 mm) to conduct 3D geomorphometric analyses. We present an example of measures of curvature, roughness, interstitial volume, surface area, and openness for three 3D interstitial spaces. The interpretation of those measures enabled establishing which interstitial spaces were the most likely to be used as a shelter for an average crab. Those spaces are characterized by smaller openness and higher roughness and curvature measures. This initial quantitative 3D characterization of an oyster cluster is the first step in establishing empirical relationships between structural complexity of biological structures like oyster clusters and their ecological role for instance in predator-prey interactions. Overall, this study demonstrates the feasibility of combining SfM photogrammetry with geomorphometry for fine-scale ecological studies.**

I. INTRODUCTION

In ecology, the structural complexity of habitats is known to play a key role, for instance by affecting predator-prey interactions, local species composition, and resilience to environmental change [1]. Structural complexity describes both qualitative (e.g., composition, spatial arrangement) and quantitative (number, size, and density) traits of habitat requirements for animals [2,3]. For example, habitats with diverse elements of varying sizes and abundance are considered to have higher structural complexity. One of the most widely accepted assumptions about the causal link between structural complexity and species interactions and composition is that an increase in structural complexity generates more abundant and diverse interstitial spaces. Interstitial spaces are volumetric gaps between elements such as crevices under boulders or spaces between biological elements like seagrasses, corals, and oysters. Those interstitial spaces work as refuges for prey species and hence reduce predation by hindering the visibility of prey and accessibility of the predators [4].

Based on those assumptions, it is generally acknowledged that an increase in structural complexity leads to an increase in biodiversity. In other words, it is assumed that the size range of species and individuals using the refuge is limited by the size and shape of that refuge. However, there has been very little empirical work examining the link between the morphology of refuges and species interactions. This is largely because of the difficulties inherent to quantifying the morphology of refuges, particularly at fine spatial scales.

Recent advances in photogrammetry now make it possible to model, in three dimensions, fine-scale structures like oyster clusters. This study aims to characterize the morphology of an oyster cluster from a 3D model produced using Structure-from-Motion (SfM) photogrammetry. Our specific objective is to link quantitative measurements of interstitial spaces (i.e. the empty space between individual oysters in a cluster) to the potential use of those interstitial spaces as a refuge for crabs.

II. METHODS

A. 3D Model of the Oyster Cluster

Among diverse photogrammetry techniques available for applications in fields like ecology and geology, SfM was deemed the most appropriate for this study considering the size of the oyster clusters in the study area (about 30 X 30 cm), their complex structures, and their accessibility (above water, intertidal environments).

A total of 149 photos were taken with a Canon 7d Mark II camera equipped with 18-55mm lens, fixed at 18mm. Photos were taken from both right and oblique angles (from nearly 5

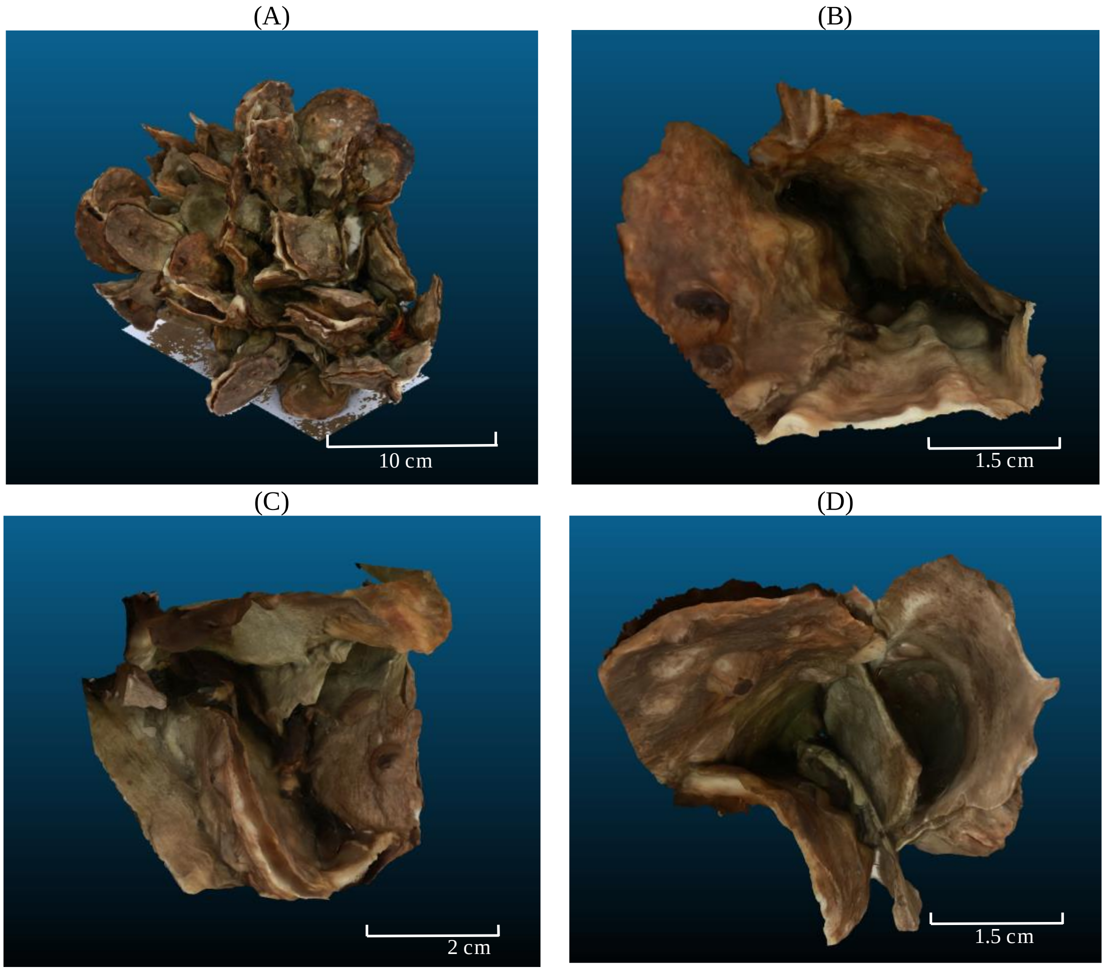


Figure 1. Texturized mesh of an oyster cluster and examples of interstitial spaces produced with the Agisoft Photoscan software. (A) View of the oyster cluster from the front. (B to D) Examples of interstitial spaces segmented using a 5x5x5 cm box.

cm distance) to fully capture the oyster cluster and its interstitial spaces. The images were then imported into the Agisoft Photoscan Pro software v.1.4.0 to produce a point cloud, a mesh, and a texturized mesh.

The accuracy of the 3D mesh was verified by measuring distances between defined features (edges of oysters and barnacles) and comparing them to the distances in the 3D mesh (n = 6). Later, the point cloud was scaled based on known distances between markers.

B. 3D Geomorphometric Analysis

The mesh was then imported into CloudCompare v.2.9.1 for further surface analyses. In CloudCompare, measures of roughness and curvature were computed, in addition to interstitial space volume (using the 'compute 2.5D volume' option). Each interstitial space was individually extracted from the mesh using a fixed size box (5 X 5 X 5 cm square; outer box) and later, subsampled points (8,000 points/cm^2) for the geomorphometric analyses. The size of the box was determined by considering the maximum of the size range of the studied crab species – and thus the size needed for an interstitial space to have the potential to serve as a refuge for the crabs – and the extent needed to fully capture the morphology of their immediate surroundings. Specifically, to measure the volume of the interstitial spaces, a 2 X 2 X 2 cm box (inner box) was used, as this is the average size of the crabs that use interstitial spaces. For more accurate results, spurious points (i.e. noise in

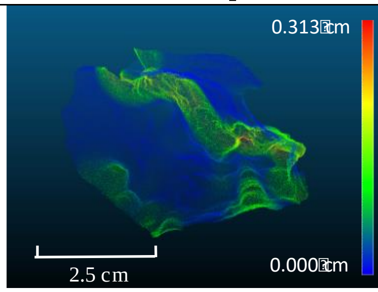
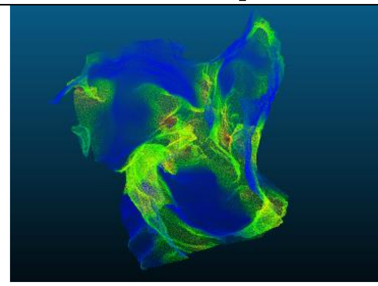
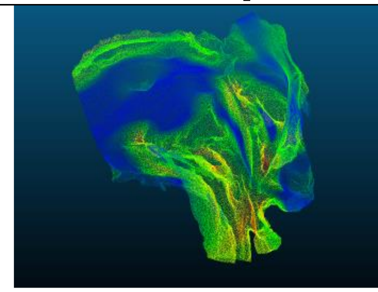
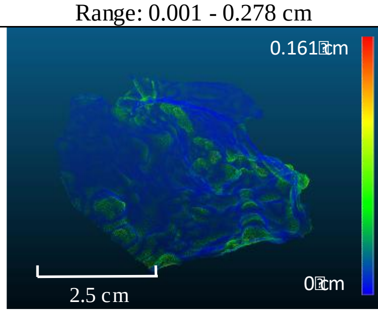
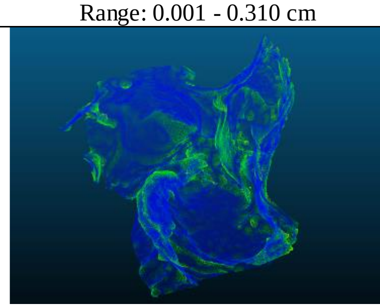
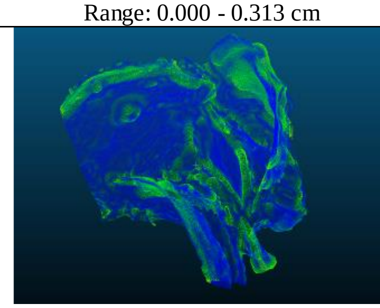
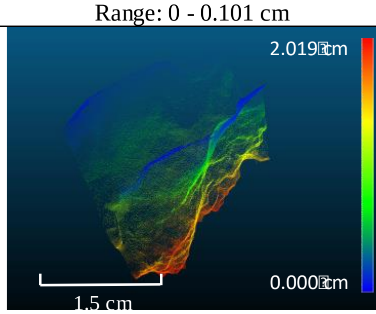
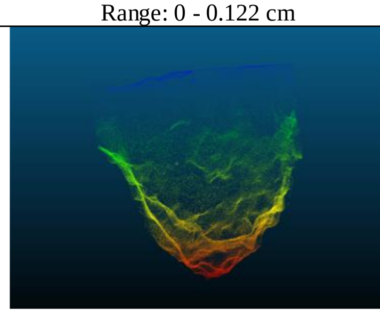
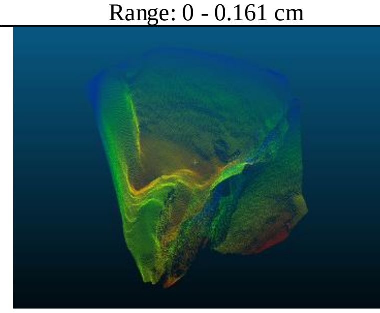
	Interstitial Space 1	**Interstitial Space 2**	**Interstitial Space 3**
Curvature			
	30.128% - 30.547% Range: 0.001 - 0.278 cm	46.178% - 46.634 % Range: 0.001 - 0.310 cm	51.086% - 51.700% Range: 0.000 - 0.313 cm
Roughness			
	28.817 - 29.489% Range: 0 - 0.101 cm	32.748% - 33.549 % Range: 0 - 0.122 cm	42.920% - 43.794% Range: 0 - 0.161 cm
Interstitial spaces (volume and surface area)			
	Volume = 2.693 Surface Area = 8.976 Openness = 0.300	Volume = 3.021 Surface Area = 10.536 Openness = 0.287	Volume = 3.351 Surface Area = 12.587 Openness = 0.266

Figure 2. Results for all metrics for the three interstitial spaces (Figures 1B to 1D). Scale bars apply to rows.

the data) and hidden points were removed. The volume per unit area was estimated by dividing the interstitial volumes by the 3D surface areas. Curvatures and roughness were measured using kernels of 0.5 and 0.2, respectively, which best described the fine-scale topography. Later, we calculated the proportion of points that had either higher roughness (higher than 0.083 cm from the fitted plane) or higher curvature values (higher than 0.020 cm from the fitted plane). Those cutoff points were determined by visually examining the changes in difference. While there were 256 total bins for the results of curvature and roughness, the range distance slightly varies among interstitial spaces resulting in a range of percentages above cutoff points.

III. Results and Discussion

A. 3D Model and Quantitative Measurements

The combination of the 149 images in Agisoft Photoscan produced a dense point cloud (83,713 points), a mesh (4,872,998 faces) and a texturized mesh (Figure 1A). The accuracy measurement showed that the point cloud (and mesh) of the oyster cluster derived from SfM photogrammetry was relatively accurate, with a mean error of 0.654 mm.

The mesh enabled the extraction of interstitial space units from the oyster cluster. Here we present three examples of 3D interstitial spaces that were extracted from the point cloud and mesh (Figures 1B to 1D).

The quantitative characteristics of the interstitial spaces that were measured in CloudCompare (i.e. curvature, roughness, volume and surface area, openness) are presented in Figure 2 for the three examples. The interstitial space number 1 had the lowest values of curvature, roughness, and volume out of the three interstitial spaces whereas interstitial space number 3 had the highest of each metric among those. All the interstitial spaces had volumes smaller than 3.351 cm^3, which could offer shelter for small crabs while protecting them from bigger predators. Interstitial space number 1 had the largest volume per unit surface area followed by number 2 and the 3.

B. Interpretation of Results in an Ecological Context

The quantitative characterization of the morphology of the three interstitial spaces provides some insights on their potential to serve as efficient shelter against predators. For example, a higher surface curvature at the interstitial space scale may result in a more difficult access to crabs for a predator. A higher curvature may make the prey less visible to the predator and make it more difficult for the predator to drag the prey out of the refuge. Surface roughness may be related to the ability of crabs to survive water turbulence (drag coefficient), and withstand predators' pulling force by holding on to rough surface. Interstitial space volume and surface area are associated with the size limitation of both individuals from the prey species and the predator species. For example, spaces with higher volume per surface unit, and thus a greater openness, have a wider entrance or cavity that expose the prey species to predators.

C. Limitations and Future Work

The results presented in this paper are those of a feasibility study. While results show that fine-scale 3D models of biological structures can be produced by using SfM photogrammetry for ecological studies, it is improper at this point to infer direct ecological relationships between refuge geometry and crab species or sizes due to the limited sample size and the lack of species morphology information. However, the approach tested in this study can now be applied to bigger datasets, which will enable to statistically test this kind of relationships. Moreover, for accurate validations of 3D models, further studies should include direct volumetric measurements of the interstitial spaces to compare to the spaces from the 3D modeled representations. Measuring the geometries of interstitial spaces will be the stepping stones of multiscale structural complexity studies, hence providing the applicability to test whether interstitial spaces of oyster reefs affect species composition. In addition, the techniques we described could be applied to the burgeoning field of ecological restoration where design and materials could be evaluated in a way that maximizes species diversity.

IV. Conclusions

In this application, we demonstrated the feasibility and adequacy of using SfM and geomorphometry to quantify the morphology of interstitial spaces of an oyster cluster. The millimeter-scale accuracy of the 3D model was achieved by taking a large number of images during low tide when the oysters were above the water, thus avoiding image distortion from the water. Although this study was limited to a few samples, it shows the possibility of using photogrammetry methods (especially SfM) for a fine-scale ecological study. The ability to accurately quantify the morphology of interstitial spaces at fine scales is an important advancement for studies of the role of structural complexity in community composition, a current frontier in the field of ecology [5,6].

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