Journal Pre-proof

Analysis of the population structure of a gorgonian forest (*Placogorgia sp.)* using a photogrammetric 3D modeling approach at Le Danois Bank, Cantabrian Sea

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Journal: Deep-Sea Research Part I

Comments from the editors and reviewers:

-Editors

- Dear Dr. Prado,

Thank you very much for submitting your manuscript to DSR I. As you will see, we have now received two reviews for your manuscript which both suggest that with some extra work it could be acceptable for publication. When preparing your revised manuscript, please consider carefully all of them.

Kind regards

Nikolaos Lampadariou

Associate Editor DSR I

PS please note both reviewers have provided annotated versions of your paper which are attached. The one with suffix PP is from reviewer#2. The other from reviewer #1. You should respond to these comments also.

Please find enclosed our revised manuscript. We thank the editor and two reviewers for their comments. We have revised the manuscript accordingly and provide specific answers below.

Please, you can find annotated versions of the paper attached. The one with suffix _rev1 is from reviewer#1. The other with suffix _rev2 from reviewer #2. You can find in there the answers of the reviewer's comments also. File with suffix _rev3_with_changes is the paper with all changes (reviewer#1 + reviewer#2) included with track changes. Finally, file with suffix _rev3 is the final version, (similar to _rev3_with_changes but without track changes).

-Reviewer 1

Thank you for your helpful comments and for taking the time to point out options to improve our manuscript. We have revised the manuscript following both reviewers' suggestions. We have revised our manuscript according to your comments and suggestions point by point (please see the revised manuscript and following answers). In the following, we reply (in standard font) to your comments (cited in blue italics font).

Please, you can find annotated versions of the paper attached. The one with suffix _rev1 is from reviewer#1. The other with suffix _rev2 from reviewer #2. You can find in there the answers of the reviewer's comments also. File with suffix _rev3_with_changes is the paper with all changes (reviewer#1 + reviewer#2) included with track changes. Finally, file with suffix _rev3 is the final version (similar to _rev3_with_changes but without track changes).

The manuscript submitted by Prado et al. explores the spatial distribution patterns of Placogorgia sp.,

Actually, the objective of the manuscript doesn't go into discussing the spatial distribution patterns of the *Placogorgia sp*., but focuses on studying the size structure of this aggregation, using a novel technique such as the 3D reconstruction based on Structure-from -Motion and photogrammetric approach.

which probably is the most common gorgonian species in Le Danois Bank.

Although the *Placogorgia sp*. is effectively one of the most common species of gorgonians in Le Danois Bank, its spatial distribution is very restricted. Despite the efforts of sampling and characterization of this MPA carried out in recent years (please see references below for details); this, is the only aggregation of *Placogorgia sp*. found to date. And although other specimens have been found, they are not considered to form a three-dimensional habitat given their isolation.

Sánchez, F., Serrano, A., Parra, S., Ballesteros, M., Cartes, J.E., 2008. Habitat characteristics as determinant of the structure and spatial distribution of epibenthic and demersal communities of Le Danois Bank (Cantabrian Sea, N. Spain). Journal of Marine Systems, 72, 64-86.

Sánchez, F., Serrano, A., Gomez-Ballesteros, M., 2009. Photogrammetric quantitative study of habitat and benthic communities of deep Cantabrian Sea hard grounds. Continental Shelf Research, 29, 1174-1188.

Sánchez, F., González-Pola, C., Druet, M., García-Alegre, A., Acosta, J., Cristobo, F.J., Parra, S., Ríos, P., Altuna, A., Gómez-Ballesteros, M., Muñoz-Recio, A., Rivera, J., Díaz del Río, G., 2014. Habitat characterization of deep-water coral reefs in La Gaviera canyon (Avilés Canyon System, Cantabrian Sea). Deep Sea Research II, 106, 118-140.

Sánchez, F., Rodríguez-Basalo, A., García-Alegre, A., Gómez-Ballesteros M., 2017. Hard-bottom bathyal habitats and keystone epibenthic species on Le Danois Bank (Cantabrian Sea). Journal of Sea Research, 130, 134-153.

While modest and simple in scope, the findings of this work are relevant to our understanding of the distribution of benthic suspension feeders based on two aspects.

First, the lack of studies published about the spatial patterns of this species in comparison to others Mediterranean gorgonians species.

Indeed, there is no similar study on the gorgonians size distribution nor morphometrics analysis on this or another species of gorgonian made in the Cantabrian Sea, due to its scarcity and the depth at which they are found (always below 500m).

And second, the lack of studies based on non-destructive sampling methods.

A study based on 3D reconstruction from images taken by underwater vehicles, gives it the advantage not only of covering the gap of non-invasive methodologies, but also taking a further step in image analysis and generating models 3D that allow to move from 2D measurements as a flat surface or length to 3D measurements made in a three-dimensional space. The 3D is an aspect of vital importance for this type of habitat in which the key is precisely the formation of three-dimensional habitats.

On the other hand, I think that there is a lack of statistical analysis that makes us better understand the distribution of Placogorgia.

The main objective of this study is therefore to establish a baseline study, a reference status of the population in terms of its 3D size structure, which can be used in the future as a reference for comparisons with existing populations under similar conditions in other areas or to monitoring along the time this gorgonian aggregation.

This is the first time that this population structure has been described. There is no aggregation under similar conditions. A statistical analysis is carried out to describing sizes, based on a novel parameter such as the 3D fan's surface of the specimens.

The study area is small, about 250 meters long and 10 meters wide (5 meter each transect). The approximately 500 colonies are geo-located and in the presented maps their spatial distribution can be observed through a visual analysis. But in this review and taking into account the reviewer’s suggestion, the spatial statistical analysis to explain the distribution of gorgonians (Ripley’s K function), has been added to the manuscript.

Below you can find some suggestions to improve this. More comments are on the word file.

Introduction

1 There is a paper that used almost the same technique that is not cited in the text: A new 3-D-modelling method to extract subtransect dimensions from underwater videos L. Fillinger and T. Funke Ocean Sci. Discuss., 9, 3879–3917, 2012

I have included it in this new version.

M&M and Results

2 Did you recorded more video transects in Le Danois Bank or only this 2? And why did you sample two times in the same area?

Le Danois Bank or El Cachucho MPA has a length of about 72 km in an east–west direction and about 15 km wide from north to south. In the space of only a few miles the depth changes from 500 m at the top of the Bank to over 4500 m at the Biscay abyssal plain. In this MPA there are numerous transects that have been made through various research cruises along the last years. These images and other type of data favored that this area was declared as the first Marine Protected Area of Spain. Unfortunately, not all image transects have quality enough to apply Structure-from-Motion algorithms and achieve 3D reconstruction, and the most of them are used to a visual interpretation.

In the study area, where most of the specimens of *Placogorgia sp*. are concentrated, there are five transects, recorded in 2014 and 2017. For this study we have selected the 2 transects using two selection criteria:

- Transects that cover the area of interest. It is not possible cover the entire gorgonian aggregation with only one transects because the swath of the images is not enough.
- Transect over gorgonians aggregation that have quality enough for application of this complex 3D methodology.

3 Is there a correlation between size and fan area?

It is expected that there is a relationship in most cases. But due to that gorgonians feeding capacity resides precisely in the filtering surface and their filtering surface depends on different forms, curvatures and ramifications of the colonies; we have decided to use the 3D area, as the most appropriate parameter in the description of sizes of this population.

4 It would be interesting to know if the distribution of Placogorgia sp. is random, clumped or regularly distributed along the transects. The statistical analysis to do that is called Ripley's K.

As the reviewer suggests, it is possible to apply some type of statistical analysis that reveals the type of spatial distribution adopted within this aggregation. The statistical analysis and the result of Ripley's K function have been included in the new version of the manuscript.

5 Is there any difference on the distribution and population structure between the two transects?

No, the results are consistent between transect. It is the same area, same gorgonian aggregation and the use of two transects is because it is not possible cover the entire gorgonian aggregation with only one transects because the swath of the images is not enough.

6 Along both transect you measure some environmental factors like slope, aspect, rugosity, curvature, etc. and also temperature and salinity. It would be interesting to see which are the factors that affect the distribution of Placogorgia along both transects by means A Canonical correspondence analysis.

Certainly, physical variables of sea-water, such as temperature and salinity, are indeed measured using a CTD attached to the ROTV. Unfortunately, in our opinion, the use of these physical parameters measured at a given time shouldn't be addressed to model the spatial distribution in our case, as long as the variability during the year, month, or even a tide period is too broad to be useful in such a small place. As for the geological variables, canonical analysis and predictive models (GAMs or MAXENT) have been carried out at a regional scale, modeling the entire MPA (Sánchez et al., 2017). Besides that, this study covers a very restrictive area with similar slope, BPI and depth than in surrounding areas where this species is absent, so there must be some other factors like fishing pressure or small scale currents, or any other determinant factor that we are not able to detect at this scale.

Sánchez, F., Rodríguez-Basalo, A., García-Alegre, A., Gómez-Ballesteros M., 2017. Hard-bottom bathyal habitats and keystone epibenthic species on Le Danois Bank (Cantabrian Sea). Journal of Sea Research, 130, 134-153.

Discussion

7 Try to go more beyond descriptive aspects and establish sound comparisons with previous relevant studies especially in the discussion.

Ok. I have tried to improve some aspects in the Discussion section.

8 There are many sentences like (line 372-374) I suggest to change the sentence and add the reference at the end of the sentence.

From this

In Gutierrez-Heredia et al. (2015) and more recently, in Royer et al. (2018), a skeletonization process was proposed to measure and quantify morphometries as complex as those of Mediterranean red coral colonies automatically.

To this

A skeletonization process was proposed to measure and quantify morphometries as complex as those of Mediterranean red coral colonies automatically (Gutierrez-Heredia et al. 2015; Royer et al. 2018).

Ok. I have improved them.

References

9 Homogenize the references format. Species in italics and abbreviations of the journals etc.

Ok.

-Reviewer 2

- Dear authors,

i was really enthusiastic when i received your manuscript and read the topic, as non-destructive methods are also in my primary interests of research. It is necessary to introduce this methods in the list of the accepted and standardized methods within the major international frameworks of research and environmental protection. The most effective way to make non-destructive, especially photogrammetry-based, methods stand out, to policy-maker agencies also, is to offer examples of their real application.

In your case, you highlight some major features of an assemblage, the Le Danois Bank gorgonian forest, stil under-studied, not well described from many point of views.

In this sense, your work is twice usefull: i) to describe a new aggregation and a vulnerable habitat, and ii) to underline the effectiveness of an emerging methods that should be adopted in order to preserve this kind of areas hosting such unique biota.

My revisions are all minor suggestions, to add or change some word or information, and i hope that they will be useful to improve the final version of the article. You will find everything directly in the revised word file that i attached here.

Let me know if there is something that you don't accept in my revision and why, or if you need more clarifications...It is also a very good occasion for me to compare points of view about this urgent and relevant topic and to learn more about other colleagues work.

Thank you for your contribution to deep Cantabrian benthos dynamic understanding,

Best wishes.

Thank you for your helpful comments and for taking the time to point out options to improve our manuscript. We have revised the manuscript following both reviewers' suggestions. We have revised our manuscript according to your comments and suggestions point by point (please see the revised manuscript).

Please, you can find annotated versions of the paper attached. The one with suffix _rev1 is from reviewer#1. The other with suffix _rev2 from reviewer #2. You can find in there the answers of the reviewer's comments also. File with suffix _rev3_with_changes is the paper with all changes (reviewer#1 + reviewer#2) included with track changes. Finally, file with suffix _rev3 is the final version (similar to _rev3_with_changes but without track changes).

Analysis of the population structure of a gorgonian forest (*Placogorgia sp.)* using a photogrammetric 3D modeling approach at Le Danois Bank, Cantabrian Sea

Abstract:

The presence of gorgonian forests and deep-sea sponge aggregations in the Le Danois Bank promoted its declaration as the "El Cachucho" Marine Protected Area (MPA) by the Spanish Ministry of Environment, and its inclusion in the Natura 2000 network. Both habitats are considered vulnerable, so follow-up surveys are being performed to monitor their conservation in compliance with the EU Habitats Directive. The use of a non-invasive methodology, which does not cause damage or alterations on benthic communities, is particularly necessary in vulnerable ecosystem studies and MPA monitoring.

This study analyzed the assemblage structure of a *Placogorgia* sp. population using a 3D photogrammetry-based method. The study was carried out through the analysis of the video transects obtained at the Le Danois Bank, using the *Politolana* underwater towed vehicle during the July 2017 ECOMARG survey. Recent developments in specific software of photogrammetric image analysis allowed extracting valuable information from these video transects. Using the Pix4D Mapper Pro software, 3D point clouds were obtained, and the size and morphometry of yellow fan-shaped gorgonian population structure could be evaluated. Due to gorgonian's high structural complexity, the use of length (i.e. height) as the morphometric descriptor of the real size of the colonies is not appropriate. Instead of length, the fan surface area covered by each gorgonian colony was selected as a suitable parameter of size. The direct measurement of this parameter was possible through a complete 3D reconstruction of the gorgonian forest.

A total of 426 colonies of *Placogorgia* sp. were digitalized to obtain surface measurements and fan spread orientation calculations in 3D models. The results show that gorgonian populations were mostly composed of a high proportion of small colonies (0-0.10 m^2). The population structure distribution shows a high proportion (~27%) of recruits (< 0.05 m^2) and also many (19%) large colonies (> 0.5 m^2). In 78% of the gorgonian colonies, facing angles were grouped inside the first quadrant (0º-90º), in accordance with the main current direction in this zone. Colony distribution and fan orientation inside the gorgonian forest can be used as data sources to improve monitoring and management programs of these unique habitats in MPAs.

Keywords: Placogorgia, gorgonian forest, Underwater photogrammetry, 3D models, Marine Protected Areas monitoring, Le Danois Bank, Structure from Motion (SfM)

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1. Introduction

Gorgonian forests conform complex three-dimensional habitats for many species, concentrating high biodiversity values in the ocean (Krieger and Wing, 2002; Buhl-Mortensen et al., 2010; Bongiorni et al., 2010; Cerrano et al., 2010; Miller et al., 2012; Ponti et al., 2016). Gorgonians and other corals are damaged by bottom-contacting fishing gear and often end up as bycatch on fishing vessels (Krieger, 2001; Fosså et al., 2002; Hall-Spencer et al., 2002; Althaus et al., 2009; Clark et al., 2010; Bo et al., 2014; Rooper et al., 2017). Their weak ability to recover from damage is mainly due to their slow growth rates (Andrews et al., 2002; Sherwood and Edinger, 2009; Doughty et al., 2014). Thus, a suitable management and regulation of fishing activities and other anthropogenic disturbances are crucial for areas where gorgonians aggregations are located. Their importance as biodiversity hot-spots in the deep-sea and their high vulnerability to disturbances have forced the establishment of national and international policies to protect coral gardens in the deep-sea in the last decade. OSPAR's definition of the habitat "Coral Gardens" describes it as a relatively dense aggregation of colonies or individuals of one or more coral species occurring on a wide range of soft and hard seabed substrata. Hard-bottom coral gardens are often found to be dominated by gorgonians, stylasterids, and/or black corals (ICES, 2007). Gorgonian assemblages are also included in the EU Habitats Directive 92/43/EC (EC, 1992) as components of the "1170 Reefs" habitat. The large gorgonian coral find among of species groups, communities and habitat-forming species that may contribute to the forming of Vulnerable Marine Ecosystems (VMEs) in the North Atlantic. The VME concept emerged from discussions at the United Nations General Assembly (UNGA) and describes groups of species, communities, or habitats that may be vulnerable to impacts from fishing activities. Protecting and restoring deep-sea coral gardens is considered crucial from the environmental perspective, but also because the sustainability of some commercial fisheries depends on their prevalence. Many protected areas are considered Essential Fish Habitats (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 a good environmental status of the ocean (Lindeman et al., 2000; Rieser, 2000; Friedlander, 2001).

There are many studies about diversity, distribution and state of conservation of gorgonian assemblages in coastal areas and in the photic zone. These works have been carried out within scuba diving depth ranges (~40 m depth), and mainly in the Mediterranean area (Harmelin and Marinopoulos, 1994; Linares et al., 2008; Kipson et al., 2015). Knowledge about offshore gorgonian assemblages is less developed. In the deep-sea, assessing gorgonian population structure, i.e. specimen size frequency distribution can be achieved using extractive sampling techniques and applying functions to model the population structure (Bak and Meesters, 1998; Meesters et al., 2001). More recently, un-invasive techniques based on underwater vehicles have become key tools for this type of studies all over the world (Mortensen and Buhl-Mortensen, 2004, 2005; Gori et al., 2011a; Grinyó et al., 2016; Ambroso et al., 2017).

The presence of deep gorgonian forests at Le Danois Bank was decisive for its declaration as "El Cachucho", the first off-shore Spanish Marine Protected Area – MPA (Spanish Ministry of Environment, BOE 2011), which immediately became part of the Natura 2000 Network as a Special Area of Conservation (SAC). To effectively 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). The El Cachucho MPA has been the subject of numerous studies and surveys in recent years to evaluate its habitat distribution (García-Alegre et al., 2014; Sánchez et al., 2017), but developing methodologies to determine the conservation status and population structure of vulnerable habitats is still necessary. Besides, the response of these habitats to protection and the effectiveness of the managing measures applied in the area have to be monitored too.

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 at El Cachucho MPA (Sánchez et al., 2008, 2009, 2017). It forms fan-shaped colonies and settles on rocky substrate bottoms in depth ranges from 500 to 1000 m. The fan may very well exceed 1 meter in diameter, and usually spreads transversally to the dominating current's direction (Wainwright and Dillon, 1969; Grigg, 1972), to maximize the volume of water flowing through the polyps, and thus increasing their access to food.

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 obtain a better understanding of these deep-sea habitats (Burns et al., 2015a; House et al., 2018). In this way, if the studies are carried out in shallow depths, in-situ measuring with divers is usual. However, obtaining parameters such as the area covered by each specimen, the occupied volume or orientation is difficult when diving without altering the coral gardens or even destroying some specimens.

In deep-sea studies the use of ROVs and other underwater vehicles has become common practice, in studies focused on geomorphology or geological processes (Obelcz et al., 2014; Embley and Rubin, 2018) or deep reefs of cold-water coral (Van den Beld et al., 2017). These vehicles are usually equipped with different data acquisition systems based on acoustic and image technologies, lighting systems, and CTD probes. Until a few years ago, the exploitation of optical information (videos or photographs) was based on visual analyses by an expert and the ability to accurately synchronize and geolocate the identified species, biophysical data of the water and visual analyses of the substrate (Sánchez et al., 2009; Neves et al., 2014; Bulh-Mortensen et al., 2015a, 2015b). The importance of the use of non-destructive methodologies for the study of vulnerable species is clear both in shallow and deep-sea habitats. Recent advances in fields such as photogrammetry and virtual reality, together with improvements in computer analysis capacity, have made it possible to apply a new approach: the 3D modeling of the study area. In near-shore areas, photogrammetry could be a pivotal tool to reduce the impact of sampling activities based on SCUBA divers operations. On the other hand, in deeper areas, not achievable by divers, it is necessary to have alternative tools to measure and sampling, thus, again photogrammetry could became one the preferable ones. Thus, by using advanced photogrammetric reconstruction techniques in deep-sea benthic habitats studies, it is now possible to generate 3D models and use them for quantitative analyses improving our ability to study coral gardens.

The algorithms based on Structure-from-Motion (SfM) use the massive identification of common points in numerous overlapping images taken along a trajectory by a vehicle in motion (Westoby et al., 2012; James and Robson, 2012). This photogrammetric approach offers the possibility of creating advanced cartographic products of the ocean floor, such as 3D models of very high spatial resolution, in a fast and low cost way (Kwasnitschka et al., 2013; McCarthy and Benjamin 2014).

Recent research uses photogrammetric reconstruction to evaluate habitat structural complexity (Ferrari et al., 2016; Priece et al., 2019) and successful studies having been carried out to obtain morphometric measurements of coral reefs (Bythell et al., 2001; Cocito et. al., 2003; Courtney et al., 2007; Burns et al., 2015a, 2015b; Lavy et al., 2015; House et al., 2018). Some approaches use this technique to map areas which are particularly difficult to sample such as habitats located on vertical walls (Robert et al., 2017) or the Antarctic benthos, using videos produced during under-ice dives (Piazza et al., 2018). This methodology has also been used for growth studies in coral colonies (Bennecke et al., 2016; Ferrari et al., 2017; Neyer et al., 2018). Studies that determine the uncertainty that can be associated with morphometric measurements (Figueira et al., 2015; Guo et al., 2016) and uncertainties associated with multitemporal studies based on SfM show promising results (Bryson et al., 2017; Raoult et al., 2017) but the application of this methodology to deep-sea gorgonian population structure is still scarce.

Studies on population structure, abundance or distribution patterns of Plexauridae gorgonians have been carried out in the Mediterranean Sea (Harmelin and Marinopoulus, 1994; Linares et al., 2008; Gori et al., 2011a; Bo et al., 2012; Grinyó et al., 2016; Palma et al., 2018) and in the North Atlantic (Buhl-Mortensen and Buhl-Mortensen, 2014). These studies deal mainly with a few shallow-water abundant species of the genus *Paramuricea* (closely related to *Placogorgia*), studies on deep-water ones (i.e. beyond scuba reachable depths) being uncommon and at a large scale of distribution (see for instance Buhl-Mortensen et al., 2015a, *Paramuricea placomus*).

No analyses of the structure of populations of plexaurids have been developed in the Cantabrian Sea. To fill this gap, the objective of the present study is an accurate determination of population structure of the *Placogorgia* sp. gorgonian forest at El Cachucho MPA. The obtaining of morphometric measurements was made exclusively by a high-resolution non-invasive methodology with a low uncertainty, based on a 3D reconstruction from underwater images. 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 for other descriptors.

2. Materials and methods

2.1. Study area

The El Cachucho fishing ground (also known as Le Danois Bank by the scientific community) is an extensive offshore bank and seamount surrounded by slopes and a complex system of channels and canyons (Fig.1). From the hydrographic point of view, Le Danois Bank is located at the depth that corresponds to the area of transition between the masses of North Atlantic central water (NACW, up to 500 m, where there is relatively minimal salinity), and the saline Mediterranean Outflow Water (MOW, whose main nucleus is between 800 and 1100 m depth). The area of the continental slope of the Cantabrian Sea seems to be in general critical to the mixing of water masses through isopycnals, which is why the topographic anomaly formed by Le Danois Bank favours the mixing of these water masses (Fiuza et al., 1998; Van Aken, 2000). The topographical effects of the Bank on the general current dynamic of the Cantabrian Sea, predominantly in a W–E direction, as in the case of the slope current (winter poleward current) or the Mediterranean water flow, have a very important role in sedimentation processes and the systems of production of the ecosystem. The current regime reaching the Bank is more intense than if it were a seamount in the open ocean. The bank and its intraslope basin (a sedimentary area between the bank and the Cantabrian Sea continental shelf) declared as El Cachucho MPA (Heredia et al., 2008) covers 234.000 ha. Depths within the area vary from 425 to 4000 meters, and several studies confirm it as a biodiversity hotspot in the Cantabrian Sea (Sánchez et al., 2008, 2017). The area's management plan includes specific measures for fishing activities, oil exploration, minerals and military activity (BOE, 2011).

The gorgonian forest is seated in a hard bottom seamount located in the south-west of the bank (Fig. 1). Its bathymetric range covers from 500 to 600 meters of depth and occupies a surface of 2.88 ha. In this area, the gorgonian colonies are fan shaped, and grow at different densities, curvatures and with varying number of branches (Fig. 2).

2.2. The *Placogorgia* species

In our present state of knowledge, the identity of the species analyzed here is difficult to elucidate although additional taxonomic and genetic studies are ongoing and will be discussed elsewhere in a taxonomic paper. The studied samples show affinities with two genera within the family Plexauridae, *Paramuricea* and *Placogorgia*. We have attributed them to the latter genus based on morphological analyses and comparison with several other Cantabrian specimens of both genera.

Six are the species of *Placogorgia* known from the northeast Atlantic and the Mediterranean Sea (Grasshoff, 1977). Five of them are known from the Bay of Biscay, although only three have been found in the southern sector: *P. coronata* (Carpine and Grasshoff, 1975), *P. graciosa* (Tixier Durivaut and d'Hondt, 1975) and *P. massiliensis* (Carpine and Grasshoff, 1975). Most species are rarely collected; they are poorly known animals and the genus needs revision (Poliseno et al., 2017). Little is known about their variability, and illustrations of long series of sclerites have been never published. However, it has been suggested that variability within the genus is presumable high, three of the recorded species probably being variants of a single one (Brito and Ocaña, 2004). Unfortunately, the contribution of genetics to differentiate among species has not been effective, not even to discriminate between *Placogorgia* and *Paramuricea* with certitude (McFadden et al., 2011; Poliseno et al., 2017), species belonging to both genera occurring in the same clades. For these reasons, a sound species identification is still pending. Despite these uncertainties, the Le Danois bank habitat-forming gorgonian has affinities with *P. graciosa*, and particularly with its anthocodial sclerites (Grasshoff, 1977; Taboada et al., 2019).

2.3. Survey description

The video transects analyzed in this study were obtained at Le Danois Bank during the ECOMARG-2017 survey, using the ROTV (Remotely Operated Towed Vehicle) *Politolana* photogrammetric sled on board the RV Ángeles Alvariño, (Fig. 3). The ROTV *Politolana*, designed by the Santander laboratory of the Spanish Institute of Oceanography (IEO), is a robust submarine towed vehicle designed to study the deep-sea floor using photogrammetric methods. The vehicle can be operated down to a maximum of 2000 m depth. In this case, transects were carried out navigating at a 0.8-1.0 knot speed at 2-4 m over the sea floor. The sled has bidirectional telemetry to control the submerged instruments (altimeter, CTD probe, compass, video and still cameras control, etc.) and sends data to the surface in real time. This vehicle acquires both still pictures and HD videos simultaneously, synchronizing them with measurements of the existing environmental conditions (Sánchez and Rodríguez, 2013).

Two video-transects were recorded in July 2017 using a FullHD video-camera (Sony HD-700-CX) and two LED lights (12600 lumens / 6000 ° Kelvin). The system was equipped with 2 parallel laser beams separated by a constant distance of 20 cm. This distance provides a method to scale and validate the resulting model. In addition, the system acquires synchronized data on pressure, temperature and salinity (conductivity) with a CTD-SeaBird 37.

Absolute positioning of the vehicle is provided by a Kongsberg HiPAP 502 Super (Ultra) Short Base Line (SSBL). This fully omni directional system can be pointed in any direction below the vessel, as the transducer has the shape of a sphere and an operating area of 200°. The ROTV is positioned by an acoustically operating transponder. An *ad hoc* designed software performs synchronization of data in real-time. An Ocean Floor Observation Protocol – OFOP software (Huetten and Greinert, 2008) processes the observation files subsequently and merges them with additional sensor data, which are corrected for space and time offsets and finally splined producing a complete data set for each individual deployment.

The video transects analyzed in this study were two parallel lines: TV18 and TV19 (Fig. 4). The analyzed sections were about 250 meters long and ran close to the top of the seamount. The footprint on the floor was around 5 meters wide; this imaging swath varies depending on the height of flight over the seabed and its topography.

2.4. Photogrammetric reconstructions

Video-sections were decomposed in thousands of geo-positioned overlapping images processed using photogrammetric Pix4D Mapper Pro software (Pix4D SA, Switzerland). This software carries out an advanced automatic triangulation based purely on image content and an optimization technique. The triangulation algorithm is based on binary local key points, searching for matching points by analyzing all images. Those matching points, as well as approximate values of image position and orientation provided by the *Politolana* telemetry system, are used in a bundle adjustment to reconstruct the exact position and orientation of the camera for every acquired image. For this study, the focal length, principal point and radial/tangential distortions were set as initial theoretical values, while the final internal and exterior orientation parameters of the camera were determined by bundle adjustment processing. The distance between parallel lasers beams (separated 20 cm) is used as reference scale. A total of 9 scales are used to fine re-scale the project.

Pix 4D software also uses a modern approach from computer vision science: dense image matching, an automated process based on dense image matching technology (Tola et al., 2010). With this complete automated integration of tie point measurements, camera calibration, and the position data given by the cameras, the software provides 3D dense point clouds (Fig. 5), Digital Surface Models (DSM) and orthomosaics (Fig. 6). The products derived from the sea floor's morphology, such as maps of slope, aspect, rugosity, curvature, etc. can be extracted from the DSM in a simple way. Since all the information is geo-referenced in a cartographic system (UTM-WGS84), all the geographic layers obtained can be included in a GIS environment.

The 3D point cloud is a cartographic product that contains coordinates (XYZ) of the points and color information, allowing the subsequent morphometric analysis.

2.5. Assessment of errors in geolocation and model reconstruction

Absolute accuracy in the geographic positioning of the points in the 3D point clouds depends on two aspects. Firstly, accuracy is established by the characteristics of the SSBL 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 the vehicle to the transducer installed on the ship's hull. Then, the sled's trajectory is recalculated according to specific uncertainty parameters during bundle adjustment processing.

Absolute uncertainty in geographic position can be achieved according to the technical specifications of the SSBL acoustic positioning system used to determine the coordinates of the vehicle's trajectory. An SSBL system measures the horizontal and vertical angles, as well as their range to the transponder, giving a 3D position projection of the transponder relative to the vessel. An error in angle measurements causes the error in the positioning to be a function of the range to the transponder, so SSBL has an accuracy bias that increases with range.

Constant distances between laser pointers projected on the frames -not used in scaling- were used to evaluate the reconstruction of the geometric model. In this way, the geometric uncertainty of the model and errors associated to measurements over the 3D point cloud were 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 was also evaluated. Once the 3D coordinates of the point were computed, the 3D point was re-projected on all the images where it appeared. The distance between the marked and the re-projected point on each image was the re-projection error (Fig. 7). This parameter could be used to validate the internal consistency of the model.

2.6. Population structure

2.6.1. *Population Size Frequency*

The size of the colonies forming the assemblage was measured. Deep-sea gorgonian forests set up a complex three-dimensional habitat. Instead of a length measurement, the 3D fan area covered by each specimen was selected as a suitable parameter of colony size. This surface is considered to be more representative of the biophysical parameters of the specimens, such as biomass, age, number of polyps, and feeding capacity. The direct measurement of this parameter is possible using a complete 3D model of the area. Using the Pix4D software, the area enclosed within each gorgonian's perimeter was calculated. Since the colonies have different shapes, branches, orientations and curvatures, the irregular perimeter of each colony was manually digitized on the 3D point cloud (Fig. 8). Thus, the total surface calculated is a sum of the irregular planar triangular surfaces formed during the digitalization process over the 3D point cloud (Fig. 9). The size frequency distribution of the gorgonian population was represented using these calculated surfaces. All specimens that could be fully reconstructed from the video-frames were digitalized. The fan surfaces data are grouped in 21 categories in a histogram, with a range of $0.05 m^2$.

Specimens with a surface smaller than $0.05\ m^2$ were considered as population recruits. This threshold was established based on the 3D methodology's resolution, since these are the histogram group of smaller colonies that can be digitalized. In Bennecke et al. (2016), colonies of *Paragorgia arborea* (Linnaeus, 1758) and *Primnoa resedaeformis* (Gunnerus, 1763) whose heights, measured on the 3D point cloud, were under 23 cm were also considered recruits, but there is no similar threshold for fan surface.

2.6.2. *Demographic parameters (density, impacts and orientation)*

The total number of colonies and the 3D surface covered by the video transect were calculated, so density (number of colonies per m2) was directly obtained for the study area. Since each sample was geo-located, both colony density and maps with the geographic distribution of these colonies could be obtained.

To analyze the spatial pattern of gorgonian distribution into this area, the multi-distance spatial cluster analysis is used. This approach is based on Ripley's K-function. A distinguishing feature of this method is that it summarizes spatial dependence (feature clustering or feature dispersion) over a range of distances. So, the selection of an appropriate scale of analysis is required. When exploring spatial patterns at multiple distances and spatial scales, patterns change, often reflecting the dominance of particular spatial processes at work. Ripley's K-function illustrates how the spatial clustering or dispersion of feature centroids changes when the neighborhood size changes.

To evaluate possible impacts on the coral populations, specimens that appeared dead in the study area were quantified and geolocated. Among the specimens quantified there were whole colonies (Fig. 10a) and fragments of different sizes (Fig. 10b) scattered along the coral assemblage studied. All were counted and geolocated in the orthomosaic images.

The orientation of the gorgonian colonies was measured taking into account the scheme shown in Fig. 11. The fan usually spreads out transversally to the direction of the dominating current. In this way, it can maximize the volume of water flowing through it. Smaller colonies were not considered in this analysis since their shape and orientation was not defined. Both shape and orientation seem to develop with increasing colony size (Mortensen and Buhl-Mortensen, 2005). In order to know the direction and strength of the water current in the area we used the information of a lander deployed in June 2014 and located 550 m east of the gorgonian forest at a 600 m depth. We used data of an Aquadopp single-point current meter located in the lander in order to record the horizontal near-bottom (ca. 2 m above the bottom) current. It was programmed at 1-minute intervals taken as 30’ burst-sampling periods (Sánchez et al., 2014).

3. Results

Individual 3D models were reconstructed for each video-transect. Trajectory reconstruction and automatic tie point extractions were performed, and a re-optimization of the model based on scales obtained from parallel laser beams was conducted. From these measurements, dense point clouds can be processed afterwards in high density mode. A basic description of the characteristics of the 3D point cloud processing conducted here is shown in Table 1. A total of 2234 video-frames were processed covering a median of 1500 m^2 per transect.

3.1. Assessment of errors in geolocation and model reconstruction

Absolute uncertainty in geographic position based in the SSBL system was determined as position calculation accuracy in the 0.2% range. Although this range varies with each the video-section, using maximum depth allows approximating this position’s error as 0.20% of 650 m, which gives a value of 1.3 m.

But in this study, more important than the uncertainty associated with absolute positioning is the uncertainty or relative error in the reconstruction model. This error is afterwards applicable to the measurements made on the 3D block. To calculate this error, 18 distances were measured between laser pointers (not used in scaling) and the Quadratic Mean Error was calculated, obtaining a value of 1.2 cm.

The reprojection error depends on the camera’s calibration quality, as well as on the quality of marked Ground Control Points (GCPs) on the images, and can be used as a robust indicator of internal consistency of the model. The mean reprojection error in pixels of both transects TV18 and TV19 was 0.114.

3.2. Gorgonian population structure

3.2.1. *Population size and status*

Analyzing the two transects and taking into account the measured gorgonians, a population density of 0.15 colonies per m2 was calculated. The photogrammetric approach used in this study allows not only to obtain an average density of specimens, but also to position them on an orthomosaic of the area. In this way, the geographical distribution of the specimens can be cartographically represented, a greater density of colonies being observed in the south-east part of the transect (Fig. 14), reaching a density in this last part of transects of 0.21 colonies per m2. The southeastern part of the study area is exclusively covered by a rocky substrate and has a much steeper slope. At the end of transects there is an abrupt topographical descent and it is precisely in this area, steep and more exposed to currents, where the largest density of colonies of this aggregation occurs (Fig. 2).

To analyze the spatial pattern of gorgonian position into this area, the multi-distance spatial cluster analysis based on Ripley's K-function is used. The number of distances to evaluate is fixed to 20, starting distance is 0.25 meter and distance increment is 0.5 meter. With this information, the statistics computes the average number of neighboring features associated with each feature; neighboring features are those closer than the distance being evaluated. As the evaluation distance increases, each feature will typically have more neighbors. If the average number of neighbors for a particular evaluation distance is higher than the average concentration of features throughout the study area, the distribution is considered clustered at that distance.

Both transects present observed K values higher than expected below 10 meters of distance. So, at this scale of analysis, the distribution of the specimens is considered clumped. Beyond 10 meter, the observed K value is smaller than expected, so the distribution is more dispersed than random (Fig. 13).

Dead colonies and broken fragments present in the area were also counted. A total of 103 dead colonies scattered over the sea bottom were counted. As in the case of the living colonies, these dead colonies were geographically positioned and can be represented by their superposition in an orthomosaic of images (Fig.14). The highest number of dead specimens was located in the northwestern area. Dead colonies included both complete colonies of a considerable size and fragments of different proportions.

3.2.2. *Morphometrics and demographic characteristics*

A total of 426 gorgonian colonies were digitalized for fan surface measurements (m^2) in the 3D models using a surface draw tool in Pix4D software. Colonies that were not reconstructed in sufficient detail were discarded from this analysis. The gorgonian size frecuency distribution was unimodal. The *Placogorgia* sp. population was positively skewed, indicating a dominance of colonies less than 0.15 m^2 in fan surface. Gorgonian surface results were grouped in 21 categories in a histogram, with a range of 0.05 m^2 per bin and their frequency distribution (shape) calculated as an indicator of population structure (Fig. 12).

A logarithmic function was adjusted to the gorgonian fan-surface distribution, obtaining an $R^2 = 0.84$.

The population structure also showed a high proportion (~27%) of recruits (< 0.05 m^2), and a considerable proportion (19 %) of large (> 0.5 m^2) colonies.

3.2.3. *Orientation and growth of sea fans*

A high percentage of the colonies of *Placogorgia* sp. identified in the area show a slightly concave shape and present a specific orientation. Polyps of cnidarians are extending mainly from the concave side and feed from the turbulent, slower water on the concave side in unidirectional flow (Mckinney and Jackson, 1989). The orientation of 393 colonies was measured. The distribution per quadrants indicated that 100% of the colonies were oriented facing a range between 0 and 180º. Of these, 78% of the colonies were facing an orientation within the first quadrant (0º-90º), and among them, 38% of the colonies were oriented between 0º-45º, and 40% of the colonies between 45º and 90º (Fig. 15).

The near-the-bottom current direction obtained through a lander located just 500m east of the gorgonian forest showed a predominant Eastward flow (Fig. 16). Furthermore, the main circulation pattern in the whole area of Le Danois Bank has an Eastward direction but there are important topographical effects that can modify this general pattern, including the presence of an anticyclonic flow at the seamount's summit (González-Pola et al., 2012).

4. Discussion

The application of techniques based on underwater images has allowed the non-destructive study of coral colonies for decades, but it was not until very recently that the study areas were modeled in 3D. The possibility of studying and measuring this type of habitat in three dimensions, with an important vertical component, opens many possibilities for study. SfM techniques were used to study a Mediterranean red coral population (Drap et al., 2017), but the colonies were sampled by divers in a small area due to the complexity entailed in the field work. The morphometric complexity of the habitat in a coral reef was also studied (Ferrari et al., 2016; Anelli et al., 2017), focused on the determination of habitat complexity measurements such as roughness and curvature using Digital Surface Models and Digital Terrain Models and their derivatives.

4.1. Photogrammetric reconstructions

The use of this methodological approach based on SfM techniques from images taken by a ROTV allowed us to perform a population study of a gorgonian forest in the Cantabrian sea bathyal ecosystem accurately and with a high resolution. Having a complete 3D reconstruction of the deep-sea floor allows us to propose a series of measures that were impossible to obtain until now.

It is clear that the use of photogrammetric techniques that achieve a 3D reconstruction of complex zones is a great advance for the study of basic parameters of deep-sea habitats. However, photogrammetric processes must be rigorous since the geometric uncertainty associated with the modeling techniques is directly related to the magnitude of the parameter being measured. In this way, it is clear the need of high quality geodetic control networks to detect small changes in coral reefs using a multi-temporal photogrammetric modeling approach (Neyer et al., 2018). The methodology used here is in line with used to for high-resolution mapping of marine vertical structures (Robert et al., 2017), and 3D reconstruction used to obtain growth rates of deep-water octocorals (Bennecke et al., 2016). These recent advances demonstrate the power and reliability of the methodology used here.

The obtained results, giving a quadratic mean error of 1.2 cm and a reprojection error of 0.1 pixels in image block adjustments, show very low values of geometric uncertainty, which validate the application of this approach for the measurement of parameters related to the size of sessile organisms living on the sea bottom. Indeed, mean reprojection error values of less than 2-pixels were assumed as indicators of the effectiveness of SfM programs for creating highly accurate 3D reconstructions of underwater habitats (Burns and Delparte, 2017).

4.2. Gorgonian population structure

The size of gorgonian assemblages is usually measured by the height of their colonies (Linares et al., 2008; Bennecke et al., 2016; Ambroso et al., 2017). This height is often understood as the maximum length of the line measured from the base of the colony. The different orientations, curvatures, ramifications and forms of the colonies, together with their capacity for partial mortality, especially in large specimens, make this parameter clearly insufficient to define gorgonian size and evaluate population structure. A key aspect of ecological studies on benthic organisms is the selection of the best morphological parameters to describe their growth and architecture (Mistri, 1995). The possibility of establishing a relationship between morphometric and biological (age, feeding capacity, etc.) aspects of the specimens will depend on this morphometrical description. These biometric parameters should be key in establishing competition relationships between colonies; and although the ecological processes and the influence of habitat complexity seems clear (Alvarez-Filip et al., 2011; Lambert et al., 2012; Graham and Nash, 2013; Gonzalez-Rivero et al., 2017), this relationship is still not well understood.

A surface measurement of the colonies is more representative of the biophysical parameters of the specimens, e.g. number of polyps, biomass, age and capacity of food collection. To date, there are too few empirical studies to establish clear relationships between biophysical parameters and the size of gorgonian colonies. A relationship between biomass and height of *Paramuricea clavata* (Risso, 1826) was established (Coma et al., 1998) and between fan surface and biomass was fixed (Palma et al., 2018); but these relationships are species dependent. The evolution from classical measurements in coral reefs to more complex ones obtained by 3D modeling is needed (House et al., 2018).

The digitalization process proposed in this study shows that it is necessary to introduce improvements in the techniques used to analyze the morphometry of coral gardens. Specifically, once the registration and representation of 3D areas has been accomplished, it is necessary to automatize and standardize the parameters to be measured (number of branches, area occupied by each colony, volume, etc.). A skeletonization process was proposed to measure and quantify morphometries as complex as those of Mediterranean red coral colonies automatically (Gutierrez-Heredia et al., 2015; Royer et al., 2018). A SfM based method is used too for the estimation of gorgonian population structure and morphometries, where the point cloud corresponding to each colony is divided into a mosaic of facets and the 3D canopy surface of the population is estimated as the sum of the individual facet surfaces (Palma et al., 2018). These methodologies are interesting and should be standardized in the future for their application in as many cases as possible.

The fan surfaces measured in this study indicate that the coral population at El Cachucho is a young one. The colonies we measured reach surfaces larger than 1 m^2, and the most abundant ones were (0-0.05 m^2) wide (Fig. 12).

Positively skewed size frequency distribution as presented here implies that a population presented values close to a good health status, with a significant contribution of young colonies and a progressive decrease in abundance with respect to colony size (Meesters et al., 2001; Linares et al., 2008). In addition, in a visual inspect of video frames we detected some very small specimens, indicating a recent settlement of larvae on the sea bottom that could rejuvenate the forest. The administrative protection of the area, where fishing activities are not allowed since 2009, is considered the main reason for this habitat recovery. Besides, the occurrence of numerous large specimens, and a scarce presence of gear remnants in the area, suggests that the bottom topography, with a very pronounced relief and a rocky substratum, saved this area from the impacts of aggressive gears that were traditionally used all along the Cantabrian Sea until the 90s.

The study of the orientation of more than 300 gorgonians within this aggregation, along with the data available on the oceanographic dynamics occurring near the bottom in the study area (González-Pola et al., 2012) show a perpendicular layout of the coral specimens with regards to the dominant current flow. Data from the lander mooring located at the sea floor indicate that 53.4% of the current data recorded in 24 hours were registered within the first quadrant (between 0 and 90º). Thus, this was the main direction of the currents throughout a day in this area. The concave side of the older individuals, where the polyps are located was oriented 'back' to the current. This is probably a strategy that combines the hydrodynamic shape that best allows them to resist the strong currents occurring in the area without being damaged, with the maximization of food availability on the turbulence created on the leeward area. This relationship has been showed in colonies of *Gorgonia ventalina* (Linnaeus, 1758); in them, the increase in drag force with surface area could place an upper limit to colony size (Sponaugle and LaBarbera, 1990). So, gorgonians may face several design conflicts between minimizing drag forces to prevent dislodgement and increasing the surface area exposed to the flow for maximal food capture and exchange.

The dead gorgonians recorded in this study were probably due to natural causes. However, it wasn't possible to establish whether the colonies were all killed by a one-time event. These animals are subject to several diseases than can cause necrosis and death (Rogers et al., 2015; Weil et al., 2016); although little is known from deep-sea species as research is mainly focused on shallow-water tropical environments. At this respect, it has been suggested that populations of *P. clavata* dominated by small colonies with few large individuals could be due to a high adult mortality or to the occurrence of large colonies only in certain microhabitats (Bo et al., 2012). Future studies will throw light on the evolution of the studied colonies at Le Danois Bank, and hopefully, help discern the causes explaining the death of these specimens.

4.3. Gorgonian abundance

Although the *Placogorgia* sp. is effectively one of the most locally abundant species of gorgonians in Le Danois Bank, its spatial distribution is very restricted. Despite the efforts of sampling and characterization of this MPA carried out in recent years (Sánchez et al., 2008, 2009, 2014, 2017), this, is the only aggregation of *Placogorgia* sp. found to date. Other specimens have been found, but they cannot be considered to form a three-dimensional habitat given their isolation.

Data on presence and abundance of deep-sea plexaurid gorgonians in Atlantic and Mediterranean European waters are limited, supporting the value of the data obtained here. See for instance the summary of gorgonian abundance and density from ROV observations from different continental shelfs in Ambroso et al. (2017). We have been unable to find data concerning the genus *Placogorgia*, most available studies dealing with well-known, abundant species of the genus *Paramuricea*, such as *P. placomus* in North Atlantic (Bulh-Mortensen and Buhl-Mortensen, 2014), *P. clavata* and *P. macrospina* in Mediterranean Sea which are mostly accessible by diving (Harmelin and Marinopoulus, 1994; Linares et al., 2008; Gori et al., 2011a; Bo et al., 2012; Grinyó et al., 2016). Some additional Mediterranean data on a few smaller species (*Bebryce mollis, Swiftia pallida*) are also available (Grinyó et al., 2016). Some examples on Mediterranean plexaurid populations were given, up to 53 col/m^2, *P. clavata* (Linares et al., 2008), 18.5 col/m^2, *P. clavata* (Gori et al., 2011a), up to 9.5 col/m^2, *P. macrospina* (Bo et al., 2012) and 3 col/m^2, *P. clavata*, 9 col/m^2, *P. macrospina* (Grinyó et al., 2016). All these studies were carried out at shallower depth range than ours. In the Atlantic Ocean, in Hardangerfjord, hard bottom coral gardens with *Paragorgia arborea* and *Paramuricea placomus* showed maximum densities of 33 colonies/100 m^2 (Bulh-Mortensen and Buhl-Mortensen, 2014).

The ability to geolocalize each gorgonian colony is one of the interesting aspects of the methodology we used, indicating that density can be spatially represented in a map and the differences in density between zones made clear. In this way, population structure can be studied with a high spatial resolution and different analytical techniques can be applied within a GIS environment. We measured a density of up to 0.15 colonies/ m^2 at Le Danois Bank site. This density is larger than the threshold of 0.1 colony m^2 used by ICES (2007) to define a coral garden habitat.

According to the Ripley's K-function spatial analysis, the aggregation shows a maximum clumped distribution at 3.75 m of distance (scale). However the colonies show a dispersed distribution for distances greater than 10 m. Our knowledge about the spatial patterns of distribution of deep-sea gorgonians is poor, although usage of ROV is increasing our knowledge on this respect (Mortensen & Buhl-Mortensen, 2004; Watanabe et al. 2009; Gori et al., 2011a; Ambroso et al., 2017). However, the factors that set them in the deep-sea are difficult to elucidate due to inaccessibility; in this respect, very little is known about factors that regulate the distribution and growth of deep-sea corals (Watanabe et al., 2009). Both clumped and random distributions, or variability from clumped to random on a same transect depending on scale, occur in deep-sea gorgonians; the former has been associated in some cases with reproduction by internal brooding and larvae settling at shorts distances from the parents and hence increasing their probability of settling on a suitable substrate (Mortensen and Buhl-Mortensen, 2004; Gori et al., 2011b; Kahng et al., 2011; Ambroso et al., 2017). However, other biotic and abiotic factors may be also involved as both affect the utilization of space by the individuals (Gori et al., 2011a; Baker et al., 2019 and references therein). Mode of sexual reproduction in *Placogorgia* sp. is unknown, although it is likely gonochoric and brooder, similar to species from the closely related genus *Paramuricea*, some of whose species have been investigated at shallow depths in the Mediterranean Sea (Coma et al., 1995). According to these authors, maturation of the larvae in *P. clavata* occurs on the colony surface and they immediately settle on the surrounding substrate after release (Coma et al., 1995). This could be the case for *Placogorgia* sp. As for other possible factors that determine the spatial pattern of the community at study, they were not investigated during this study but, given the importance of this species in Le Danois Bank, we hopefully will approach their study in the forthcoming years.

Parameters defining the population structure of a colony offer data to characterize it at a given time (Linares et al., 2008; Kipson et al., 2015; Grinyó et al., 2016), but also allow monitoring the evolution of this population over time (Coma et al., 1998) and even study its response to specific phenomena impacting it (McClanahan et al., 2001; Linares et al., 2005).

Finally, it is worth highlighting the contribution of this study to the implementation of the Marine Strategy Framework Directive (MSFD) for the monitoring of the health status and recovery of benthic populations that characterize vulnerable habitats in MPAs (Rice et al., 2012). This approach allows the estimation of the main population parameters in control areas representative of each habitat. This facilitates the analysis, through multi-temporal successive samplings and the use of indicators of the degree of recovery that the population has undergone once that management measures reducing anthropogenic impacts are implemented. In particular, the methodology proposed here allows estimating some indicators associated with descriptor (1) of the MSFD, Biological diversity (EC, 2008; Borja et al., 2011), such as "Area covered by the species", "Population abundance", and "Population demographic characteristics" of vulnerable benthic species that structure habitat 1170 Reefs, of the EU Habitats Directive 92/43/EC (EC, 1992), in a non-invasive way.

5. Conclusions

Photogrammetry represents a non-destructive, cost-effective tool for coral reef monitoring. This approach achieves a greater resolution and provides quantitative measures, allowing the integration of the information obtained in a GIS environment. However, its application to deep-sea habitats is still in an early stage.

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

The determination of the distribution of sizes, densities, orientations and other population parameters using this high resolution method, represents a considerable advance in the study of gorgonian aggregations. The results obtained are crucial to increase knowledge on the area and its relationship with other parameters of interest such as accompanying fauna, biodiversity, growth studies, EFH, etc.

In addition, studies regarding the population structure of the various organisms inhabiting and MPA are fundamental when monitoring its environmental status and evaluating the effectiveness of the management measures implemented to preserve it.

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Figures:

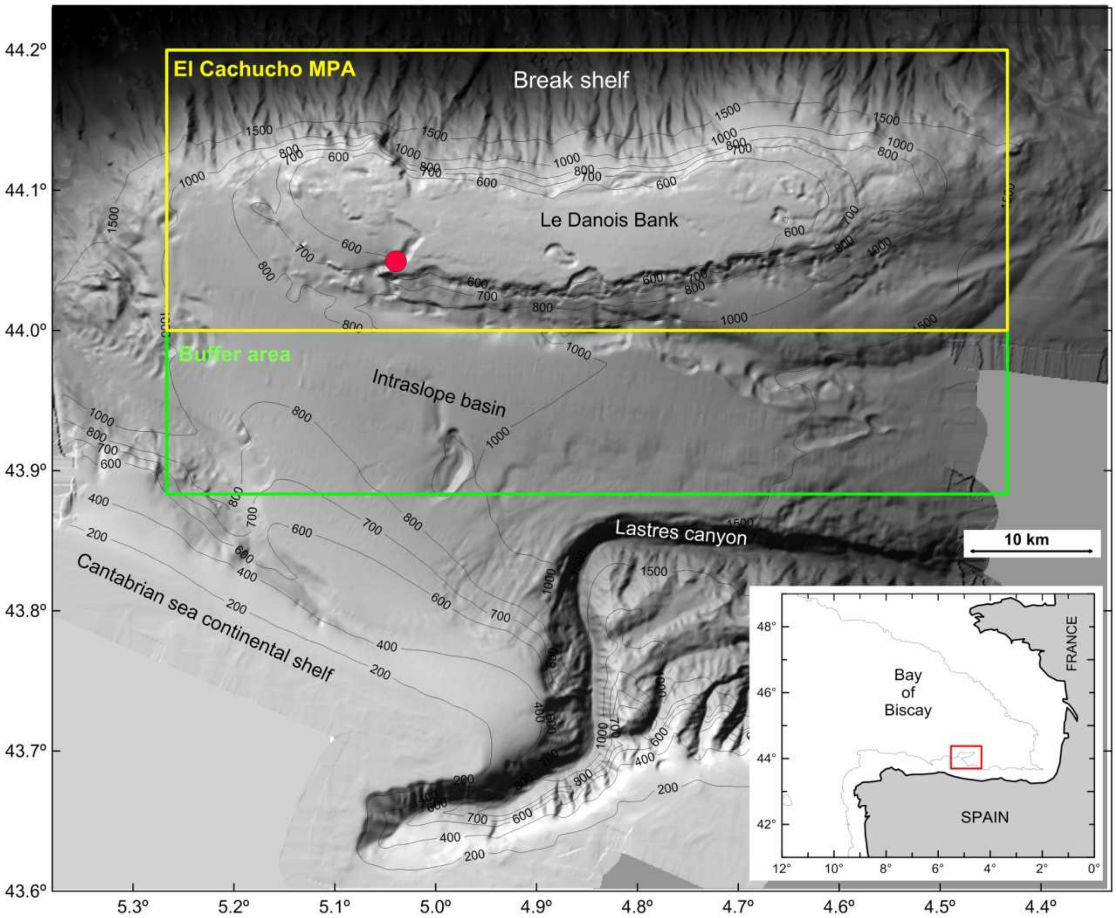


Figure 1. Location of "El Cachucho" MPA on the Bay of Biscay, and some topographic features that characterize the area. The red circle shows the location of the gorgonian forest analysed in this study.

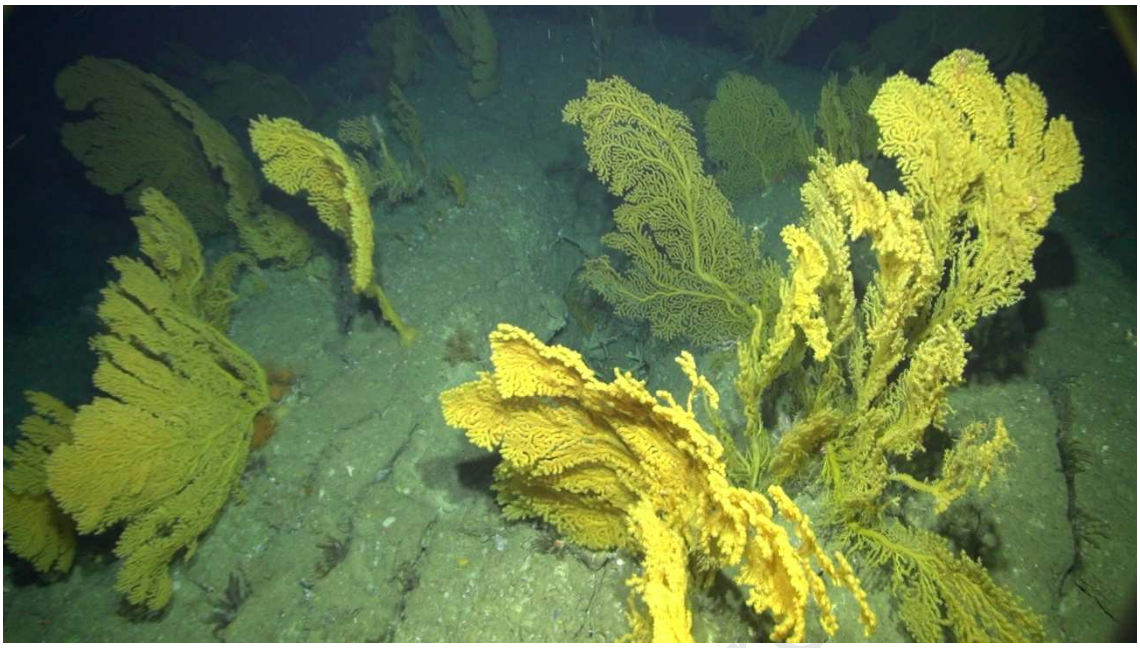


Figure 2. Example picture extracted from one of the video-sections showing some of the gorgonian individuals analyzed and the rocky substrate at 528 m depth.

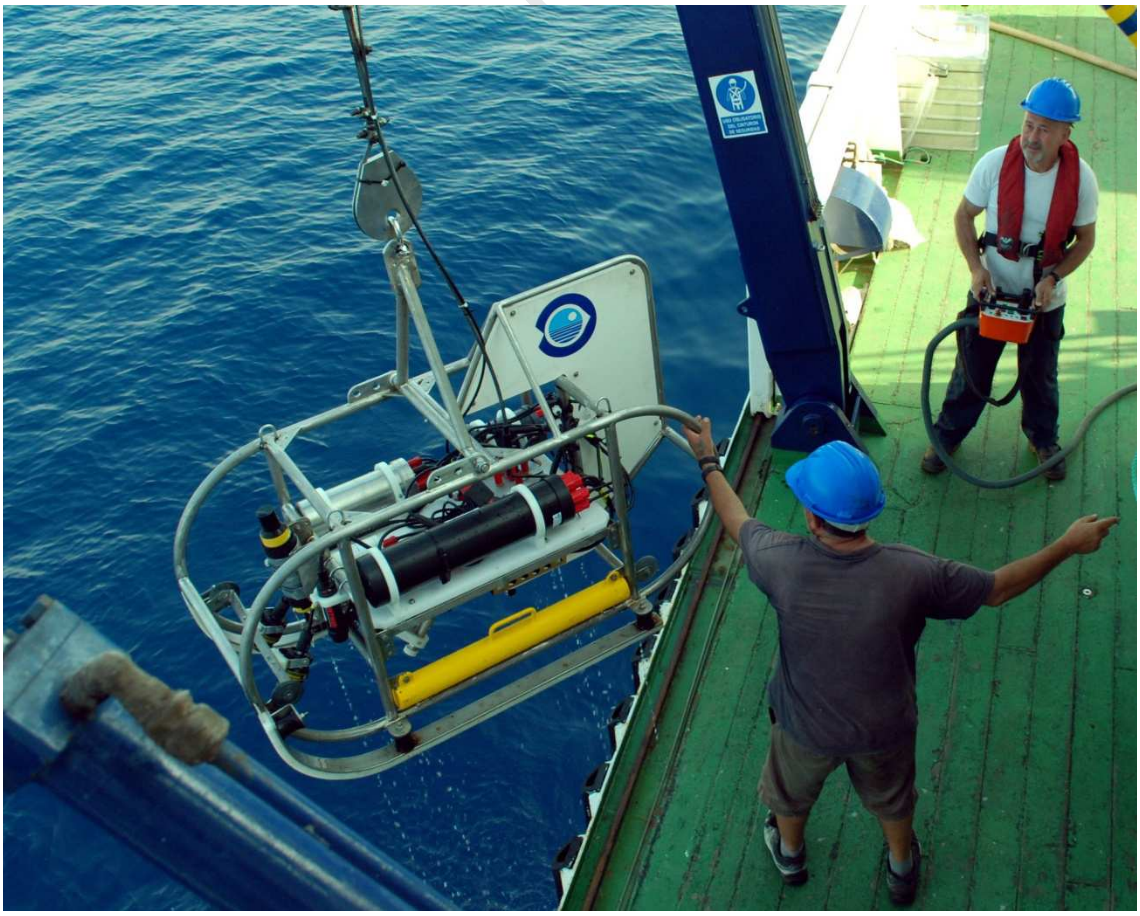


Figure 3. *Politolana* towed vehicle during its deployment maneuvers at the ECOMARG survey.

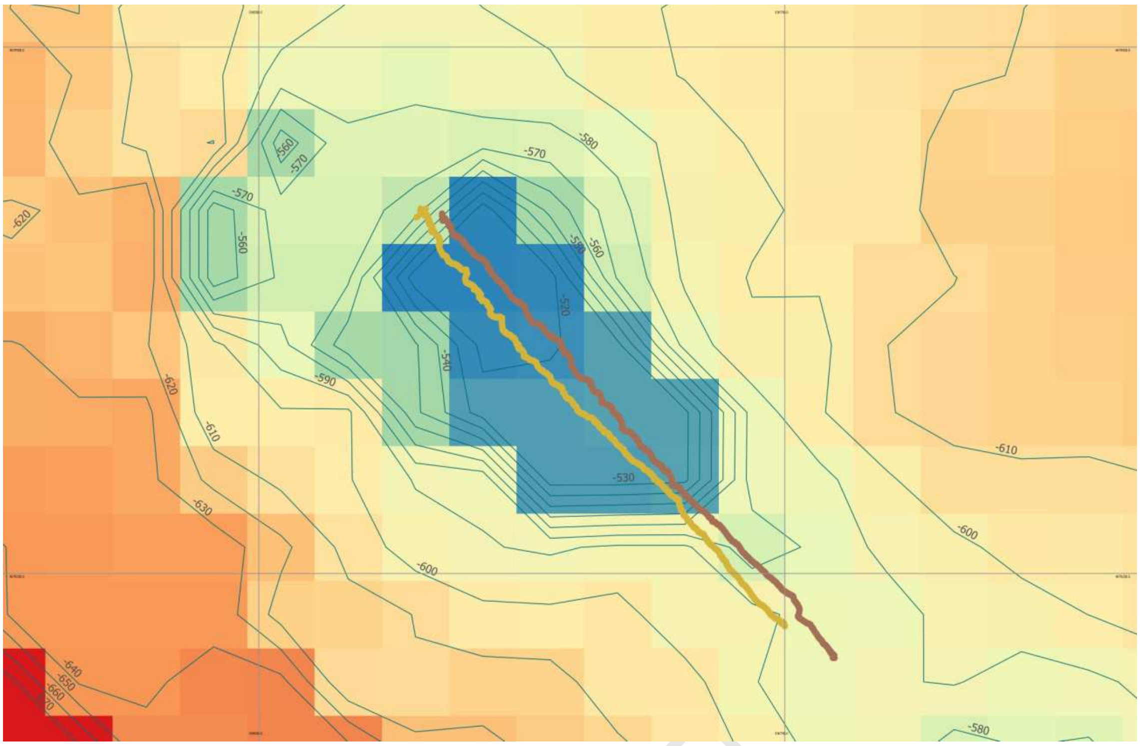


Figure 4. Video transects carried out in this study above the gorgonian assemblage. The background image shows the EMODNET bathymetry layer.

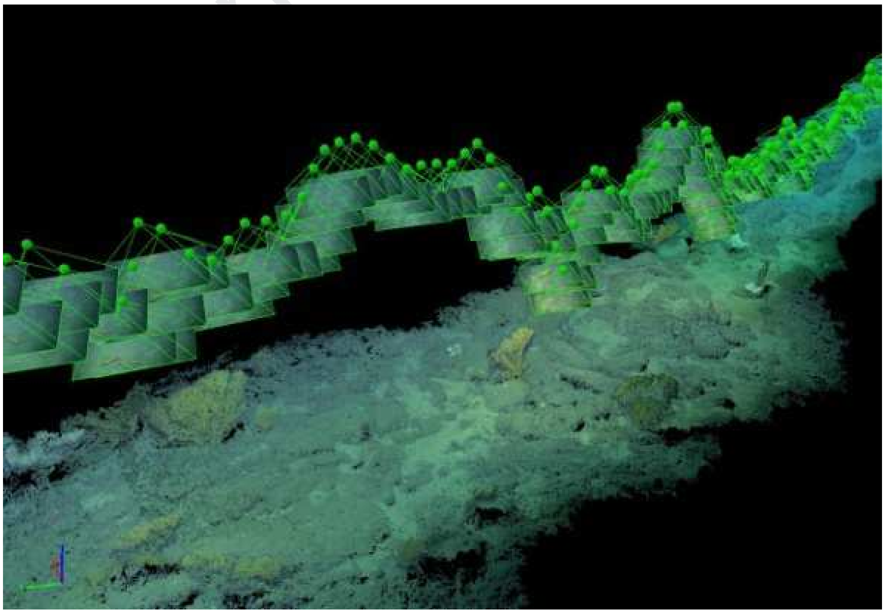


Figure 5. 3D reconstruction of one of video transect. Green points show the camera's position.

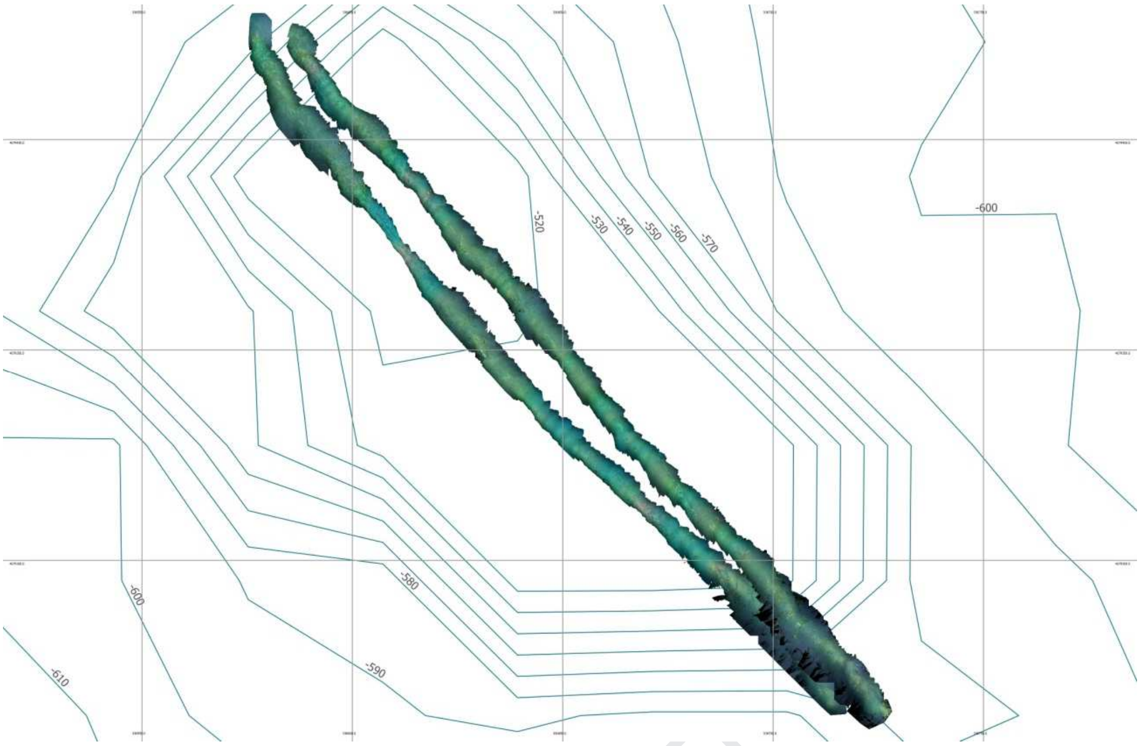


Figure 6. Orthomosaics of the 2 video-sections conducted over the gorgonian forest.

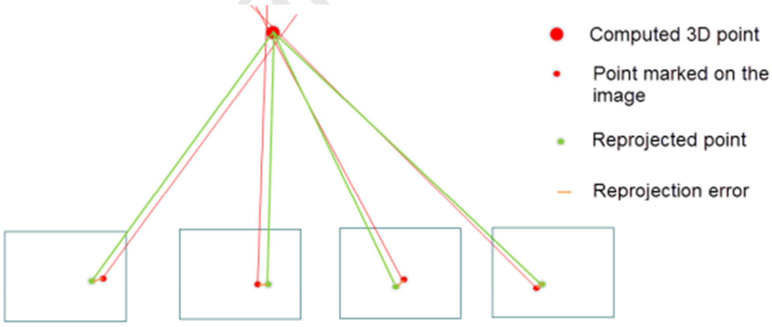


Figure 7. Graphic representation of the re-projection error in a triangulation model (source: Pix4D Support).

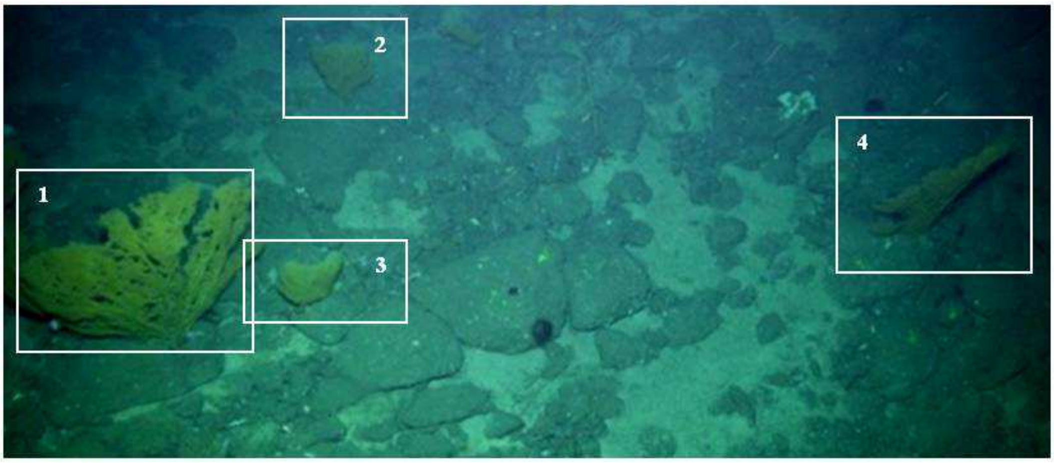


Figure 8a. Video-frame example with specimen selection (no geometric properties).

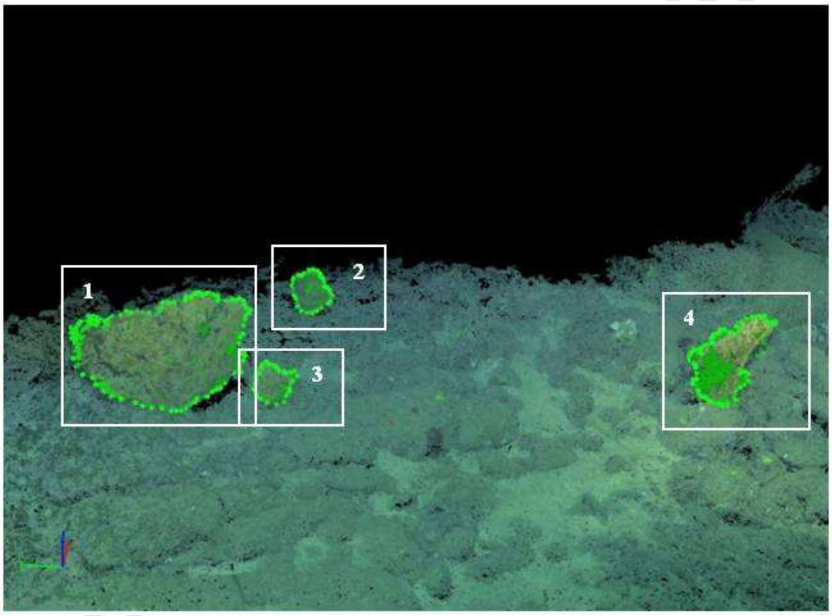


Figure 8b. 3D point cloud (xyz) of the same zone with digitalized gorgonian colonies.

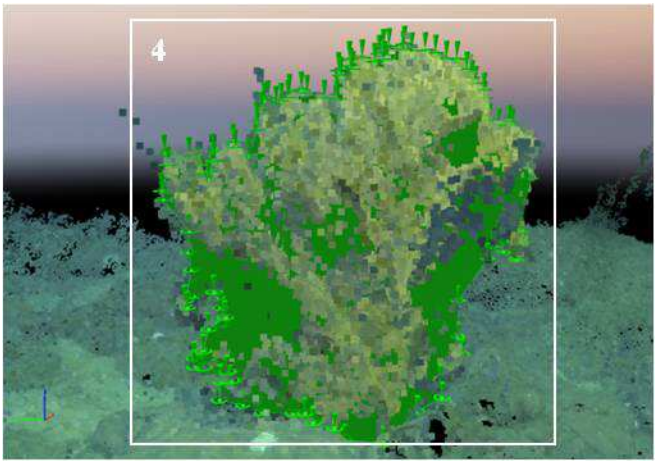
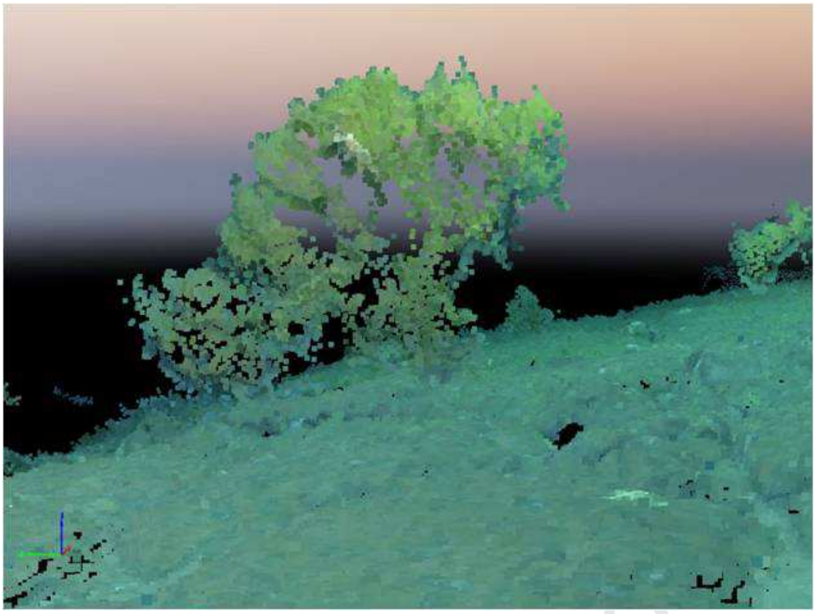
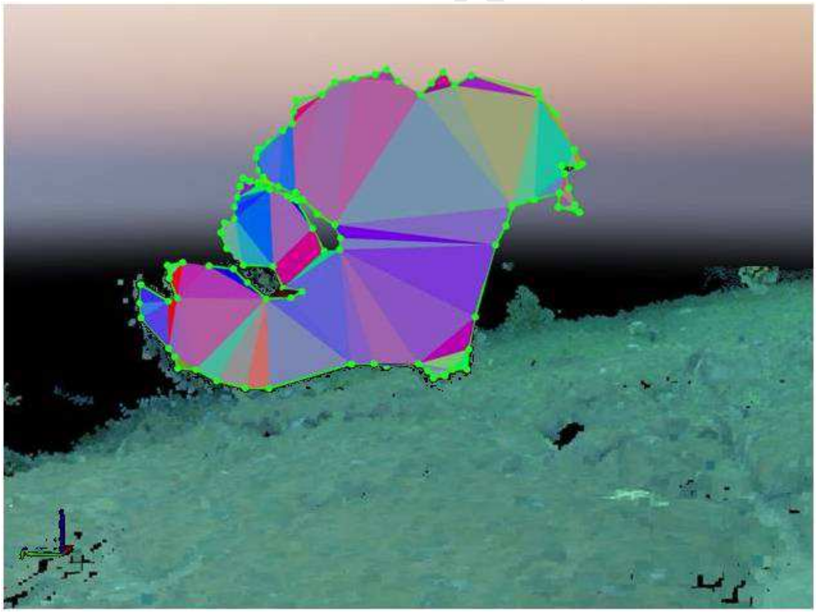


Figure 8c. Zoom in the digitalized perimeter of colony 4.



Fiure 9.a: Example of a 3D point cloud of a gorgonian colony



Fiure 9.b: Example of gorgonian surface forming with succesive planar triangles.

Figure 10.a: Example of dead colony in the study area

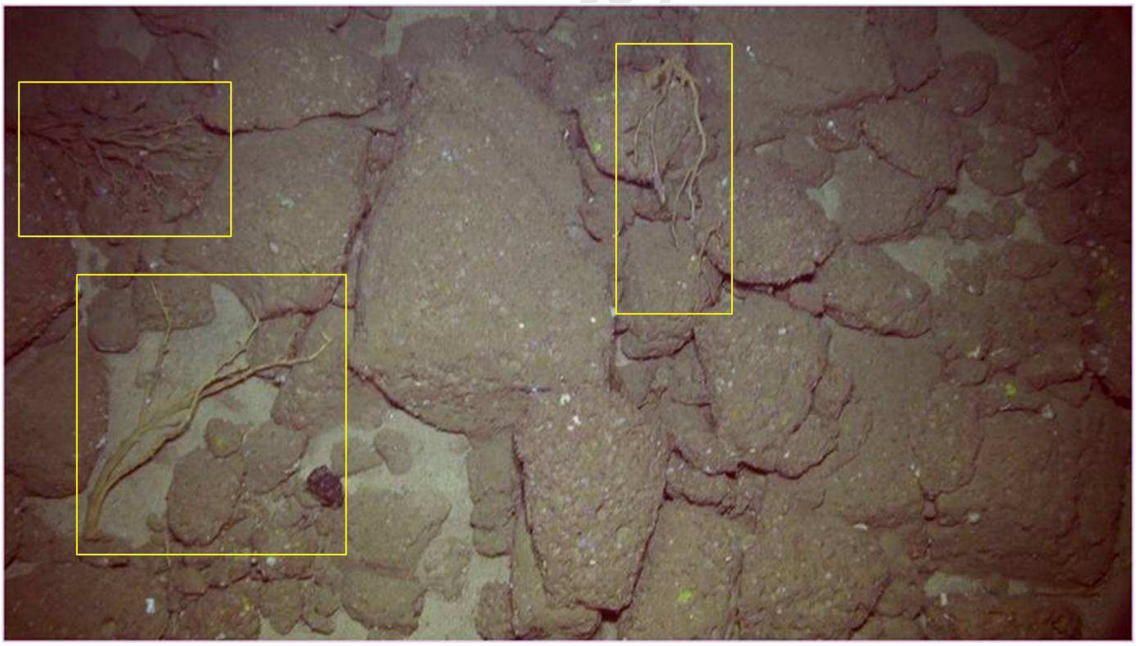


Figure 10.b: Example of fragments of dead colonies in the study area

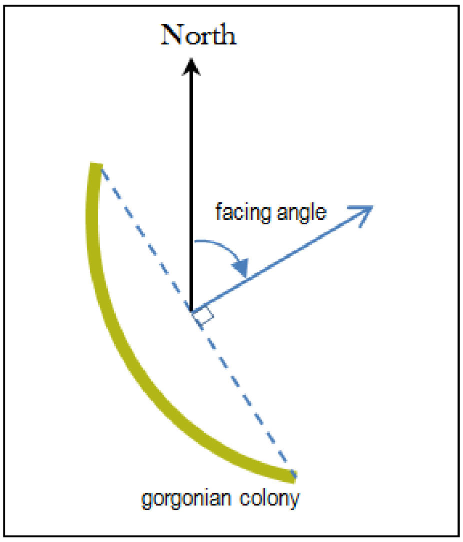


Figure 11: Graph showing the facing angle as measured in this study

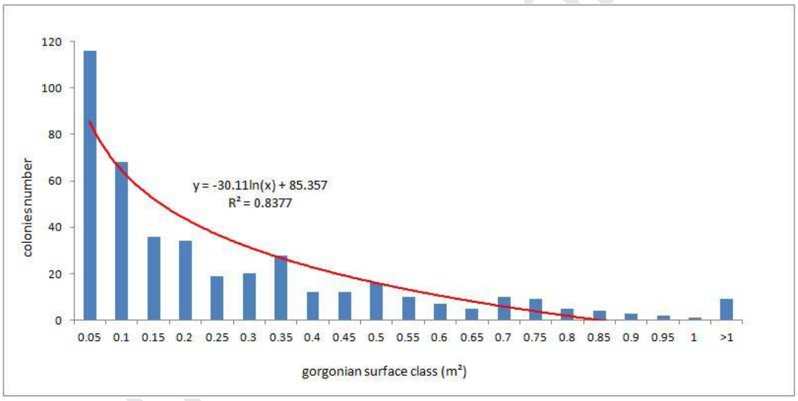


Figure 12: Histogram of fan surface area (m^2) distribution of *Placogorgia* sp. at Le Danois Bank

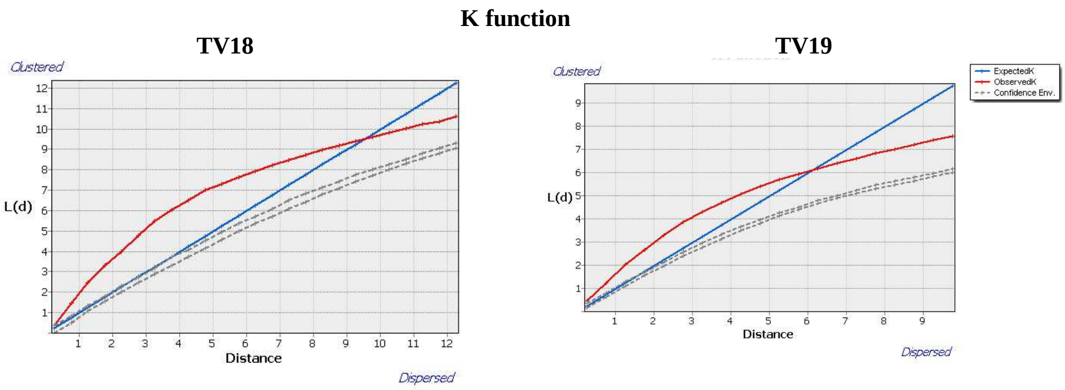


Figure 13: Results of Ripley's K function for both TV18 and TV19 transects. The graphs show a clustered spatial distribution for distances below 10 meters with a maximum clumped distribution at 3.75 meters.

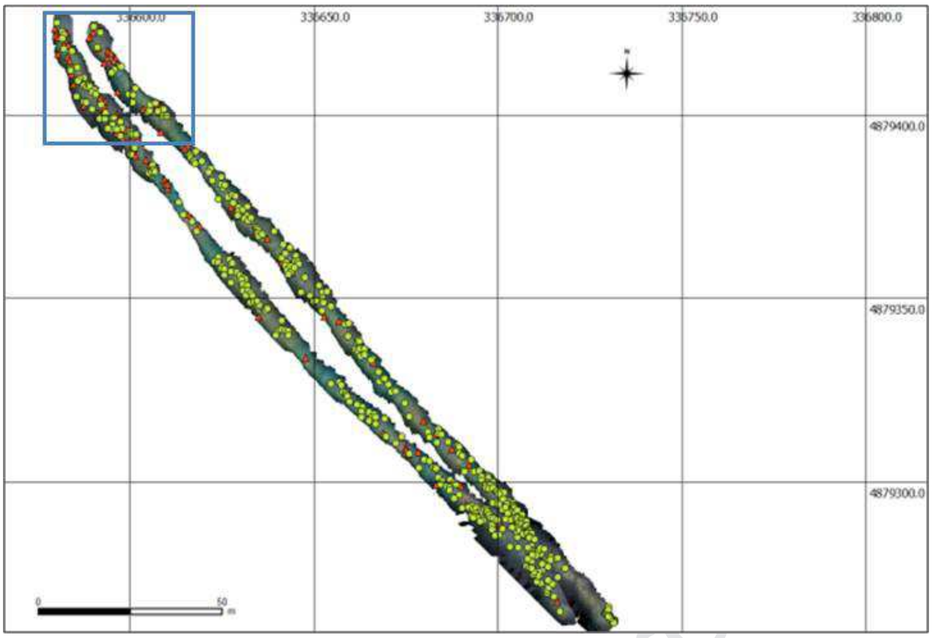


Figure 14a: Orthomosaic of the area. Yellow: *Placogorgia* sp. colonies / Red: dead colonies

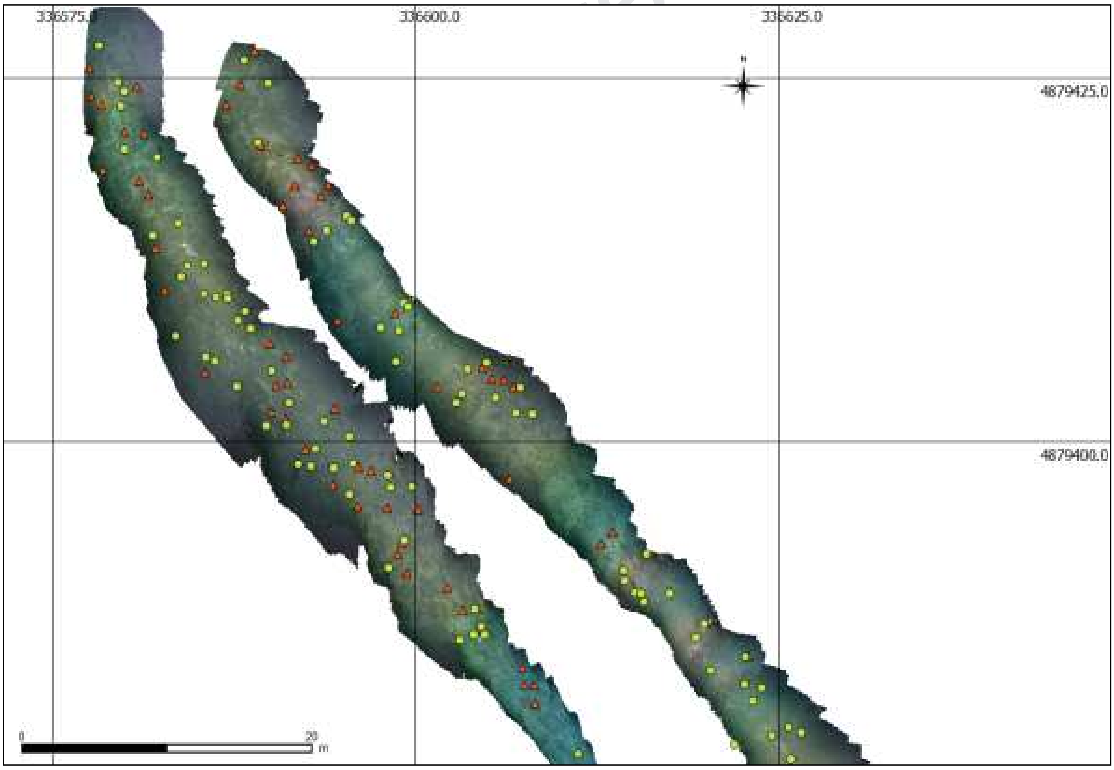


Figure 14b: Zoom into the north-west area of the orthomosaic. Yellow: *Placogorgia* sp. colonies / Red: dead colonies.

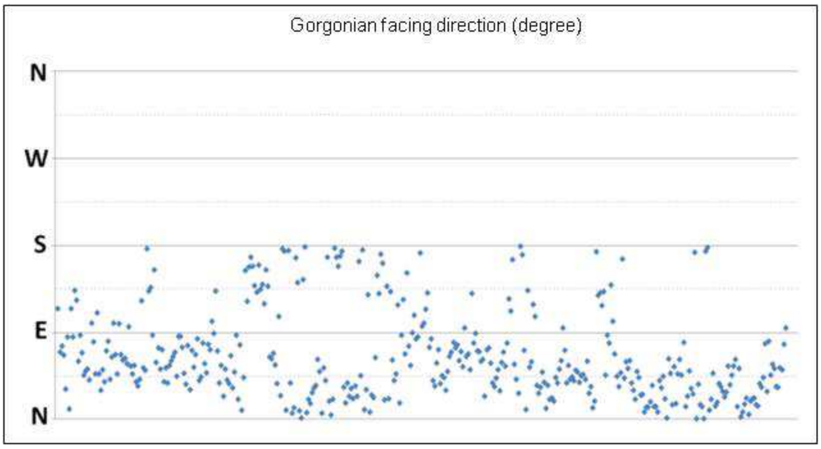


Figure 15: Gorgonian facing angles according to the scheme that appears in Fig. 11.

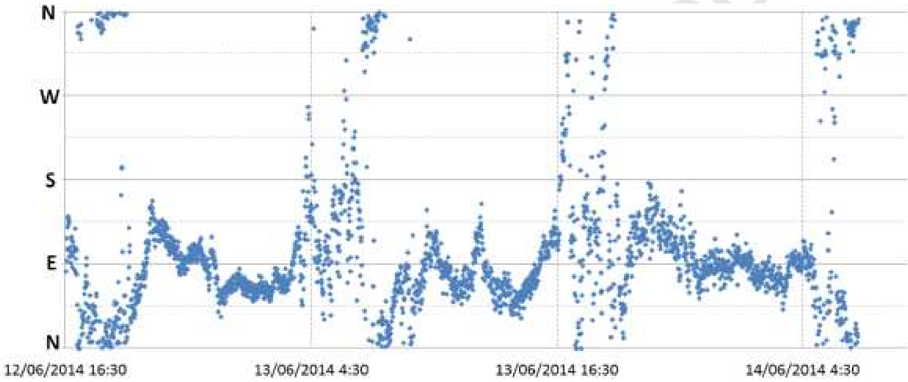


Figure 16. Near bottom current direction recorded in the study area from a single-point current meter.

Table 1. Basic data regarding the image dataset and the 3D Point Cloud densification process.

	TV18	TV19
Dataset: number of calibrated images	1085	1149
Average Ground Sampling Distance (GSD) in cm	0.27	0.26
Area Covered (ha)	0.1397	0.1489
Median of keypoints per image / matches per calibrated image	9533 / 2743.43	9306 / 2528.38
Number of 2D Keypoint for Bundle Block Adjustment	2927544	2928525
Number of 3D Points for Bundle Block Adjustment	1020754	1044876
Number of 3D Densified Points / Average Density (per m³)	15390469 / 171667	15129025 / 147168
Mean reprojection error (pixel)	0.114	0.114