SEMI-AUTOMATIC METHOD OF FAN SURFACE ASSESSMENT TO ACHIEVE GORGONIAN POPULATION STRUCTURE IN LE DANOIS BANK, CANTABRIAN SEA

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ABSTRACT:

This study presents a semi-automatic method to estimate fan surface of a *Placogorgia* sp. octocoral assemblage using 3D point clouds in El Cachucho MPA at 550 m of depth. The presence of gorgonian forests and deep-sea sponge aggregations in Le Danois Bank was the cause of its declaration as 'El Cachucho' Marine Protected Area (MPA), being included in the Natura 2000 network. The *Placogorgia* sp. is a structuring species of the deep Cantabrian Sea; parameters such as population structure and morphology inform on the overall health of this vulnerable habitat, but the estimation of gorgonian metrics often requires destructive sampling. The use of non-invasive methodology, which does not cause damage or alterations on benthic communities, is particularly necessary in vulnerable ecosystem studies and Marine Protected Areas (MPA) monitoring. This study proposes a semi-automatic methodology to assess gorgonian morphometries fitting planes to colonies. Video transects acquired in Le Danois Bank, during the ECOMARG-2017 survey using the Politolana underwater towed vehicle were used. Using Pix4D Mapper Pro and Cloud Compare software, size and morphometry of fan-shaped gorgonians and forest population structure were assessed. RMS of fitting planes shows that the geometrical figure chosen is suitable to retain the morphometric characteristics of the specimens of this species. The adjustment of semi-automatic values with a sample of digitized surfaces manually is validated (R2=0.97). The results show that gorgonian population was mostly dominated by small colonies. The population structure distribution shows a high proportion (~22%) of recruits (< 0.05 m^2) of fan surface.

1. INTRODUCTION

Deep-sea gorgonian (Octocorallia: Alcyonacea) forests set up a complex three-dimensional habitat for many species and focus high biodiversity in the deep ocean. Their weak ability to recover from damage is mainly due to slow growth rates (Andrews et al., 2002; Sherwood and Edinger, 2009; Doughty et al., 2014). Suitable management and regulation of fishing activities and other anthropogenic disturbances are crucial for these areas. Several national and international policies to protect deep-sea species in the last decade have been established. Hard-bottom coral gardens are often found to be dominated by gorgonians, stylasterids, and/or black corals (OSPAR, 2008). Gorgonian assemblages are also included in EU Habitats Directive 92/43/EC (EC, 1992) as "1170 Reefs" habitat type. Protecting and restoring deep-sea coral gardens is considered crucial from an environmental perspective. Many protected areas are considered Essential Fish Habitat (EFH) for some commercial species, as recruitment or spawning areas. Both EFH management and protected area regulatory initiatives can help to maintain productive fisheries and good environmental status of the ocean (Lindeman et al., 2000; Rieser, 2000; Friedlander, 2001).

The knowledge about offshore gorgonian assemblages has not been widely addressed. In the deep-sea, assessing gorgonian morphometries parameters, such as height, surface, orientation, etc. and their population structure, i.e. specimen size frequency distribution, can be achieved using extracting sampling techniques; but recently, the use of underwater vehicles has become a key tool for these types of studies (Mortensen and Buhl-Mortensen, 2005; Gori et al., 2011; Grinyó et al., 2016).

The declaration of 'El Cachucho' as the first off-shore Marine Protected Area (MPA) in Spain (BOE, 2011) was a key ecological milestone. To design and manage conservation areas monitoring programs of the protected species must be carried out (Fraschetti et al., 2002; Claudet et al., 2006; Addison, 2011). El Cachucho MPA has been subject in recent years of numerous studies and surveys to evaluate the condition of the habitats (García-Alegre et al., 2014; Sánchez et al., 2017), but developing methodologies to determine the conservation status of vulnerable habitats and to monitor over time the health status of the populations is still necessary.

The need to increase the level of detail of the measurements to define the morphometry of the gorgonians is clear. The problem lies in the complexity of the methodology to be used for the measurement of different parameters other than height. Structural complexity can be defined as the physical three-dimensional structure of an ecosystem; this 3D feature is the key to assess a better understanding of these deep-sea habitats (House et al., 2018).

The software packages that implement algorithms based on Structure-from-Motion (SfM) and point cloud densification using multi-view stereo (MVS), offer the possibility of creating advanced cartographic products, such as 3D models, of very

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high spatial resolution, in a fast and low cost way of the ocean floor (McCarthy and Benjamin 2014; Kwasnitschka et al., 2013). Based on photogrammetric techniques, successful studies have been carried out focused on the morphometric measurements of coral reefs (Bythell et al., 2001; Courtney et al., 2007; Burns et al., 2015a, 2015b; Lavy et al., 2015 and House et al., 2018). Ferrari et al. (2017) show that high-resolution 3D maps and derived metrics can predict a large percentage of variance in fish abundance. But the application of this methodology to deep-sea gorgonian population structure is still scarce today.

The geometrical structure of a gorgonian can consist of thousands of branches and polyps in complex arrangements. The structure contains a lot of useful information, as, what are the colonies orientations? How many branches have the colonies? Where are located the polyps on the colonies? These data can be used to assess habitat health and evolution along time. However, because of the immense complexity, capturing the structure of each gorgonian colony in an assembly is an almost impossible task.

Manual extraction in dive range of morphological information on large colonies, such as the number of branches or diameter of each node, is a difficult task. Using images, the characteristics of these input point clouds, or orthomosaics, are problematic. Usually data are almost always incomplete and suffer from significant self-occlusion. Besides, manual digitization over images or point clouds is a very time-consuming processing. In Royer et al. (2018) an automatic process for the extraction of morphological data is proposed. Applying skeletonization algorithms an analytic representation and shape of several colonies of red coral is extracted.

When the images, representing each gorgonian colony, are not enough detailedspatially, a complex skeletonization process cannot be addressed. Hence, the alternative is to look for simple geometric figures that retain as much as possible the most important geometric characteristics of the specimens (Palma et al., 2018). Although this approach is relatively common in the analysis of different trees in the forest field, there are very few works in this regard in marine habitats.

No studies involving the morphometries of plexaurids (Holaxonia: Plexauridae) populations have been developed in the Cantabrian Sea. To fill this gap, the goal of the present study is to validate a semi-automatic and non-invasive methodology to get an accurate determination of fan-surfaces of the colonies of a *Placogorgia* sp. gorgonian forest, and use them to assess population structure. This determination of morphometric measurements is made exclusively based on 3D reconstruction from underwater images.

2. MATERIAL AND METHODS

2.1 Study Area

El Cachucho fishing ground (also known as Le Danois Bank by the scientific community) is an extensive offshore bank and seamount with surrounding slopes and a complex system of channels and canyons (Fig.1). The bank and its intraslope basin (a sedimentary area between the bank and the Cantabrian Sea continental shelf) cover 234.000 ha. The management plan includes specific measures for fishing activities, oil exploration, minerals and military activity (BOE, 2011). Depths within the area vary from 425 to 4000 meters - an amazing diverse biological hotspot (Sánchez et al., 2008, 2017).

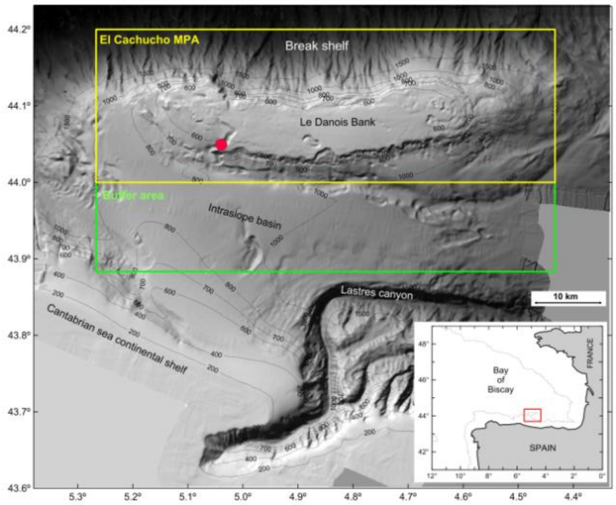

Figure 1. Location of "El Cachucho" MPA on the Bay of Biscay and some topographic features that characterize the area. The red circle shows the location of the gorgonian forest analysed on this study.

Placogorgia sp., a Plexauridae gorgonian coral originally identified as *Paramuricea* cf. *placomus* (Linnaeus, 1758) in Sánchez et al. (2017), is one of the most vulnerable species cited in the MPA of 'El Cachucho'. In this area, it grows as fan-shaped densely-branched colonies, and settles on rocky substrate bottoms in a depth range for this area from 500 m to 1000 m (Fig.2). The fan may very well exceed 1 m in diameter, and is usually spread out transverse to the dominating current direction (Wainwright and Dillon, 1969; Grigg, 1972).

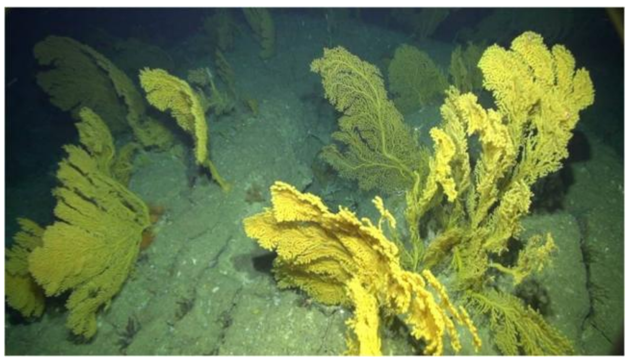

Figure 2. Example picture extracted from a video-sections that shows gorgonians and the rocky substrate at 528 m depth.

2.2 Survey description

The video transects analyzed in this study were acquired in Le Danois Bank during the ECOMARG-2017 survey, carried out with the RV Ángeles Alvariño, and using the ROTV (Remotely Operated Towed Vehicle) Politolana photogrammetric sled. The vehicle can be operated up to a maximum of 2000 m depth and transects were carried out navigating to 0.8-1.0 knot of speed at 2-4 m over the sea floor. This vehicle acquires simultaneously still pictures and HD video, and synchronized it with environmental variables.

Three video-transects were recorded in July 2017, with a FullHD video-camera (Sony HD-700-CX) and two LED light (12600 lumens / 6000 ° Kelvin). The system was equipped with 2 parallel laser beams separated by a constant distance of 20 cm. Absolute positioning of vehicle is provided by a Kongsberg HiPAP 502 Super (Ultra) Short Base Line (SSBL).

2.3 Photogrammetric reconstruction

Video-sections were decomposed in thousands of overlapping images with geo-position data attached; and processing was performed using photogrammetric Pix4D Mapper Pro software (Pix4D SA, Switzerland). Approximate values of image position and orientation provided by SSBL and Politolana telemetry system, are used in a bundle adjustment to reconstruct the exact position and orientation of the camera for each acquired image. The focal length, principal point and radial/tangential distortions were set as initial theoretical values and the bundle adjustment processing determines the final internal orientation parameters of the camera.

After a complete automatic integration of tie points measurements, camera calibration, geographic position data of cameras and dense image matching step, the software gives a 3D dense point cloud (Fig. 3). The distance between parallel lasers beams (20 cm apart) are used as a scale. This information is used to finely re-scale the project. The 3D point cloud is used to assess valuable information about gorgonian morphometric parameters.

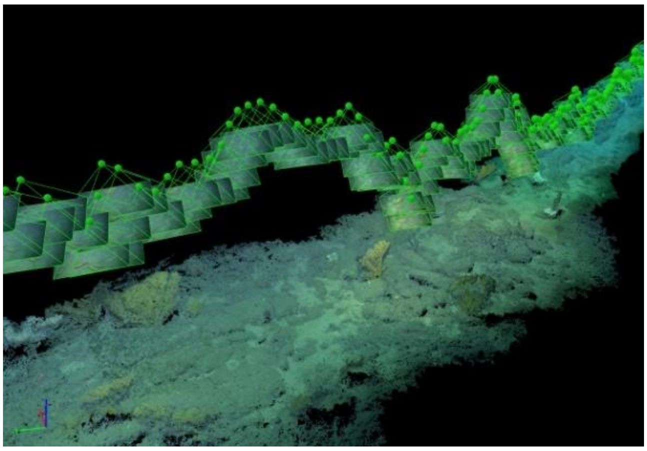

Figure 3. Example of 3D point cloud reconstruction of video transect.

2.4 Assessment of errors in geolocation and model reconstruction

Geolocation uncertainty is established by the characteristics of the USBL acoustic positioning system used to determine the absolute coordinates of the vehicle's trajectory. This uncertainty is a function of the angle and depth from vehicle to transducer installed in the ship hull. Then, sled's trajectory is recalculated according to specific uncertainty parameters in the bundle adjustment processing.

Constant distances between laser pointers projected on frames - not used in scaling- have been used to evaluation the relative geometric uncertainty of the 3D point. This way, error in measurements done over 3D point cloud is estimated. It is necessary to be careful selecting distances that have been projected on a flat ground.

The re-projection error calculated for the 3D model is also evaluated. This parameter can be used to validate the internal consistency of the model.

2.5 Fan-surface assessing and population structure

A key aspect of ecological studies on benthic organisms is the selection of the best morphological parameters for describing growth and architectural features. Mistri (1995) reviewed different parameters that had been used to study growth of another plexaurid octocoral, *Paramuricea clavata* (Risso, 1826), as height and width, branch length, skeleton rings diameter, etc.

Due to gorgonian structural complexity, and the fan-shape adopted, the use of height as morphometric descriptor of the size of the colonies has been rejected. Instead of measuring the length, the 3D fan area covered by each specimen was selected as a suitable parameter of colony size. Gorgonian fan surfaces of the colonies forming the assemblage are assessed.

Semi-automatic methodology that allow assess morphometric measures has been used. First, manual segmentation of gorgonian colonies has been done in the 3D cloud point to isolated individual point clouds. Then, a plane has been adjusted to each gorgonian colony using CloudCompare (CC) software. A 2D polygon (facet) tool has been used to fit a plane on each point cloud (Fig.4). The extents of the fitted planes follow the cloud contours. Similar methodology has been applied in Palma et al. (2018) to calculate the maximal height, maximal width and planar fan surface of gorgonian forest of *Paramuricea clavata*.

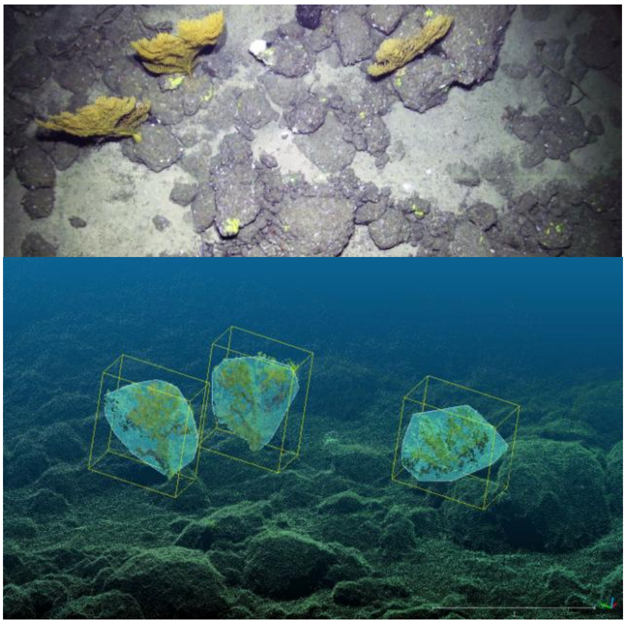

Figure 4. (Up) video frame with three colonies of *Placogorgia* sp. (Down) Planes fitted to assess gorgonian fan surface using CloudCompare semi-automatic process.

188 gorgonian fan surfaces have been assessed using this method; and from these surfaces, the size frequency distribution

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of the gorgonian population is represented. All specimens that have been fully reconstructed from the video-frames have been assessed.

2.6 Plane fitting and fan-surface values validation

Gorgonian point clouds are a 3D group of points that defines each *Placogorgia* colony but fan surface are approximate to 2D geometric figure, a plane. So, Root Mean Square RMS errors associated with the plane fitting relative to the 3D point clouds that defines each colony have been checked. In this way the suitability of choosing a simple surface (i.e. plane in this case) to adjustment of gorgonian colonies is verified. Low values in this field indicate that a plane can pick up the geometric characteristics of the gorgonian point cloud.

To validate the results, Pix4D software has been used. Since the colonies have different shapes, branches, orientations and curvatures, the irregular perimeter of each colony has been manually digitized on the 3D point cloud. Through this method, area enclosed in 47 gorgonian colonies perimeter is calculated (25% of the full sample). The surface is a sum of irregular planar triangles surfaces forming in the process of manual digitalization over the 3D point cloud (Fig. 5).

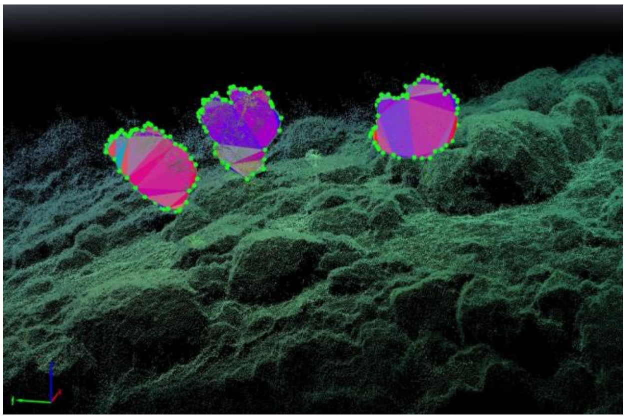

Figure 5. Gorgonian fan surface using Pix4D Mapper Pro software. Manual digitalization process and sum of linked triangles are used to assess the colony fan surface.

The estimated morphometries using this semi-automatic methodology were validated against the manual digitalized morphological truth dataset and a linear regression model performed to assess the accuracy of morphometries estimation. The direct measurement of this parameter is possible in a complete 3D model of the area.

3. RESULTS

3D point cloud was reconstructed from a video-transect in Pix4D Mapper Pro software. Trajectory reconstruction and automatic tie points extractions were performed, then re-optimize the model based on several scales obtained from parallel laser beans. Afterwards dense point cloud can be processed in high density mode. A total of 1085 images were used. The average of Ground Sampling Distance (GSD) is 0.27 cm, covering an extension of 0.1397 (ha). Median of keypoints per image and matches per calibrated image are 9533 and 2743 respectively. The number of 3D densified points in the point cloud generated contained more over 15 million points, with an average density per m^3 of 171.667 points.

3.1 Assessment of errors in geolocation and model reconstruction

The absolute uncertainty in geographic position can be achieved according to technical specification of USBL acoustic positioning system used to determine the coordinates of the vehicle's trajectory. An SSBL system measures the horizontal and vertical angles together with the range to the transponder, giving a 3D position projection of the transponder relative to the vessel. An error in the angle measurement causes the position error to be a function of the range to the transponder, so SSBL has an accuracy error that increases with range. Basically position error in the system used in this study is determined as position accuracy in 0.2% of range. Although this range varies along the video-sections, using the maximum depth we can approximate this position error as 0.20% of 650 m, obtaining a value of 1.3 m.

However, in this kind of study it is more important the uncertainty or relative error in the 3D reconstruction of the point cloud is more important than the uncertainty associated with absolute positioning. This error will be applicable to the measurements made on the 3D block. To calculate this error, 18 distances were measured between laser pointers and the Quadratic Mean Error was calculated, obtaining a value of 1.2 cm.

Mean reprojection error of the transect is 0.114 pixels. Reprojection error can be used as a robust indicator of internal consistency of the reconstructed model.

3.2 Fan-surface assessing and population structure

Fan surface (m^2) of 188 gorgonians were semi-automatic assessed from 3D point cloud using the plane fit tool of CloudCompare software. Colonies that have not been reconstructed in sufficient detail were discarded for analysis. The gorgonian surface results are grouped in classes and their frequency distribution (shape) calculated as an indicator of population structure (Fig. 6). The *Placogorgia* population was positively skewed, indicating the dominance of colonies less than 0.15 m^2 of fan surface.

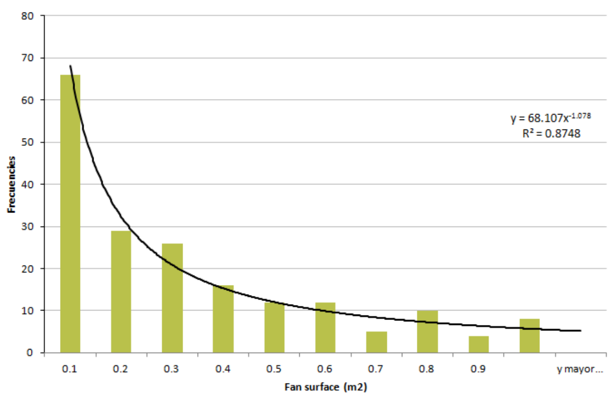

Figure 6: Histogram of fan surface area (m^2) distribution of *Placogorgia* sp.

A potential curve has been adjusted to the gorgonian size distribution, getting an $R^2 = 0.87$.

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The population structure shows a high proportion (~22%) of recruits (< 0.05 m2) for fan surface measurements. In general terms, the demographic structure of the population presents values close to a good health status, with a significant contribution of young colonies and a progressive decrease of abundance with respect to the colonies size.

3.3 Plane fitting and fan-surface values validation

Figure 7 shows the RMS values associated with the adjustment of a plane to each point cloud that defines a gorgonian colony. There are a majority of planes with very low RMS values; 58% of planes have an RMS below 0.03; average of calculated RMS is 0.03. High values of RMS occur in specimens whose morphometry does not fit a plane due to irregular growth of colony, or even to damage to its structure (i.e. split branches).

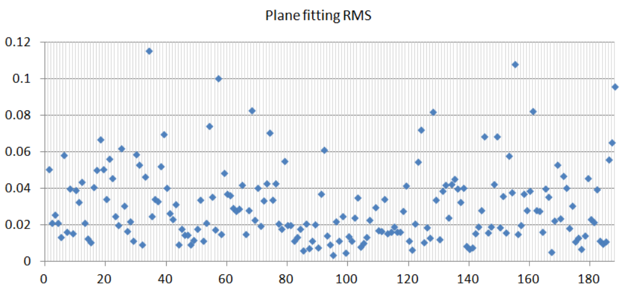

Figure 7: Plane fitting RMS of 188 gorgonian 3D point clouds

The difference between manual procedure based in the sum of planar triangles and semi-automatic method to adjust a unique fitting plane in 47 colonies was -0.134 m^2 and 0.059 m^2. Linear regression shows an adjustment of 0.97 for the R^2 value (Fig.8).

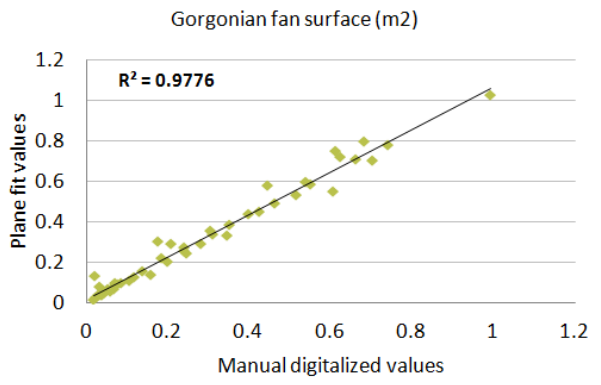

Figure 8: Correlation between *Placogorgia* sp. manual digitalized area in 3D point cloud and plane fit with semi-automatic tool

4. CONCLUSIONS

Photogrammetry represents a non-destructive, cost-effective tool for coral reef monitoring. This approach achieves greater resolution and quantitative measures, allowing the integration of information in a GIS environment. However, its application to deep-sea habitats is still in an early stage. The use of this methodological approach based on SfM techniques from images taken by a ROTV has allowed us to perform with accuracy and high resolution a population study of a gorgonian forest in the Cantabrian Sea bathyal ecosystem.

The need to increase spatial resolution of the measurements to define the morphometry of the gorgonians is clear; the problem lies in the complexity of the methodology to be used for the measurement of different parameters other than height. Structural complexity can be defined as the physical three-dimensional structure of an ecosystem; this 3D feature is the key to assess a better understanding of these deep-sea habitats (House et al., 2018).The determination of distribution of fan surfaces from high resolution method, represent a great advance in the study of gorgonian aggregations. The results obtained are crucial for the knowledge of the area and its relationship with other parameters of interest such as accompanying fauna, biodiversity, growth studies, EFH, etc.

The different orientations, curvatures, ramifications and forms of the colonies, together with their capacity for partial mortality, especially in large specimens, make length or height, clearly insufficient to define the gorgonian population structure. The possibility of relationship between morphometric and biological aspects of the specimens (age, feeding capacity, etc.) will depend on this morphometry description.

The utility of automatic algorithms is demonstrated. These methodologies must retain the shapes of target species; planes, cones, cylinders, etc. can be used. This improves the process of extracting information from the 3D point cloud and avoids tedious and time consuming manual digitization.

Segmentation algorithms and quality (density) of 3D point clouds must be improved too. This would allow morphologically complex specimens to be monitored. For this task it is important to use automatic algorithms of adjustments that use sum of small facets (Palma et al., 2018) or complex skeletonization algorithms (Royer et al., 2018).

This is the first time that the population structure of a *Placogorgia* species is studied with accuracy in the Cantabrian Sea at 500-600 m depth. This gorgonian together with *Callogorgia verticillata* (Pallas, 1766) are the main structural species of a deep-sea coral garden inside the MPA of El Cachucho. The morphometric measurements are made exclusively by a non-invasive methodology with very high spatial resolution and low uncertainty in the measurements, based on 3D reconstruction from underwater images.

In addition, studies of the population structure, carried out periodically, can be useful in monitoring environmental status of protected areas and in evaluating the effectiveness of management measures.

In the context of the Marine Strategy Framework Directive (MSFD; EC, 2008), the proposed method can improve the benthic habitats Good Environmental Status (GES) assessment by using benthic habitat indicators under descriptor 1 (Biological diversity) and descriptor 6 (Seafloor integrity), with potential implications on other descriptors.

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