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# Characterization of North Western Mediterranean Coralligenous assemblages by video surveys and evaluation of their Structural Complexity

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## Abstract

The increase of awareness regarding the key ecological role of coralligenous habitats in the Mediterranean Sea is addressing several research projects to standardize protocols for the description of its main features and conditions. Here we examined 13 stations along the Italian coast of the Western Mediterranean Sea, using video-transects technique, comparing the structure of coralligenous assemblages and testing the importance of their tridimensional complexity as a proxy to define their level of integrity. We considered the nature of substrata, the entity of injury and marks of anthropic impacts. The analysis of the stations allowed to develop a gradient in the coralligenous conditions, evidencing the most rich in species and diverse stations and the site with the highest equitability. Here we develop a method to evaluate coralligenous complexity, selecting Structural Descriptors to define the systems tridimensional structure and to assess a unique Index of 3D - Structural Complexity for the system coralligenous, that identified the stations with the highest and the lowest tridimensional complexity.

*Keywords:* Bioconstructions, Tyrrhenian Sea, 3D, health index, animal forest.

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## 1. Introduction

The coralligenous is a typical coastal Mediterranean biogenic formation inhabited by a peculiar biota [75]. It is dominated by calcareous organisms, consisting of blocks of organic concretionary material, originated primarily by accumulation of dead thalli of coralline algae and secondarily by calcareous skeletons of animals as polychaetes and bryozoans [4]. The bioconstructions that constitute the coralligenous are formed by species that, with the superposition of skeletons of previous generations, change the primary geological habitats creating a secondary hard substrate, representing a privileged habitat for the settlement, spawning, recruitment, feeding and shelter of an enormous variety of marine species. It is a key ecosystem recognised as a natural habitat of community interest and Zone of Special Conservation at European level (92/43/CE Habitat Directive [34], habitat code 1170-14: Reefs, coralligenous assemblage). In the Mediterranean Sea, coralligenous assemblages [65, 76] develop in dim-light littoral systems (between 25 – 30 and 150 – 200 m depth) on vertical rocky cliffs and on flat or semi-flat biodetritic bottoms [90, 92], wherever irradiance is reduced between 2 – 3% and 0 – 0.5% of the surface irradiance [37] and in relatively constant conditions of temperature, currents and salinity. The unique information available regarding growth dynamics evidences a very low growth rate,  $0.19 \text{ mm year}^{-1}$ , ranging from 0.11 to  $0.26 \text{ mm year}^{-1}$  [77]. Simplifying the scheme of [71] it is possible to recognize four levels of organization, due to cryptic/boring, encrusting, massive, and arborescent organisms. Perforating and insinuating forms may affect the interface water/substrate [12, 16], encrusting and massive specimens help to trap and stabilize sediment [25] erect organisms reduce light penetration and water movement [79]. The integrity of these layers is able to affect not only the chemico-physical equilibrium of coralligenous rims but also their biological dynamics and associated fauna [70, 69]. The typical abrasive effects that human activities play on sea floor, on mature coralligenous communities act primarily on the most exposed layers. Once these layers are damaged, lower layers start to be involved in further erosion, down

to the coralligenous bioconcretion. This process leads to the fragmentation of the populations involved in the structuring of coralligenous assemblages. These effects can be faced only with a quick interruption of the activities playing the impact. If this does not happen, the community begins to offer space to new pioneer and/or opportunistic species triggering new successional stages. Owing to its fragility, coralligenous assemblages are particularly sensitive to mass mortality events, mainly due to increase of temperature of water column and climate changes [23, 49] and to a series of stressors of anthropic origin affecting the coralligenous architecture and functioning [85]. Anchorage and fishing activity, especially recreational and artisanal, negatively affect the structure of coralligenous communities [50]. The large-size epifaunal invertebrates, such as arborescent sponges and gorgonians, can clearly be affected by mechanical stressors and show the injuries also for years after the event of damage [7]. Moreover, the documented general increase of turbidity and sedimentation along coastal areas [56], can compromise mainly suspension feeders [14, 64]. Pollution and wastewaters affect richness and density of the biggest epifaunal species and increase the abundance of most tolerant ones and bioeroders [47]. In case of turbidity and pollution bioeroders are represented mainly by Porifera, and can play a key role in the accretion dynamics [24]. In areas particularly known for their naturalistic value, diving tourism [74] impacts mainly on the large-size invertebrates of the coralligenous communities [28] and affect organisms with slow-growing and fragile skeletons [40, 54]. Finally the coralligenous communities are threatened by the invasion of non indigenous species, such as ones of the genus *Caulerpa*, the most common green alga invading all kind of substrata from 0 to 40 m depth [84] and affecting key ecosystem functions and services, or *Womersleyella setacea*, a red turf alga forming dense carpet, enhancing sediment trapping [1] and inhibiting photosynthesis and growth of coralligenous builders [67, 5]. It is essential to develop a correct interpretation of coralligenous health status, according to the Marine Strategy Framework Directive adopted in 2008, whose purpose is to join a Good Environmental Status (GES) of European marine waters within 2020. Destructive methods have been used for long time because

of excellent results for studying sessile organisms, particularly suitable for studies with strong taxonomical components, but they are not suitable for studies on assemblages and long-time monitoring, leading to the necessity to use other  
65 non-destructive methods of investigation, such as transects or quadrats. The study of bioconstructions, such as coralligenous accretions in the Mediterranean Sea, provided up today important general knowledge concerning the composition of benthic communities [4, 42, 21]. The lack of detailed cartographic data of the distribution of this habitat at small scale represents the most important  
70 gap for the development of well focused management plans [91]. Recent papers modelled the distribution of coralligenous habitats at basin scale [43, 55] and at local scale [92]. In the NW Mediterranean region [21] evidenced, after a study lasted five years, moderate/low spatial and temporal variability in assemblages composition. Anyway, a standard and common protocol is still lacking,  
75 delaying a shared conservation strategy for the Mediterranean Sea. Up today, efforts in listing of species [10, 84], genetics [30, 61] and cartography [91, 92] are among the main used approaches, as the focus on environmental factors and impacts of climate changes. In this work, we examined 13 stations along Italian coasts. The recording of video-transect allowed us to apply non-invasive  
80 methods to collect covering data. A list of 28 phytobenthic and 97 zoobenthic taxa were considered. In addition, regarding gorgonians, we estimated the entity of injury, the covering of epibionts, marks of anthropic pressure, and the nature of substrata. The analysis of covering data allowed us to evidence and compare richness and diversity for each site. Moreover we proposed a method to  
85 define different typologies of coralligenous, based on different structural descriptors (SD), describing the 3D architecture of the system. The approach allows to define different levels of architectural complexity for the coralligenous and to assess an Index of 3D - Structural Complexity, avoiding complex time-consuming methodologies as chain transects or 3D reconstructions.

## 90 2. Material and methods

### 2.1. Studied sites

The study focused on 6 sites, 13 stations (Table 1) along the NW Italian coasts (Figure 1).

- Santo Stefano shoal, in the Ligurian Sea, develops perpendicularly to the coast, for about 3 km. It has a profile of about 8 km and it is about 300 m large close to the coast side, with a wide tip at seaward side. At 25 meters of depth, on the top of the shoal, a *Posidonia oceanica* meadow is mixed with detritic sediments and coralligenous pinnacles. The eastern side, exposed to the main littoral Ligurian current flowing westwards [86], is characterized by a coralligenous habitat developing on a vertical cliff, mainly structured by a *Paramuricea clavata* facies. At 30–40 m depth, the base of the cliff is characterized by a discontinuous belt of boulders wrapped by coralligenous rims [84]. The western side is undercurrent, very silty, with a wall leaning slightly. Here we considered four stations, La Luna (SSLu), Canyon (SSCa), Croce Cappello (SSCC) and S Croce (SSCr).
- Gallinara Island, in the Ligurian Sea, is 1.5 km far from the main coast and the separation channel is 12 m deep. The coastal line is constituted by a rocky cliff and the bottom is rocky reaching a depth of 30–40 m, where organogenous debris and mud mainly characterize the sediment. The numerous biocoenosis biocoenoses reflect the heterogeneity of the substrata, varying from biocoenosis typical of hard substrata at lower depths to *Posidonia* meadows and detritic-muddy bottom at higher depths. Here we considered two sampling stations, Punta Sciuscia in the southeastern side and Punta Falconara in the southwestern side..
- MPA of Portofino: Portofino Promontory has a coastline of 13 km and its geomorphologic characteristics determine an environment rich of gorges and small caves that favour the development of a rich benthic fauna. *P.*

120 *oceanica* meadows develop inside the bays and in tracts with lower slope, while the coralligenous, characterized by the presence of *P. clavata*, *Eunicella species*, *C. rubrum* and rich populations of sponges, cnidarians and ascidians, dominate the rocky cliff extending beyond 50 m depth, followed by detritic bottom. Here we considered three stations PTF sect 1, PTF sect 2 and PTF sect 3.

- 125 • Punta Manara: .It is a wide promontory 15 km Eastern from close to Portofino MPA. Here the rocky bottom is mainly built by big rocks coming from the upper cliff likely related to ancient landslides and bioconstructions. The coralligenous starts on the rocky shoals located at 24 m depth and develops down to – 85 m depth. Here we monitored one station  
130 (PM).
- MPA of Tavolara and Punta Coda Cavallo: Tavolara is an island of a small archipelago characterized by limestone-dolomite rock [6], whose epibenthic community has been described by [63] and [62]. Here we considered two nearby stations, Papa 1 (TVP1) and Papa 2 (TVP2), the first ranging from  
135 15 to 39 m, the latter from 24 to 43 m. Both the stations are populated by forests of *P. clavata* and *E. cavolinii* [17, 13].
- MPA of Secche di Tor Paterno: this the only offshore MPA in Italy and the shoal is a compact aggregation of rocky outcrops, developing for 4 km from 18 m to roughly 50 m depth. The system is characterized by *P. oceanica*  
140 meadows and coralligenous biocoenoses, and is affected interested by the Tevere River outfall. The area is populated by *P. clavata* and *Eunicella* species. Here we monitored one station (TP).

## 2.2. Data collection

Data were collected in the 13 stations by 10 meters long video-transects  
145 recorded from 2004 to 2008 (months from May to June) between 27 and 35 meters depth, by using a camera Sony HVR-A1 with modality HD (1080i),

equipped with underwater Amphico housing and Hartemberger lighting system. A specific depth range was selected in order to avoid the potential effect of depth in the outcome of the surveys. Surveys were conducted at constant  
150 depth and speed of 5 meter for minute, for both run directions, both above and below the tape positioned to track the transect, in order to amplify the sampled surface and reduce the redundancy of data. Videos recorded on magnetic support (miniDV) were acquired by software FinalCut PRO and a grid 10 x 10 was superimposed in timeline through transparency transparency image  
155 (luma key effect) for 1 second of duration each 4 second in the central portion of the frame of videos, in order to elude effects of distortion of image due to the lenses of the camera. Covering data were collected by analyzing freeze-frames of the videos with superimposition of the grid 10 x 10, choosing 0.25 % as level of precision of covering of the whole area of each square of the grid. Organisms  
160 were visually identified at the lowest possible taxonomic level and assigned to systematic and/or ecological groups, formulating a list of categories that was checked during reading of the video-transects in order to assess their presence and abundance. Moreover we estimated the entity of injury or necrosis, the nature of substrata, epibiosis and marks of anthropic damage as the presence  
165 fishing-lines.

### *2.3. Data analysis*

Covering data of species belonging to coralligenous assemblages of the 13 stations were square root transformed and Bray-Curtis similarities were calculated. Data were analysed with permutational multivariate analysis of variance  
170 PERMANOVA (Permutational ANOVA and MANOVA) [2, 57] under the unrestricted permutation of raw data (9999 permutations) and Principal coordinates analysis (PCO) [83, 44] with Spearman correlation  $> 0.5$ . The Analysis of Similarities Percentages (SIMPER) were used to evidence contributions to the variability of the stations in order to identify species or families characterizing  
175 the studied stations The Diversity Analysis was performed for the stations in exam by calculating Margalef Richness, Shannon Diversity and Pielous even-



ness indexes for each assemblage (shown in graphics as means  $\pm$  SE). Data were square root transformed, normalized and analysed using PERMANOVA, Pair-wise tests on Euclidean distances, with unrestricted permutation of raw data (9999 permutations) and Principal Component Analysis (PCA). Observed diversity was compared with theoretical expected diversity of Caswell's neutral model [22] and the V statistics was used to test the deviation from neutrality, considered as an indicator of stress, in order to evidence the stations likely affected by some disturbance factor. Fishing impact (i.e. frequency of lost fishing gears) and damage on colonies as frequencies percentages were evaluated. Data were arcsin transformed, checked with Cochran's test and analysed with Anova and SNK Test, choosing  $p < 0.01$  as basal level of significance.

#### 2.4. Coralligenous Structural Complexity of Assemblages

In order to evaluate the complexity of coralligenous assemblages we aggregated data into categories particularly sensitive to multiple stressors. These categories generally reply with the modulation of their actual structural features, from here defined as Structural Descriptors. We consider:  $\alpha$  nude substratum (NS);  $\beta$  non-crustose coralline algae (nCCA);  $\gamma$  crustose coralline algae (CCA);  $\delta$  encrusting/basal fauna (EPI I);  $\varepsilon$  massive epibenthic fauna (EPI II);  $\zeta$  branching epibenthic fauna (EPI III).

Aggregated data were analysed with PERMANOVA, Principal coordinates analysis (PCO), with Spearman correlation  $> 0.2$  and Similarities Percentages (SIMPER) Analysis. Frequencies percentage of the groups in each site are shown in graphics as means standard errors. Finally, the value of each Structural Descriptor (X,  $\alpha \dots \zeta$ ) was calculated as the ratio between the sum of proportion of covering of the taxa included in each descriptor and the total covering of the community (tot) as:

$$X, \alpha \dots \zeta = (\sum \pi \times \alpha \dots \zeta) / \text{tot}$$

Since all descriptors ranged from 0 to 1, we divided them into 6 classes ( $\alpha=0$ ,  $0 < \alpha < 0.2$ ,  $0.2 < \alpha < 0.4$ ,  $0.4 < \alpha < 0.6$ ,  $0.6 < \alpha < 0.8$ ,  $0.8 < \alpha < 1$ ) assigning to

each class a score between 0 and 5.

The scores obtained from Structural Descriptors were combined in order to obtain a unique Index of 3D - Structural Complexity for the stations, as following:

$$3D\ C-index = \sum (d_{\alpha} + s\ d_{\beta} + s^2\ d_{\gamma} + s^3\ d_{\delta} + s^4\ d_{\epsilon} + s^5\ d_{\zeta}) / 5s^i = \sum_{i=0}^5 s^i d_i / \sum_{i=0}^5 s^i$$

Where

- i = the number of descriptors
- d = scores obtained for each i-th descriptor
- s = number of scores used to range descriptors

The method merges the structural descriptors weighting the scores obtained from the range values of such descriptors ( ). It achieves a unique 3D - Structural Complexity Index, ranging between 0 and 1, and avoiding that the same Index value or similar values are obtained for multiple configurations. 3D Structural Index was calculated for each assemblage (shown in graphics as means  $\pm$  SE) and analysed with Permutational Anova and Pair-wise tests on Euclidean distances calculated on square root transformed data, with unrestricted permutation of raw data (9999 permutations).

### 3. Results

#### 3.1. Species analysis

The analysis of video-transects allowed identifying 28 taxa regarding plants and algae and 97 considering the fauna. These included 9 species of Chlorophyceae, 6 species belonging to Phaeophyceae, 9 species of Rhodophyceae and *Posidonia oceanica* for Monocotyledoneae. Concerning animal taxa, 26 species were identified among Porifera, 26 species among Cnidaria, 9 species of Mollusca, 6 species among Crustacea, 6 species of Bryozoa, 8 species of Polychaeta, 11 species among Echinodermata and 6 species of Tunicata. PCO analysis ordinated samples in the Euclidean space by evidencing the two axes that explain

the highest percentages of variation and relationships of considered categories across the plot, where length and directions of each vector indicates respectively strength and sign of relationship between variables and axes. The visual analysis of covering of species (Figure 2) showed a high spatial heterogeneity of samples among stations and low portions of variability was explained by the first two PCO axes (23,8% and 13,2 %,respectively). The ordination of samples showed dispersion and segregation for S. Stefano shoal stations. Closed to this latter and roughly overlapping appeared Santa Croce (SSCr) and Punta ManaraPM and the two stations of Gallinara (GS, GF), with correlation to Algal felt. Closed to S. Stefano La Luna (SSLu) and Canyon (SSCa) and diverging from the other stations, appeared the stations of Portofino, with overlapping among stations and clustering especially for Sector 3 (PTF3), with correlation with Inorganical detrital substratum, *P. clavata*, *Lythophyllum fasciculatum* and *Leptosamnia pruvotii*. Another group is represented by Tor PaternoTP, PapaTVP 1 and PapaTVP 2, these latter more clustered but all not so segregated and correlated to *Udotea petiolata*, solitary madrepores, empty tubes and *Peyssonellia* sp.. In contrast to samples of the other stations that appeared quite dispersed, the stations of PortofinoTavolara, PapaTVP 1 and 2 resulted more clustered, with the best fit for Portofino sectPTF 3. Besides the high variability evidenced, the comparison among assemblages of the 13 stations showed differences among all surveyed stations (PERMANOVA,  $P = 0.0001$ ; Pair-wise Tests,  $P = 0.0001$ ). The Analysis of Similarity Percentages performed at different taxa levels (Table 2) evidenced the species or groups mainly contributing to the variability of the stations, with frequencies percentages representing species/groups contributions.

### 3.2. Diversity analysis, anthropic pressure and damage of colonies

The variability in the composition resulted in the Diversity Analysis of the stations (Figure 3). The analysis highlighted differences among stations (PERMANOVA,  $P=0.0001$ ), with significant differences among all stations ( $P<0.001$ ), lower difference between SSLu and SSCa ( $P=0.0209$ ) and TP ( $P=0.457$ ), while

similar values were found between SSCC and GS, SSCr and PM, and PTF1 and PTF2. In particular differences among stations were found in species richness  
 265 (PERMANOVA,  $P=0.0001$ ), with TVP stations showing richness similar and higher than PTF3 ( $P=0.0036$ ) and all the other stations ( $P=0.0001$ ), followed by the other two stations of Portofino PTF1 and PTF2 ( $P<0.01$ ). Lower than PTF were evidenced values of S Stefano SSLu, SSCa, PM, SSCr and TP ( $P<0.001$ ) and then the stations of Gallinara (GF and GS) and SSCC, this latter with  
 270 the lowest species richness ( $P=0.0001$ ). Differences were evidenced in diversity (PERMANOVA,  $P=0.0001$ ) and evenness too (PERMANOVA,  $P=0.0001$ ). The site of TVP1 was the most diverse of all ( $P=0.0001$ ), followed by TVP2, PTF3 ( $P<0.05$ ) and PTF1 and PTF2, SSLu, TP and GF, with similar values. Finally we evidenced SSCr, PM and the lowest diversity at SSCC and GS, values similar and lower respect to all the others ( $P<0.05$ ).  
 275 Equitability was higher in SSLu, PTF, TVP, TP and GF ( $P<0.05$ ), while lower values were evidenced at SSCa, SSCC, GS, SSCr and PM ( $P<0.05$ ). Caswells V Statistic highlighted that greater diversity was found in TVP stations, PTF1 and PTF3, TP and SSLu, whilst lower diversity was found in SSCa and SSCC, PTF2 and GS. Significant departure from neutral model was evidenced for SSCr, PM and GS, whose  
 280 levels evidenced stress conditions. The analysis of fishing impact (Figure 3 a) evidenced differences in anthropic pressure among stations (Anova,  $P=0.0000$ ). In particular for Portofino sect 2 we found the highest value (6,08%) of all stations (SNK,  $P<0.01$ ), followed by similar values of Portofino sect 3, Gallinara Falconara (SNK,  $P<0.01$ ) and lowest values of TVP2, TP and GS (SNK,  $P<0.01$ ).  
 285 Damaged colonies were evidenced for *P.clavata* and *E. cavolini* (Fig. 4 b, c). In particular the highest values (13.62 %) of damage of 1/3 of *P. clavata* were evidenced in TVP 2 (SNK,  $P<0.01$ ), followed by lower and similar values in TVP1 and TP (SNK,  $P<0.01$ ), while lower values were found in SSCa and PTF2 (SNK,  $P<0.01$ ).  
 290 Damage of 2/3 of colonies were highest (12.32%) in TVP1 (SNK,  $P<0.01$ ), while lower values were evidenced at TP, SSCa and Portofino (SNK,  $P<0.01$ ). Damage of 3/3 of colonies showed low and similar values in Portofino, TVP1 and SSCa. Also *E. cavolini* showed differences in level

of damage among stations (Anova,  $P=0.0056$ ). In particular damage of 1/3 and  
295 2/3 of colonies was evidenced without differences in the stations of TVP1, TP  
and Portofino, while TVP1 showed higher values of damage of 3/3 of colonies  
respect to PTF3 (SNK,  $P<0.01$ ). In all cases damage showed always values  
lower than 1%.

### 3.3. Coralligenous Structural Complexity of Assemblages

300 Analysis performed considering the Structural Descriptors highlighted a strong  
correlation of roughly all segregated stations with branching fauna and less  
strength with encrusting and massive fauna, with exception of SSCC, whose  
samples appeared separated from the main clustered group and strongly cor-  
related to nude substratum and crustose coralline algae (Figure 5). We evi-  
305 denced differences in abundance among all stations (PERMANOVA,  $P=0.0001$ ,  
;Pair-wise Tests,  $P = 0.0001$ ) of Nude Substratum (NS), Crustose Coralline  
Algae (CCA), non Crustose Coralline Algae (nCCA), encrusting fauna (EPI  
I), massive fauna (EPI II) and branching fauna (EPI III).The Similarity Per-  
centages Analysis evidenced the characteristic groups for each site (Table 2)  
310 and this characterization resulted in a different composition of the commu-  
nity assemblages in each site (Figure 6). SSLu resulted to be characterized  
mainly by massive fauna, coralline algae with similar values and lower encrust-  
ing fauna ( $P<0.01$ ). SSCa resulted characterized by a high cover percentage  
of branching fauna ( $P<0.01$ ), non-crustose coralline algae and lower massive  
315 and encrusting fauna ( $P<0.01$ ). The site of SSCC was mainly characterized  
by higher cover percentage of nude substratum ( $P<0.01$ ) and coralline algae,  
with similar values. The site of SSCr resulted composed mainly by non-crustose  
coralline algae, higher than all others ( $P<0.01$ ), and similar values of massive  
and encrusting fauna. Also the site of PM was characterized principally by  
320 non-crustose coralline algae, higher than all others ( $P<0.01$ ), followed by sim-  
ilar values of massive fauna and crustose coralline algae and encrusting fauna.  
In the site of PTF1 were evidenced branching fauna, with percentage simi-  
lar to nude substratum and higher than crustose coralline algae ( $P<0.01$ ) and

similar values of massive fauna and non-crustose coralline algae. In the site  
 of PTF2 were evidenced massive and branching fauna, crustose coralline al-  
 325 gae and encrusting fauna, with similar values. PTF3 was characterized by  
 massive fauna, similar to nude substratum and branching fauna, higher than  
 crustose coralline algae ( $P < 0.01$ ) and lower encrusting fauna ( $P < 0.01$ ). TVP1  
 resulted to be composed mainly by non-crustose coralline algae, higher than all  
 330 the others ( $P < 0.01$ ), similar values of crustose coralline algae, massive fauna,  
 branching one and lower encrusting fauna ( $P < 0.01$ ), while TVP2 resulted char-  
 acterized by higher crustose coralline algae ( $P < 0.01$ ), massive fauna similar to  
 encrusting one and higher than non-crustose coralline algae ( $P < 0.01$ ). The  
 site of TP resulted characterized by crustose coralline algae, similar to branch-  
 335 ing fauna, non-crustose coralline algae and lower encrusting fauna ( $P < 0.01$ ).  
 Gallinara Falconara (GF) was characterized by higher crustose coralline algae  
 (CCA) ( $P < 0.01$ ), similar nude substratum and non-crustose coralline algae, mas-  
 sive and encrusting fauna, while Gallinara Sciuscia (GS) resulted composed for  
 highest contribution by non-crustose coralline algae ( $P < 0.01$ ), massive fauna  
 340 and lower branching one ( $P < 0.01$ ). The nude substratum was therefore preva-  
 lent in the site of SSCC. Non crustose coralline algae were dominant in SSCr,  
 PM and GS, with low contributions of the other structural groups, while lower  
 contributions of nCCA together with higher contributions of the other struc-  
 tural groups were found in TVP1. Crustose Coralline Algae were dominant in  
 345 TVP 2, TP and GF. Massive fauna resulted the most contributor in the site  
 of SSLu, with high contributions of algae and basal fauna and with increasing  
 frequencies from the site of PTF2 and PTF3, these latter characterized also by  
 branching fauna. Branching fauna was dominant in PTF1, with low values of  
 the other groups and with the highest contributions in the site of SSCa. The  
 350 Structural Descriptors differently characterized the stations, lending in each site  
 a peculiar configuration of the structure of the communities composition that  
 describes the coralligenous system. The peculiarities in the structure of the com-  
 munity composition of the coralligenous assemblages were expressed through a  
 3D-Coralligenous Index, with values ranged between 0 (lowest complexity) and

1 (highest complexity), for each site in exam, showed in Table 3 and Figure 7  
 355 3D-Coralligenous Index evidenced differences among stations (PERMANOVA,  
 P=0.0001) and in particular Pair-wise Tests evidenced SSCa as the site with the  
 highest Structural Complexity, higher than PTF1 (P=0.02007), TP (P=0.0054)  
 and all the other stations (P=0.0001), followed by Portofino PTF1-2-3 and TP.  
 360 The lowest values were obtained by GF and SSCC (P=0.0001).

#### 4. Discussion

The increasing attention towards the urgency to find shared methodologies  
 to assess health conditions of coralligenous assemblages has been highlighted by  
 several international symposia focused on this topic (UNEP-MAP-RAC/SPA,  
 365 2009; 2014). In 2011 a list of categories of species to be considered in the inven-  
 tory and/or monitoring of coralligenous communities was provided by UNEP-  
 RAC/SPA (2011): Algal builders, Animal builders, Agglomerative animals, bio-  
 eroders, Species of particular importance (particularly abundant, sensitive, ar-  
 chitecturally important or economically valuable), Invasive species. Since dif-  
 370 ferent regions and areas within regions are characterized by different composi-  
 tion and the heterogeneity is strongly related to the scale of observation, the  
 assessment of coralligenous based on the above-mentioned morpho-functional  
 categories list may simplify the way to find the coralligenous patterns across  
 the Mediterranean. Taking into account this approach, the list here proposed  
 375 selects categories considering the effects that several stressors can play on the  
 physical complexity of coralligenous assemblages, clearly affecting the corallige-  
 nous ecosystem functioning. To have a shared and common list of simplified  
 categories to consider for quick assessments can offer an good comparative basis  
 towards a general view on Mediterranean coralligenous assemblages. This ap-  
 380 proach provides a functional perspective, focusing on indicators easily detectable  
 through the analysis of video recording. The recording of videotransects allows  
 to develop a quick methodology both during the underwater workphase and at  
 the lab, avoiding the huge effort to recognize species in the different frames.

This approach is successful for the monitoring of the Good Environmental Status (GES) within the Marine Strategy Framework Directive requirements and COP18 EcAp Decision. Our results confirm the high spatial variability of coralligenous assemblages especially at a small-scale [21, 87, 82, 68]. In this work 13 stations along Italian coasts of Mediterranean Sea were studied by analysis of video-transects to verify the presence and abundance of 28 taxa of algae and 97 taxa of animals. Algae and Cnidaria resulted the main categories to characterize coralligenous assemblages, in particular Phaeophyceae, Chlorophyceae, Plexauridae and Scleractinia. Comparing the richness and diversity of the studied stations, TVP1 and TVP2 were found to be the most rich in species and the most diverse, while SSCC was the less rich and diverse. TVP1 and TVP2, Portofino (PTF1-2-3) and GF were found as the stations with the highest equitability, while stress conditions (according to [22]s neutral model) was evidenced in SSCr, PM and GS. Lost fishing gears were detected for half of the 13 stations and in particular fishing impact was higher in PTF2 with values around than 10%, while minor damage of colonies was evidenced for *P. clavata* in TVP stations with values close to the 10%. According to the intermediate disturbance hypothesis [29], species diversity is low where disturbance is minimal because of competitive exclusion between species, with relaxed competition and increased diversity in increased levels of stress, while with high level of disturbance species became eliminated by stress with downfall of diversity, underlining that diversity is highest in intermediate levels of disturbance, due to biotic or abiotic factors. Threatening of coralligenous communities due to abrasive activities acts primarily on the external layer and then on the underlying layers, reducing the number of dominant species, leading to the fragmentation of the community structure and creating niches for new pioneer and /or opportunistic species, so maintaining high biological diversity, but causing deep changes in the population diversity. A multidisciplinary approach has been attempted to studies marine stations considering parameters such as vulnerability, aesthetic or rarity values, addressing both biological and geomorphological aspects and to combine them in a synoptic view [73]. On both terrestrial and marine habi-



415 tats (e.g. forests, coral reefs, rocky intertidal, mangrove), the habitat structures  
 have a strong influence on the diversity and abundance of species [8], confirming  
 the role of topography in the distribution of the biodiversity. Habitat structure  
 can be defined by structural complexity, scale and heterogeneity [58] and struc-  
 tural complexity of substrata, measured by relief, interstitial space and surface  
 420 area [45, 9], can be named as topographic complexity, roughness or substrate  
 heterogeneity [58] . Many techniques [89] and indexes have been proposed to  
 study how substrata affect density and diversity of species and to make compar-  
 ison within habitats [58, 33]. Conversely, measurement of substrata complexity  
 are related to the scale of observations, size and arrangement of organisms to  
 425 compare habitats [8, 11, 92] and difficulties are related to the comparability of  
 indices between habitats and scales [58]. Moreover condensing substrata com-  
 plexity into single measures may lead to a great loss of information [80] and  
 habitat complexity and benthic composition can be reliably estimated visually  
 [89]. Small scale topographical heterogeneity is considered the cause of patch  
 430 distribution, influencing recruitment and offering suitable refuges and micro-  
 habitats with different physical conditions [3, 51, 88], suitable for a particular  
 high faunal diversity [52]. In coralligenous assemblages competition for space  
 represents one of the main processes determining patterns of distribution of the  
 system, in which crustose organisms compete intensely for substratum because  
 435 of the limited use of space in two dimensions [20] and this process could con-  
 cur to increase patchiness. Predation pressure, which can limit diversity [59],  
 is furthermore reduced in semi-enclosed microhabitats [52]. An important con-  
 sideration refers to correlation of ecological status of coralligenous assemblages  
 of Mediterranean coasts to human pressure. In tropical areas, [35] analysed  
 440 the responses of reef assemblages to modifications in environmental parameters  
 caused by terrestrial pressure. Besides these approaches, in this work together  
 with all analysis performed at species level, we proposed a method to assess the  
 complexity of the assemblages composing the coralligenous systems, taking into  
 consideration different groups of organisms, named here Structural Descriptors,  
 445 that describe the structural complexity of the community. A different compo-

sition of the assemblages was therefore evidenced not only at species level, but evaluating the whole coralligenous assemblage. The methods allowed us to evidence some patterns in the structure of assemblages, that could probably let hypothesize a succession in coralligenous structuring, from dominance of nude substratum towards dominance of branching fauna that could represent a climax in coralligenous habitat, with the highest expected tridimensionality. The method finally allowed us to assess a measure of 3D-Complexity Structure for the habitat of coralligenous, based on quantitative covering data of species analysed by video-transects, combining the individuated Structural Descriptors in order to obtain a unique Index of 3D - Structural Complexity ranged between 0 and 1 and avoiding that the same index value or similar values are obtained by multiple configurations, as occurs obtaining the sum of metrics. Up today many proposed indexes deals with the ecological status assessment of the coralligenous system, from medium depth to the mesophotic assemblages, based on chosen metrics, combined by sum [41, 33, 19]. Moreover, the proposed method of evaluation takes in consideration not only some chosen metrics, but all organisms composing the coralligenous system, all with their own coverage contemplating also the situation where only substratum is present. The proposed method of evaluation of structural complexity of coralligenous assemblages could moreover be suited as a procedure to more rapidly and easily analyse assemblages, giving the possibility to collect data not only strikingly on singles species, but directly on the groups of organisms identified by Structural Descriptors, even without taxonomical specialization. It will allow us to use such information as baselines for monitoring over time the coralligenous systems and to detect eventual loss in complexity of the communities. Further investigations are needed in order to confirm the role of branching fauna as ecosystem engineer in coralligenous accretions. All efforts addressed to the knowledge of coralligenous accretions will constitute the baseline for environmental protection programs. The variability of habitats present at S Stefano, from *P. oceanica* meadow and detritic to sandy bottoms, to vertical cliffs of coralligenous rims more exposed to current flows, allowed us to evidence here different levels of structural complexity, from the

low one due to the high presence of nude substratum in Croce Cappello (SSCC), to the highest structural complexity due to the presence of branching fauna at SSCa. The high presence of non-crustose coralline algae in SSCr, PM and GS, as  
480 of coralline algae in GF, but however with strong presence of nude substratum and non-crustose coralline algae, could be justified by their heterogeneity of the bottom, strongly composed by *P. oceanica* meadow and sandy-muddy bottom, that could prevent the settlement of a more structured coralligenous community. Although a more structured coralligenous was represented in TVP1 respect to  
485 the previously mentioned stations, non-crustose coralline algae were also here strongly present, probably due to a high light availability that at this site facilitate the colonisation of photophylous algae, while a lower one at the other site of Tavolara (TVP) probably enhanced the development of a more sciaphilous community. Crustose coralline algae were dominant also at TP, but a stronger  
490 presence also of branching fauna increase the three-dimensionality of the bottom. Basal and massive fauna, together with a strong presence of branching one, characterized instead Portofino, with a well-structured coralligenous community evidenced in a very rich rocky substratum. Finally, the highest dominance of branching fauna at SSCa lead to the highest three-dimensional coralligenous  
495 community. Besides the highest richness and diversity evidenced at Tavolara and Portofino, where we showed respectively damaged colonies and fishing impacts, a lower richness and diversity but the highest three-dimensionality of coralligenous structure was found at SSCa. This could be due to the vertical cliff and the exposure to current flows that could be key conditions here for the  
500 establishment of a more rich branching fauna population. These evidences could justify differences in fauna also along the same stretch of the shelf [46, 72] providing more complex habitats and effects on circulation. The high topographic complexity could therefore support a high structural complexity of the assemblages, in terms of three-dimensionality of the community, measured for the  
505 first time in this work. Moreover canyons concentrate sediment rich in organic detritus providing trophic resources for suspension-feeders [36]. The availability of nutritive particles in suspension by current flows and controlling of resuspen-

sion and sediment rates by cascading processes, seems to greatly influence coral distributions [18, 32]. Despite the stability of coralligenous habitats [66, 39] ,  
510 destructive events such as mass mortalities can strongly affect the coralligenous community [81, 25, 49, 38]. While impacts due to fishing are diluted in time but very marked, altering density and size of the structuring epibenthic organisms [85] and the recovery is quite unlikely [7], phenomena of mass mortalities are usually of acute intensity even if occasional and a possible recovery can occur  
515 [53, 31, 23]. The resistance and the resilience of the community depend on its health status, leading to even local extinction of entire populations in case of already impacted communities, or to a fast and complete recovery of the community in previous healthy situation [49, 60]. This underlines the importance of ancient baseline or historical data to actually estimate the magnitude of change  
520 of the coralligenous assemblages and therefore estimate a state of relative health. Anthropogenic activities and climatic changes cause modifications of environmental parameters and indirectly on organisms, populations and communities, leading to the necessity to improve the knowledge in the composition and distribution of populations, their viability and reaction towards natural or anthropic stresses  
525 finalized to the creation of datasets as the starting point for a spatial and temporal monitoring. Physical human impacts, climate change, acidification, and pollution deeply influence coralligenous assemblages [48, 15, 27, 26, 50], maintained by the balance between bio-construction and bio-erosion, very sensitive to environmental changes [78, 37].

## 530 **Acknowledgements**

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Table 1: Surveyed stations

<b>Sites</b>	<b>Longitude</b>	<b>Latitude</b>
Secca di Santo Stefano (SS-Lu, -CC, -Ca, -Cr)	412658	4853221
Gallinara Island (GP, GS)	438276	4874941
AMP Portofino; Punta del Faro (PTF)	517408	4904983
Punta Manara (PM)	532264	4899424
AMP Tor Paterno (TP)	460946	278469
AMP Tavolara, Secche del papa (TVP)	562801	4529091

Table 2: Table of Similarity Percentages Analysis (SIMPER)

Site	Main current direction	MPA or other conservation measures	River proximity over-current	Exposure	Distance from towns (km)
SSLu	westward	No	6 km (Rio San Lorenzo)	east	0.5
SSCC	westward	No	13 km (Impero creek)	east	0.5
SSCa	westward	No		east	0.5
SSCr	westward	No		east	0.5
GF	westward	No	2 km (Centa River)	west	2
GS	westward	No		south	2
PTF1	westward	Yes	9 km (Entella River)	east	10
PTF2	westward	Yes		south	10
PTF3	westward	Yes		south	10
PM	westward	No	1.5 km (Gromolo creek)	south	2
TVP1	northward	Yes	19 km (Rio Siligheddu)	South-east	10
TVP2	northward	Yes		South-east	10
TP	northward	Yes	18 km (Tevere River)	North	10

Table 3: 3D Index of Coralligenous Complexity

<b>3D C-Index</b>	<b>means</b>	<b><math>\pm</math> SE</b>
SSLu	0,057	0,005
SSCa	0,500	0,037
SSCC	0,031	0,009
SSCr	0,125	0,015
PM	0,059	0,011
PTF1	0,366	0,029
PTF2	0,288	0,015
PTF3	0,313	0,021
TVP1	0,256	0,014
TVP2	0,245	0,027
TP	0,346	0,024
GF	0,029	0,002
GS	0,048	0,004



Figure 1: Map of the studied stations. 1) Santo Stefano Shoal; 4 stations (SSCC, SSCa, SSLu, SSCr). 2) Gallinara Island; 2 stations (GF, GS). 3) Portofino MPA; 3 stations (PTF1, PTF2, PTF3). 4) Punta Manara (PM). 4) Tavolara Capo Coda Cavallo MPA; 2 stations (TVP1, TVP2). 5) Secche di Tor Paterno MPA; 1 Station (TP).

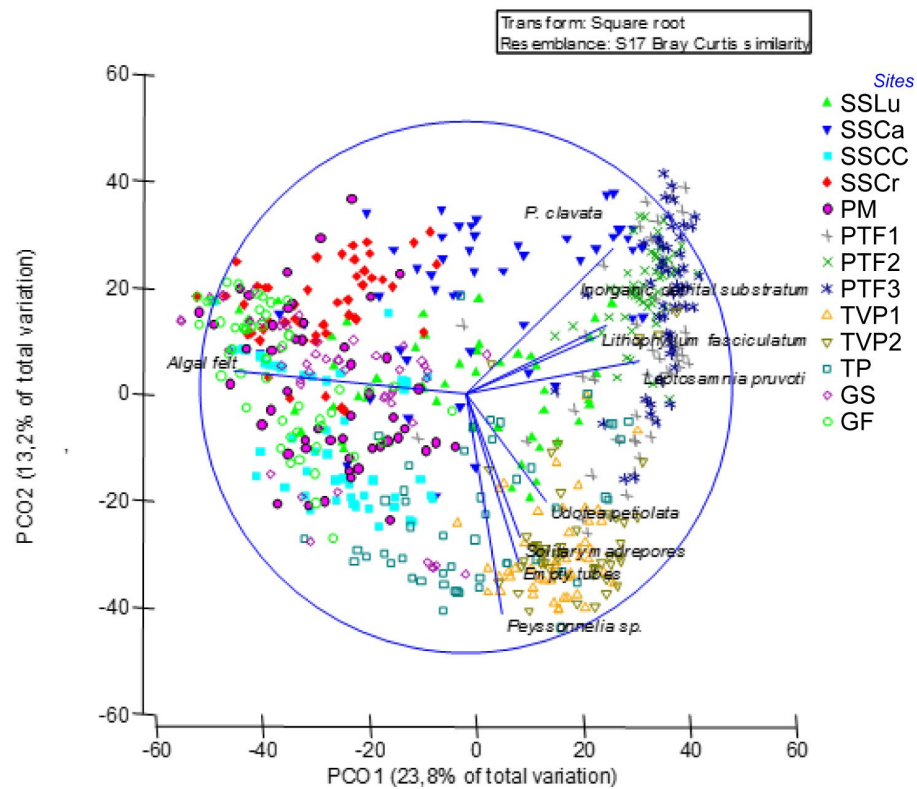


Figure 2: PCO ordination plot based on Bray-Curtis similarities of square root transformed percentage of species covering data in the 13 stations in exam. Vectors superimposed on the PCO plot represent Spearman correlation  $\geq 0,5$  of the most important groups with PCO axes.

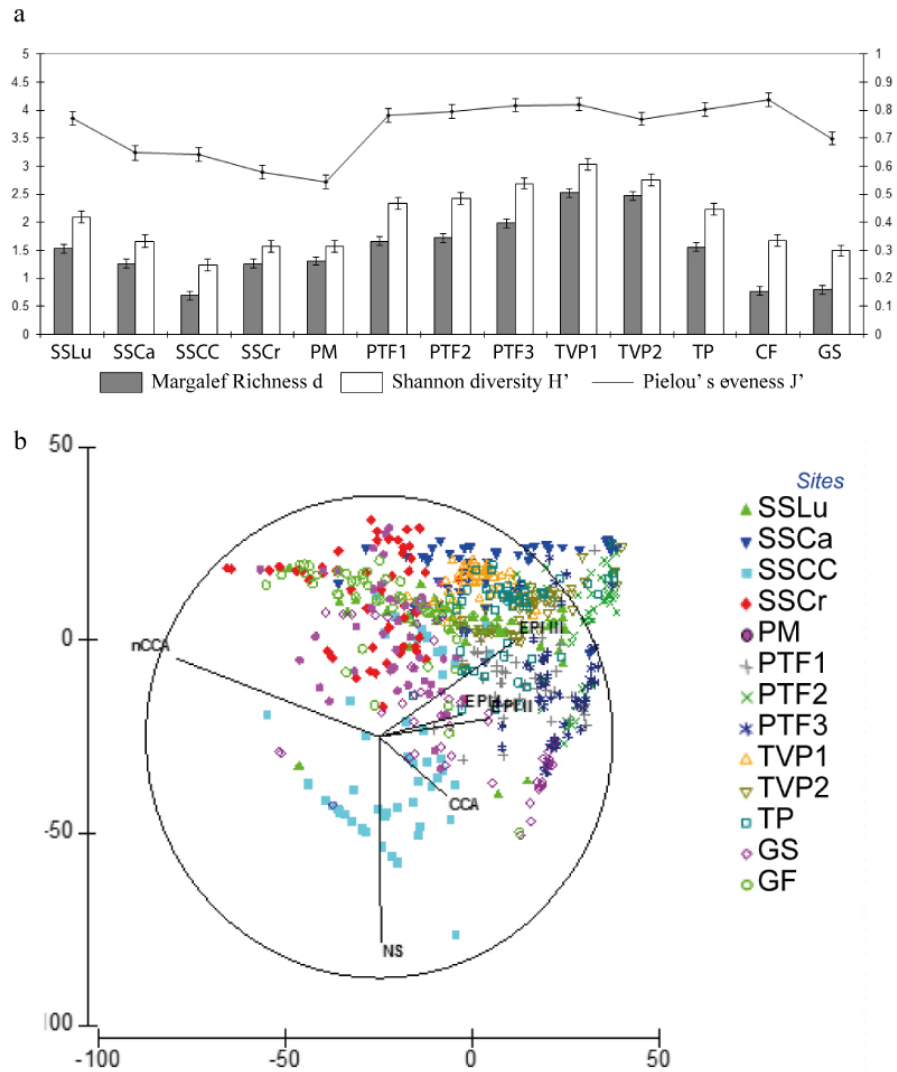


Figure 3: Diversity analysis (a) and PCA (b) of the stations in exam: Margalef richness d; Shannon diversity  $H(\log 2)$  and Pielou evenness J are indicated.

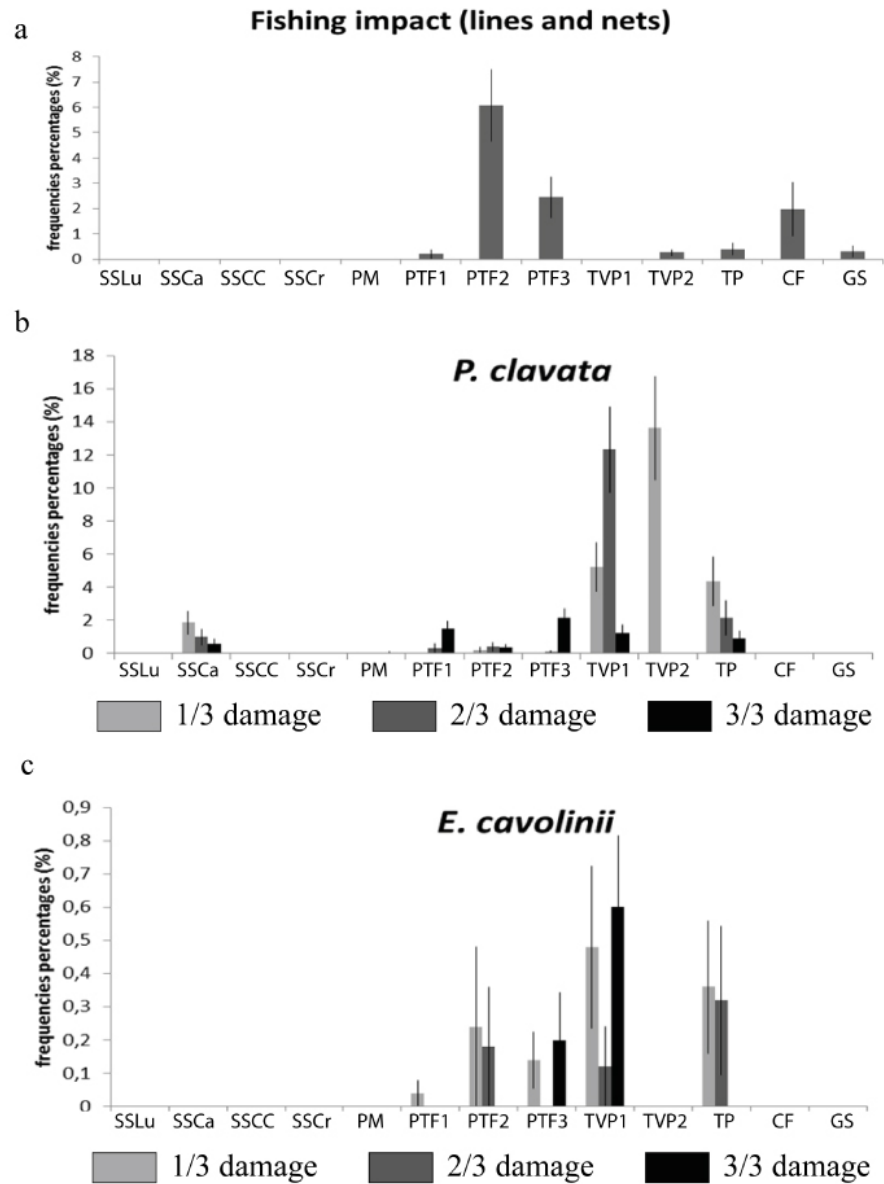


Figure 4: Frequencies percentages of anthropic pressure: fishing impact (lines and nets)(a) and damage on colonies of *P. clavata* (b) and *E. cavolinii* (c).

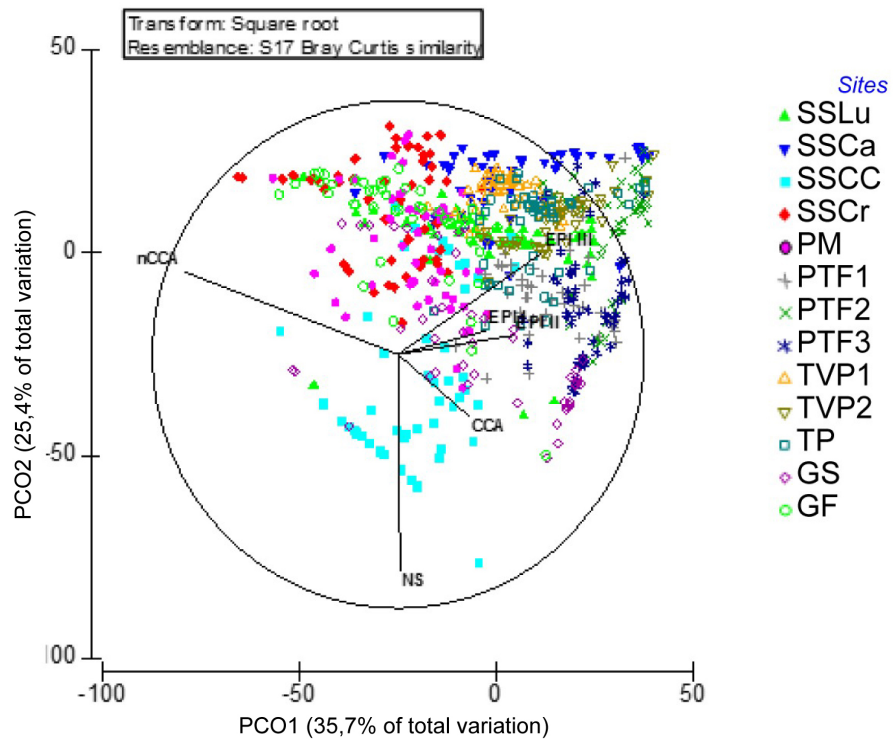


Figure 5: PCO ordination plot based on Bray-Curtis similarities of square root transformed percentage of covering data of groups structuring coralligenous assemblages in the 13 stations in exam. Vectors superimposed on the PCO plot represent Spearman correlation  $> 0.2$  of the groups with PCO axes.



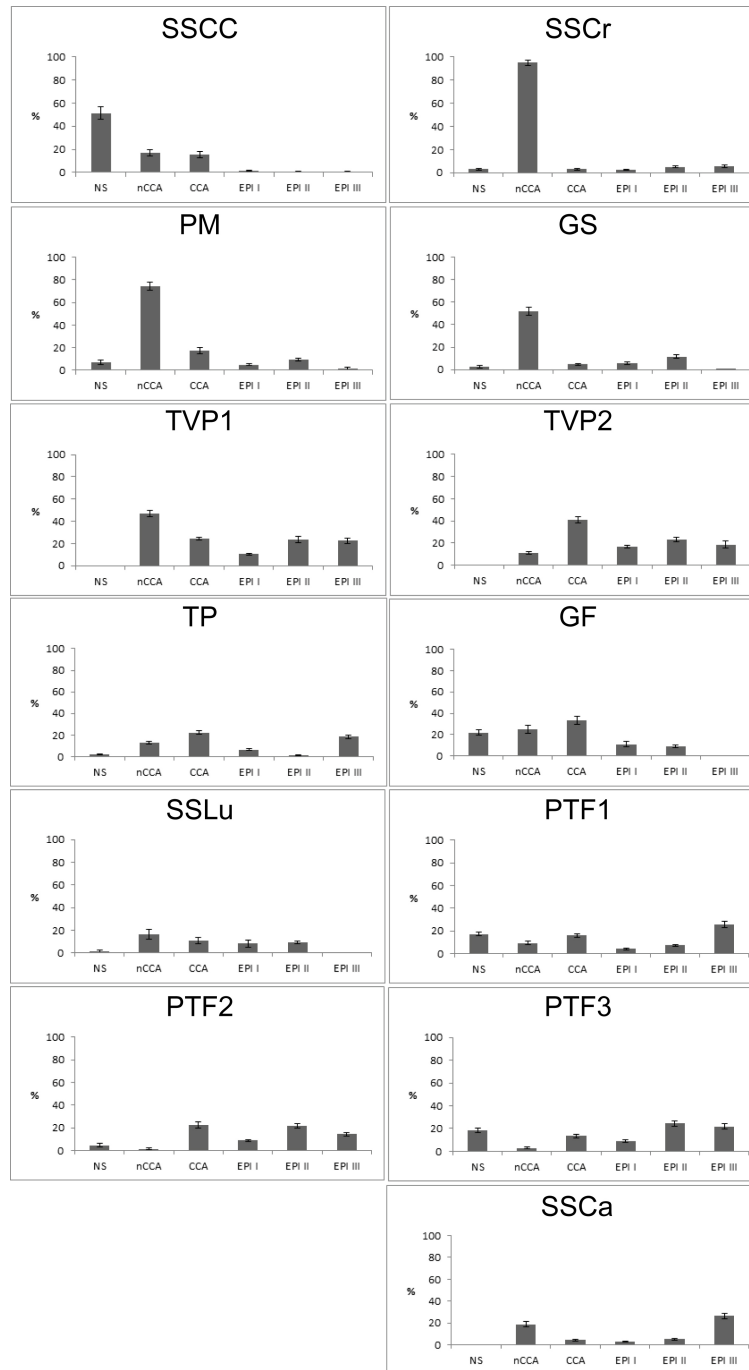


Figure 6: Frequencies percentages of Structural Descriptor in the stations in exam: nude substratum (NS), non-crustose coralline algae (nCCA), crustose coralline algae (CCA), encrusting/basal fauna (EPI I), massive fauna (EPI II) and branching fauna (EPI III).

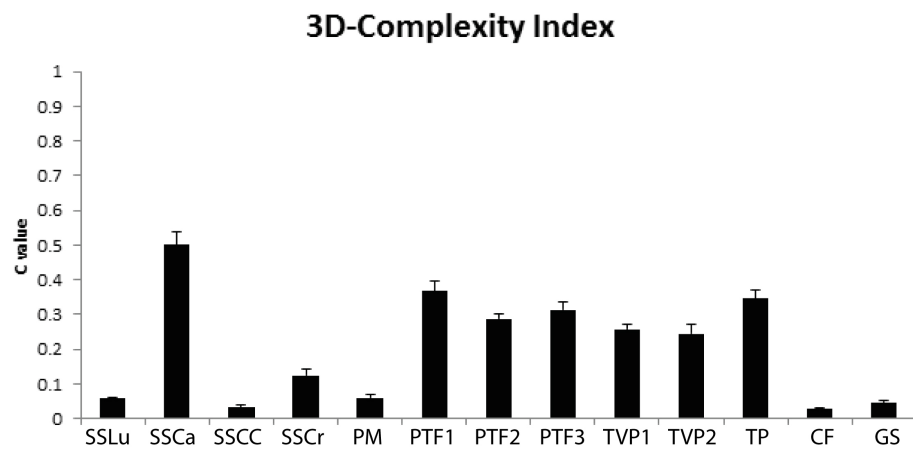


Figure 7: C Values of 3D- Complexity Index of the stations in exam.