UNIVERSITÀ POLITECNICA DELLE MARCHE

DIPARTIMENTO SCIENZE DELLA VITA E DELL'AMBIENTE

Corso di Laurea Magistrale

Biologia Marina

SVILUPPO DI UN INDICE PER LA VALUTAZIONE DELL'IMPATTO MECCANICO SULLA COMUNITÀ BENTONICA DEL CORALLIGENO

DEVELOPMENT OF AN INDEX FOR THE EVALUATION OF THE PHYSICAL IMPACT ON THE BENTHIC COMMUNITIES OF THE CORALLIGENOUS HABITAT

Tesi di Laurea Magistrale

Annalisa Storari

Relatore

Dott.ssa Cristina Di Camillo

Correlatori

Prof. Carlo Cerrano

Prof. Barbara Calcinai

Sessione febbraio 2021

Anno accademico 2019/2020

Abstract (Italiano)

L’attività subacquea ricreativa è in rapida crescita e uno degli ambienti marini di maggiore attrazione è l’habitat del coralligeno. Essendo un habitat caratterizzato da una comunità fragile e a crescita lenta è particolarmente vulnerabile all’impatto antropico. Il controllo del potenziale impatto meccanico sulla comunità bentonica è di fondamentale importanza per preservare la grande biodiversità di questo ecosistema. Negli ultimi anni sono stati sviluppati diversi metodi e indici per valutare l’impatto antropico sulla comunità del coralligeno. Tuttavia, spesso si tratta di metodi di difficile applicazione, che richiedono persone esperte nel settore.

Lo scopo principale di questo studio è l’elaborazione di un indice di semplice applicazione per stimare l’impatto fisico sulla comunità bentonica del coralligeno considerando tre canyon sommersi nel nord est della Sardegna come caso di studio. L’indice è stato sviluppato considerando la caratterizzazione della comunità bentonica potenzialmente affetta dall’impatto meccanico, attribuendo diversi valori a fattori di vulnerabilità, come il grado di esposizione o l’elevazione dal substrato, di organismi target (*Corallium rubrum*, *Myriapora truncata*, *Eunicella cavolini*, *Eunicella singularis*, spugne erette e serpulidi). La comunità di specie erette presente lungo le pareti dei canyon è stata comparata con la componente biogenica dei sedimenti raccolti alla base dei canyon, per verificare se i frammenti ritrovati nei sedimenti riflettessero la composizione della comunità di organismi calcarei in parete. Lo studio è stato condotto in tre diversi canyon, facenti parte di tre siti di immersione. L’analisi è stata fatta tramite un semplice disegno di campionamento che include: photographic sampling, video-survey e il sorting dei sedimenti raccolti. L’indice ha rivelato un impatto attuale ridotto, che è stato confermato dall’analisi dei sedimenti che non hanno presentato frammenti freschi e recenti. Tuttavia, la presenza di diversi taxa di briozoi all’interno del detrito, assenti in parete, ha dimostrato un elevato impatto meccanico passato, essendo tra gli organismi più fragili caratterizzanti la comunità bentonica.

La riduzione dell’impatto attuale può essere stata dovuta all’aumento dell’istruzione dei subacquei grazie a briefing più accurati prima delle immersioni, e alla contemporanea diminuzione della frequentazione dei siti di immersione. La diminuzione dei visitatori è evidente specialmente nell’ultimo anno (2020), a causa della pandemia di COVID-19 e delle conseguenti restrizioni del turismo. Il metodo

illustrato, che include la caratterizzazione della comunità delle pareti e l'analisi dei sedimenti, permetterà di registrare eventuali variazioni nella comunità bentonica a lungo termine, e aiuterà nella valutazione del possibile impatto meccanico.

Abstract (English)

Recreational scuba diving is a rapidly growing activity and the coralligenous habitats are among the most attractive seascapes. Coralligenous outcrop is characterized by a fragile and slow-growing community, making this habitat particularly sensitive to the anthropic impact. The control of the potential mechanical impact on the benthic community is fundamental to preserve the great biodiversity of this ecosystem. In recent years, several methods, and indices to assess the status of the coralligenous habitats have been developed. However, the application of these methods is often difficult and requires expert people.

Main objective of this study is to develop an easy-to-apply index to estimate physical impacts on the benthic coralligenous assemblages considering three submerged canyons in the north-east of Sardinia as case study. The index has been developed characterizing the benthic community living along the walls of the canyons potentially affected by mechanical impact, attributing different values to vulnerability factors, such as exposure degree or elevation from the substate, of target organisms (*Corallium rubrum, Myriapora truncata, Eunicella cavolini, Eunicella singularis,* erect sponges and serpulids). The walls' assemblages were compared with the biogenic component of sediments collected at the base of the canyons, to verify whether the fragments found in the sediments reflected the species composition of skeletal calcareous organisms living on the walls. The study has been conducted in three different canyons, in three diving sites. The analysis has been done through an easy sampling design, including photographic sampling, video-survey, and sorting of the collected sediment. The index revealed a reduced recent impact. This is confirmed by the analysis of sediments, which did not reveal fresh and recent fragments. However, the presence of different taxa of bryozoans in the collected detritus, absent in the walls' assemblages, have been evidenced an elevated mechanical impact in the past. In fact, bryozoans are among the most fragile species characterizing the benthic community.

The low impact at present can be due to the higher education of the divers, thanks to more accurate briefing before the dive, and at the same time to the decreasing of the frequentation of the dive sites. The decreasing in the number of visitors is mainly evident in the last year (2020), attributable to the COVID-19 pandemic and the consequent restrictions of the tourism flux. The method above mentioned,

including the characterization of the walls' assemblages and the analysis of collected sediments, will allow to record eventual variations in the benthic community at long-terms, and will help to assess the potential mechanical impact.

Sommario

1. Introduction

Recreational scuba diving is a rapidly growing activity that is leading to an increasing demand for marine resources (in terms of marine areas and flora and fauna associated) (Davis & Tisdell, 1995).

The direct impact of scuba divers may alter the morphology and the dimensions of organisms, reducing the capacity to perform their biological activity. It can engrave on their healthy state and they become more susceptible to epibiosis and necrosis phenomena. At least it can reduce coverage and abundance of vulnerable species, with consequences like landscape alteration (aesthetic damage), habitat degradation and reduction of ecosystem services. Especially, scuba divers can affect marine environment in several ways, both intentionally and unintentionally: through direct contact by fins and other part of their scuba equipment; through the entrapment of air bubbles in marine caves; or through the resuspension of sediments (Di Franco et al., 2009; Milazzo et al., 2002; Talge, 1990). The control of these potential sources of impact does represent a fundamental key to manage diving activity in highly frequented diving spots (Di Franco et al., 2009).

In the particular case of management of scuba diving impact, the carrying capacity is the maximum number of dives that a site can support without showing any evident degradation (Coma et al., 2004; McCool & Lime, 2001). Different studies have evidenced that the impact of scuba divers on the marine environment can be more affected by divers experience and behavior rather than the number of divers visiting a site (Rouphael & Inglis, 1997). The high variability in physical and biological features of a given site may influence its vulnerability and consequently the number of divers that can visit it (Di Franco et al., 2009). For these reasons the calculation of a value for the recreational carrying capacity is not easy and this “top-down” approach seems too simplistic (Rouphael & Inglis, 1997).

The coralligenous habitats are among the most attractive seascapes, which coupled to its slow dynamics and longevity make it one of the habitats most exposed to human impacts (Ballesteros, 2006).

In recent years, several methods and indices to assess the status of the coralligenous habitats have been developed (Bavestrello et al., 2016).

Table 1

Index-Aim-Method-Descriptors-Impacts-Complexity-References

Index	*Aim*	*Method*	*Descriptors*	*Impacts*	*Complexity*	*References*
ESCA (Ecological Status of Coralligenous Assemblages)	Assess the ecological status of coralligenous assemblages through the analysis of the macroalgal community, according to the principles of the WFD	Photographic sampling	Presence/absence of sensitive taxa, diversity of assemblages (α-diversity), heterogeneity of assemblages (β-diversity)	Biological invasion by *C. Racemosa*, sedimentation, nutrient enrichment	●●●●○	(Cecchi et al., 2014)
CAI (Coralligenous Assemblage Index)	Evaluate water quality through the sampling of coralligenous assemblages, according to the principles of the WFD	Photographic sampling	Bryozoa % cover, sludge % cover, builder species % cover	Fish farming, population development, industrial development, agriculture, tourism, fishing, ports, urbanization.	●●●○○	(Deter et al., 2012)
COARSE index (COralligenous Assessment by Reef-Scape Estimate)	Characterization and evaluation of coralligenous reefs evaluate the state of coralligenous reefs as an indicator of seafloor integrity rather than coastal water quality	RVA (rapid visual assessment)	Basal layer: percent cover of benthic community, thickness and consistency of calcareous layer, borer marks; interemediate layer: specific richness, erect calcified organisms, sensitivity of bryozoans; upper layer: species coverage, height, necrosis	Seawage plant outflow, diving activity, fishery, sediment resuspension	●●●○○	(Gatti et al., 2015)
EBQI (Ecological Quality Index)	Assess the ecological status of coralligenous outcrops, applying the ecosystem-based approach, according to the principles of the WFD	Photographic sampling, visual census, RVA (rapid visual assessment)	Builders and invertebrates, non-calcareous algae, benthic filter- and suspension-feeders, bio-eroders, grazers, planctivorous and predatory teleosts, cephalopods, predators, benthic POM, detritus feeders	Not specified	●●●●○	(Ruitton et al., 2014)
CavEBQI (CaveEcosystem-Based Quality Index)	Evaluate the ecological quality of the Mediterranean undersea caves applying the ecosystem-based approach, according	Photographic sampling, visual census	Passive feeders, large active filterers, small active filterers, filterers stratification, detritus feeders and omnivores	Diving activity, urbanization, waste, seawage plant outflow	●●●●○	(Rastorgueff et al., 2015)

	to the principles of the WFD		mysids, characteristics carnivores, associate carnivores,			
CBQI (Coralligenous Bioconstructions Quality Index)	Development of a new index for the evaluation of the quality status of different types of coralligenous bioconstructions through an easily and rapidly applicable method	ROV survey	Coralligenous structuring, coralligenous stress, bottom abiotic factors	Fishing activity	●●●●○	(Ferrigno et al., 2017)
INDEX-COR	Evaluate the ecological status of coralligenous habitats, through an easily and rapidly applicable method	Photographic sampling, in situ observation	Sensitivity of the taxa to organic matter and sediment deposition, observable taxonomic richness, structural complexity of the assemblages	Sewage outfalls, diving activity, yachting, fishing activity, industry, anchoring	●●●●○	(Sartoretto et al., 2017)
STVI (Scuba Trail Vulnerability Index)	Define an index of vulnerability for dive trails	Photographic sampling	Coverage, height from the substrate, organism shape, exposure, rock type presence of suspended sediment, breakage resistance, growth rate, presence of permanent fish	Diving activity	●●●●●	(Di Franco et al., 2009)
D-index (Disturbance Index)	Define a disturbance index for scuba divers' impact in caves	Photographic sampling	Exposure degree, substrate elevation, diameter of the colony, presence of damaged organisms	Diving activity	●●○○○	(Di Camillo et al., 2019)

*WFD: EU Water Frame Directive (Directive 2000/60/EC)

Index: different indices proposed; Aim: the aim of the approach; Method: the sampling method adopted from the approach; Descriptors: the metrics adopted from the index; Impacts: the impacts considered in the development of the indices; Complexity: an estimation of the complexity of the use of the index considering the index application and the method adopted from the approach.

As we can see in Table 1, all the approaches described are based on non-destructive methods, adopting different metrics for the status assessment. Some indices are based on the analysis of a limited number of species, like the ESCA (Ecological Status of the Coralligenous Assessment) index (Cecchi et al., 2014) and the CAI (Coralligenous Assemblage Index) (Deter et al., 2012), while others on the whole ecosystem as the EBQI (Ecological Quality Index) (Ruitton et al., 2014). This can implicate different issues.

A small scale at species level gives high resolution information about the communities composition but requires taxonomic experts and organism sampling, while a large scale at ecosystem level gives an useful overview but it is more time consuming for the study of the several components included in the index (Ferrigno et al., 2017). Another concern is the consideration of different anthropic pressures, which can complicate the selection of the right metrics, that must be related to these anthropic pressures, and the interpretation of the results as well.

The achievement of a good status for marine coastal waters is an important aim of two European directives: the Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (MSFD 2008/56/EC) which both promotes the conservation of aquatic systems and the development of management strategies for sustainable use of water (Cecchi et al., 2014). The Ecological Status of Coralligenous Assemblages index (ESCA index) (Cecchi et al., 2014) and the Coralligenous Assemblages Index (CAI) (Deter et al., 2012) both adopt the state of coralligenous communities as an indicator of coastal waters according to the WFD. They are based on data collected by photographic sampling and subsequent image analysis using free software.

The ESCA (Ecological Status of Coralligenous Assemblages) index, developed by (Cecchi et al., 2014) has the aim to assess the quality of coastal waters on the basis on analyses of coralligenous macroalgal assemblages, therefore it is not just related to the status of coralligenous *sensu stricto*. However, it is based on coralligenous structural and functional analysis as required by WFD. The index is based on a photographic method in line with the WFD, but in case of macroalgal identification can have some negative implications. In fact, some species are morphologically very similar, preventing their identification in photographic samples. In these cases, species not recognizable were classified into morphological groups, based on both available literature and results of multivariate analysis (CAP), which provides the response of assemblages to different stressors and the species responsible for the response. Thus, morphological groups were based on organisms with the same thallus characteristics and the same response to stress. Three descriptors have been defined (Table 1): presence/absence and abundance of sensitive taxa/groups, diversity of assemblages (α-diversity) and heterogeneity of assemblages (β-diversity). This study also considers three pressure indicators: biological invasions by *Caulerpa racemosa*, increased sedimentation and nutrient enrichment. These are combined to give a final value for the Ecological Quality Ratio (0-1), scale ranges from 1 (best conditions) to 0 (worst conditions), and the definition of 5 quality classes. According to the WFD, the ecological status must be defined as an Ecological Quality Ratio (EQR) value obtained from the ratio between the value of the metrics/index calculated for the studied site and the same value obtained for the Reference Conditions. In this study Montecristo Island was listed among the Reference Sites of the intercalibration network (GIG, 2013) so the reference conditions chosen for this study follow the WFD and correctly represent the pristine condition for the considered biogeographical area. However, the application of ESCA in other parts of the Mediterranean basin will require an evaluation of the geographical range in which the reference values established in this study can be considered valid and to eventually determine other area-specific reference conditions (Cecchi et al., 2014). Concerning the coralligenous ecosystem is one of the most complex and relatively poorly known, so it may be problematical to set a "reference condition". Results of the study confirmed the potential for using macroalgal coralligenous assemblages as an ecological indicator, especially the heterogeneity (β-diversity) seemed to respond significantly to stress suggesting that it may be a more valid descriptor of ecological quality of coralligenous assemblages (Cecchi et al., 2014). In fact, heterogeneity is a fundamental characteristic of the coralligenous ecosystem; due to the great biological interactions coralligenous assemblages usually show a patchy distribution, maintaining habitat heterogeneity at very high levels of β-diversity (Cecchi et al., 2014).

In the case of the Coralligenous Assemblages Index (CAI) (Deter et al., 2012), the metrics are selected considering their ecological meaning; several metrics has been selected and then tested for a link with the anthropological pressures present in the area. Definitive metrics (Table 1) included sludge percent, percent cover of builders and percent cover of bryozoans. All the metrics included were obtained from photographic quadrats. This cheap method presents the advantages to provide objective and repeatable estimations thanks to a fast and non-destructive underwater work (Bianchi et al., 2004). The assessment of the quality status has been obtained through the calculation of the EQR and the definition of a reference value. Given that pristine condition was not definable for the area, a “theoretical optimal site”, corresponding to the best values of each metric noted in the field has been used as reference value. It is necessary to take into consideration that the reference conditions of coralligenous habitats situated close to areas with a naturally high sediment and organic matter inputs are different from those situated offshore or far away from river mouths (Sartoretto et al., 2017). Therefore, the acquisition of annual datasets would be necessary to better define the quality of coralligenous habitats (Sartoretto et al., 2017). The main issue with the study in question is concerning the selected metrics, in particular gorgonians. Because of their long life expectancy and slow dynamics, gorgonian populations are particularly vulnerable and show long-term consequences of disturbances (Garrabou & Harmelin, 2002; Linares et al., 2007). Because of this weak resilience, it is thus difficult, without population historic and long-term data, to link present observation with present anthropogenic pressures especially potentially recent enhancements; in other terms, metrics acquired during the study might be more explained by former events (Deter et al., 2012). Although further applications and validation are needed, the selection of metrics that are cheap and easy to be acquired and analyzed may help the understanding by coastal managers and stakeholders.

Differently from the existing approaches, the COARSE (COralligenous Assessment by ReefScape Estimation) index uses SCUBA diving observations and measurements to gather data useful to evaluate the state of coralligenous reefs as an indicator of sea-floor integrity rather than coastal water quality (Gatti et al., 2015). It is based on the RVA (Rapid Visual Assessment), which optimizes underwater work allowing the direct collection of a sufficient amount of data with a congruent diving effort (Gatti et al., 2012). Since it is based on a direct visual method, the index may suffer the consequences of the variability between observers that can affect both the visual estimations of percent cover (Meese & Tomich, 1992) and the correct identification of species (Thompson & Mapstone, 1997). As coralligenous assemblages show a stratified structure, for each replicate bionomic data were collected separately for three distinct layers: basal layer, constituted by encrusting or with limited (<1cm) vertical growth organisms; intermediate layer, composed by organ- isms with moderate (1–10cm) vertical growth; upper layer, characterized by organisms with considerable (>10cm) vertical growth (Gatti et al., 2015). For each layer scuba divers applied the RVA obtaining data as (Table 1) percent cover of benthic categories (encrusting calcified rhodophyta, non-calcified encrusting algae, encrusting animals, turf-forming algae, sediment), the thickness and consistency of calcareous layer, the list of species, the maximum height of each species, the percentage of necrosis and just for the second layer six photographs were randomly shot without a frame over the sampled surface, to integrate the list visually compiled underwater (Gatti et al., 2015). Different criteria for the assignation of quality scores to each descriptor have been defined and this can make the index quite intricate. The photographs have been used to test the robustness of the visual estimation obtained underwater of the cover percentage of the benthic categories. In this case has been analyzed only the percent cover of benthic categories, so: encrusting calcified rhodophyta, non-calcified encrusting algae, encrusting animals, turf-forming algae. Visual estimations of expert and non-expert observers result to be likely close to the actual cover with only few discrepancies, which seems to suggest that the RVA can be an efficient tool to assess seafloor integrity of coralligenous reefs even by non-expert scuba divers. Even though this method seems to be valid to evaluate the percentage cover of macro-groups of organisms it can be less reliable in terms of the correct identification of species (Thompson & Mapstone, 1997).

The EBQI (Ecological-Based Quality Index) combines multiple parameters to indicate the status of the ecosystem (Rastorgueff et al., 2015). The ecosystem-based approach is the keystone of the Marine Strategy Framework Directive (MSFD 2008/56/EC) that established a framework for conservation in the field of marine environmental policy (Personnic et al., 2014). It is based on non-destructive methods which are essentially photographic sampling and visual census. This method has been developed by Personnic et al. (2014) to assess the status of *Posidonia oceanica* meadows and then has been adapted for the assessment of the ecological quality of other ecosystems: coralligenous outcrops by Ruitton et al. (2014) and caves by Rastorgueff et al. (2015). In both cases they considered several components of the ecosystems (Table 1) considering the relative ecosystem models. Each component has been evaluated through a semi-quantitative scale (very bad, moderate, and very good) and the importance of every component has been defined from the lowest to the highest weight. The range of values of the EBQI index is from 0 (worst quality of the ecosystem) to 10 (best quality of the ecosystem). In addiction each component is accompanied by a Confidence Index to give an insight of its reliability for a given site (Personnic et al., 2014) on the bases of the recency of data. Concerning the CavEBQI, the cave ecosystem can be really variable and heterogeneous and this has been taken into consideration, but consequently, although the model of cave structure and functioning is applicable to caves of the Mediterranean Sea, adjustment for species with different ecological requirements and distributions may be needed (Rastorgueff et al., 2015). In this study the main impact considered is the water warming which seems to have the main deleterious effect on cave communities, while scuba divers' impact does not appear as a major threat. Scuba divers' impact is just considered as an activity that can affect sedimentation and vertical water stratification (Di Franco et al., 2010; Guarnieri et al., 2012), but it disregards some behaviors like the contact with the organisms which often is unintentional (Chung et al., 2013). Among them, fins are the main source of damage to benthic organisms (Giglio et al., 2020). On the other hand, the method elaborated for the assessment of coralligenous ecological status is not related to a certain type of impact. The use of EBQI needs a "reference condition" of a non-impacted area to compare the status of the site under exam, concern this, certainly the EBQI method is enough robust to assess the status of *Posidonia oceanica* meadows, which is the best documented marine ecosystem of the Mediterranean coastal areas (Personnic et al., 2014), but can be less adequate to describe less-known or more complex ecosystems. Indeed, coralligenous outcrops are a much more complex and less well-known ecosystem than *P. oceanica* meadows, calculation of coralligenous EBQI will require the participation of experts in several fields of marine ecology (Ruitton et al., 2014).

The CBQI (Coralligenous Bioconstructions Quality Index) developed by Ferrigno et al. (2017) has the aim of developing a new index, more widely applicable, based on a synthesis of recent knowledge, for the evaluation of the quality status of different types of coralligenous bioconstructions (Ferrigno et al., 2017). However, in this study have been considered specific sites, indeed all the sites have high depth (from 30m to 150m depth) and the index is focused on the fishing threat. These precise characteristics make the index not easily replicable. Moreover, the sampling method is based on the use of ROV survey, which might be rather expensive and so not affordable. By contrast it is quite fast and avoids the use of

Scuba divers at considerable depths, and provides sufficient levels of detail and a great deal of information (Smith & Rumohr, 2005). The index considers three groups of variables (Table 1): coralligenous structuring, which consider the coralligenous cover, the morphological groups of the organisms and the fan corals density; coralligenous stress, measured by the percentage of necrosis/epibiosis, the percentage of organisms covers and the percentage of fishing gears; bottom abiotic factors, that are depth, degree of the slope and substrate type. An important innovation of CBQI is exactly the inclusion of bottom abiotic factors in the index calculation. All these factors can profoundly affect the coralligenous community. In particular, the reduction of slope and the increase of depth are important factors negatively influencing the primary production and, consequently, the growth of the whole coralligenous communities, causing an increase of sedimentation and turbidity (Piazzi et al., 2004). The CBQI is a good index for the investigation of deep coralligenous habitats with the above-mentioned characteristics. In addition, it is not of great complexity in terms of number of variables and mathematical calculation, but rather in terms of impact assessment it may require an adaptation in case the main impact should not be the fishing activity.

Similarly, the aim of the INDEX-COR is the evaluation of the coralligenous status through an easily and rapidly applicable method. The development of the index is based on photographic samples and in situ observation, similar to the RVA approach used in the COARSE index (Gatti et al., 2015). The index integrates three metrics (Table 1): the sensitivity of the taxa to organic matter and sediment inputs, the taxonomic richness, and the structural complexity of assemblages. Different types of pressures have been considered as well as the organic matter and sediment input, diving and anchoring, fishing activity and presence of litter, all of these have been related to different levels of pressures. The index seems to reflect well the presence of human impact, assuming lower values in stations particularly exposed to sediment inputs. However, precise information about the sensitivity to sedimentation and organic matter inputs are almost nonexistent for species thriving in coralligenous assemblages (Montefalcone et al., 2017). Another concern is the quantification of sediment and organic matter inputs, since they may be very patchy (Sartoretto et al., 2017). Hence, the expert judgment has been used as the main criterion. The third metric is based on the structural approach also adopted by the COARSE index (Gatti et al., 2015). In fact, the structural complexity has been obtained in the same way, combining the three layers recognizable in the coralligenous structure (basal, intermediate and high level) and as seen in the COARSE index (Gatti et al., 2015) a correlation with the level of pressure has been proved. Particularly, the intermediate and the high level seems to be affected especially by the physical impact (e.g., scuba diving and anchoring). Due to the lack of knowledge the formulation of the reference condition required by the WFD is quite complex. The INDEX-COR provided the first assessment in a specific area as a 'current baseline' that can be used to compare future evaluations of state (Sala et al., 2012). The acquisition of other annual datasets in the same sampling stations with no notable variations of human impact will allow estimating the robustness of the index (Sartoretto et al., 2017). In this way it could be possible to obtain theoretical reference values of INDEX-COR by combining the highest values obtained for each metric, according to the WFD.

Concerning more specific indices to assess the impact from scuba diving, the STVI index is based on a "bottom up" approach, characterizing the benthic communities that can potentially be affected by the diving activity and evaluating their vulnerability. This is the first step for effectively managing scuba diving (Lloret et al., 2006). This index takes into consideration both the physical and the biological traits, considering benthic assemblages and environmental features. Only non-quantitative traits has been considered, the representation through qualitative categories is a good compromise between the simplification of sampling procedures and the preservation of important information (Di Franco et al., 2009). Nine traits have been selected (Table 1): coverage, height from the substrate, organism shape, exposure, rock type, presence of suspended sediment, breakage resistance, growth rate, presence of permanent fish. Each of them is related to five vulnerability classes: from VC1 (minimum vulnerability) to VC5 (maximum vulnerability). Five vulnerability classes may represent the right trade-off between simplicity and resolution (Angel et al., 1998). Each trait presents from two to five categories which represent the different degrees of vulnerability to the presence of scuba divers. At this time, a fuzzy approach has been adopted: each category of a trait was associated to the five VC with values from 0 to 1, on the bases of personal knowledge and experiences. This methodology provides the tools to deal with uncertain and/or qualitative data and it allows to incorporate subjective expert knowledge into ecological models.

Instead of the classical ‘yes-no’ approach, the fuzzy approach allows to relate a category of the scuba trail to a VC with a membership grade that can range between 0 and 1 (Di Franco et al., 2009). The result of this procedure is a huge matrix made of 37 lines and 5 columns. After that, a weight has been assigned to the nine traits based on their importance (on the bases of personal knowledge and experiences), for example the trait “organisms shape” was related to the highest weight while “presence of permanent fish” had the lowest. To calculate the STVI, weights were normalized, and the fuzzy output can also be “defuzzified” to obtain a single numerical value. This index can be useful for the management of MPAs, for example if the STVI is high, managers may intervene proposing dramatic solutions, such as permanent closures of temporary permitting a limited access to the site only to expert divers. For intermediate classes of vulnerability, it could be sufficient to rotate scuba diving sites, opening some to visitors and closing others. For cases of very low vulnerability however, no particular management strategies may be required (Di Franco et al., 2009). Although the index seems to be a valid and complete tool to evaluate the vulnerability of benthic community toward the presence of scuba divers, it is also not easily applicable. Indeed, a huge amount of knowledge and experience is required because of the use of the fuzzy approach and the consideration of non-quantitative traits, but also due the formulation of the index with so many variables. All these considerations can make this index not be within everyone’s reach.

The estimation method of scuba divers impact is related even to the study reported by Di Camillo et al. (2019). The aim of the study is the assessment of the effects of recreational scuba divers through the comparison between protected and non-protected caves. The approach adopted is based on the collection of sediments and on video and photo surveys. It considers two different methods to evaluate the scuba divers’ impact in submerged caves: the former is based on the collection and sorting of sediments while the latter is the formulation of the D-index (Disturbance Index). In fact, the analysis of sediments is an effective approach to evaluate the impact, considering the variation of the number of the organisms’ fragments found during the sorting. The higher the number of fragments the higher the impact. While the index is based on vulnerability factors (Table 1) of target species: exposure degree, substrate elevation, width of the colony and presence of damaged organisms. Different classes and different scores have been assigned to each factor and the summation of the scores provides the index value. The definition of the status of the caves is based on the definition of five quality classes. The target species considered are fragile and erect species: *Corallium rubrum*, erect bryozoans, annelids, and erect or massive sponges. Both methods seem to well reflect the impact in the caves, in particular protected caves resulted less impacted than non-protected ones. The use of the index seems to have some advantages, particularly shortening the time needed for the analysis. Moreover, the identification of species through the sorting of sediments might requires expert people whereas the data collection and the analysis of data needed by the index approach require even just trained people. This makes the index approach a simple and fast applicable method and, therefore, easily replicable.

The aim of this study is to give an estimation of the physical impact on the benthic coralligenous assemblages in the submerged canyons in the north-east of Sardinia, through the development of a simple applicable index and the evaluation of collected sediments, following the caves' study principles (Di Camillo et al., 2019).

2. Materials and methods

2.1 Study area

The study has been conducted in the coralligenous assemblages located in Costa Paradiso, in the north-east of Sardinia (Figure 1). The area is exposed to an intense touristic pressure, especially during the summer season. Besides, there are several diving trails used by the Diving Center Costa Paradiso since 1996.

The study area is characterized by granite rocky cliffs extending to a wide sandy platform at about 35-40m depth.

Three dive sites have been selected: Canyon del Vikingo (41° 2' 41.9" N 8° 55' 8.8" E), Agnata (41° 3' 10.8" N 8° 56' 4.7" E) and Rocca Ruja (41° 3' 55.1" N 8° 57' 1.0" E). All of them are distinguished by the presence of canyons along the dive trail. These different canyons vary in terms of width and this may influence the risk of physical impact. The chosen sites share the same main characteristics. The cliffs are steep and reentrant, facilitating the settlement and the growing of sciaphilic organisms typical of the coralligenous assemblages, such as relevant species as the red coral, *Corallium rubrum*. The vertical walls terminate steeply to the sea bottom, that in this area consists in a sandy sediment. Another important feature took in consideration is the exposure to the local wind regime. In fact, the two sides of the canyons considered have comparable orientations, respectively South East (SE) and North West (NW).

The site Canyon del Vikingo presents the narrowest canyon among the three sites, about two meters width. The canyon hosts important species as *Corallium rubrum*, *Eunicella cavolini* and erect bryozoans as *Myriapora truncata*, which are also very attractive for scuba divers.

On the contrary, Rocca Ruja has a several meters width canyon, the widest one. Furthermore, this canyon is characterized by the highest abundance of red coral and this explains the high frequentation of this site.

At last, the Agnata's canyon shows a bottleneck structure, measuring only a few meters at its narrowest point. The sampled area corresponds to the section right after canyon entrance.

Diving attendance. Data regarding the attendance (number of divers per year) of all the dive sites in the study area were obtained from a register kept by the staff of the dive center in the period from 2011, when data started to be recorded, to 2020. These data were used to define the scuba diver flux during those years, that could mirror the diving pressure in the sites.

Then, data relative to the yearly attendance in the three considered canyons (Rocca Ruja, Agnata, Vikingo) were compared with the variation in the total number of divers per year. To go deeper into the analysis even the diving qualification of the scuba divers has been stored based on two categories: Open Water Divers (OWD) and Advanced Open Water Divers (ADV) or higher levels.

Figure 1. Study aera and sampling stations

2.2 Field work

The three sites were sampled during September 2020, after the summer season. In each site, three transects were placed, indicate by a banded nail, on both sides of the canyon at three depths (20m, 25m, 30m). Data were collected by two scuba divers, my colleague and me, taking 20 photoquadrats (25 x 25cm) along the transect. The number of photoquadrats was set to be representative of all the canyon diversity. The small dimensions of the frame were necessary because of the uneven trend of the walls. For this reason, respectively 10 photos of the crevices and 10 photos of the walls have been taken.

The photoquadrats were took randomly along a transect 4.5m length x 1m width (Figure 2). A digital camera equipped with the housing and a spotlight were fixed in a metallic structure to increase stability.

After the photo-sampling, a videotransect were taken at each depth. This is useful to determine the trade of the walls and, furthermore, to report the presence of eventual nets or marine litter.

In addition, for all the erect organisms, such as bryozoans, annelids and gorgonians, the elevation from the substrate were measured. To complete the characterization of the sites, some physical parameters were recorded at all depths for instance, temperature and orientation of the wall. Besides, to have a better assessment of the physical impact, three samples of sediment (250ml) were collected below the transects, for each side of the canyons. Only the superficial detritus was collected, almost the first 10cm-layer.

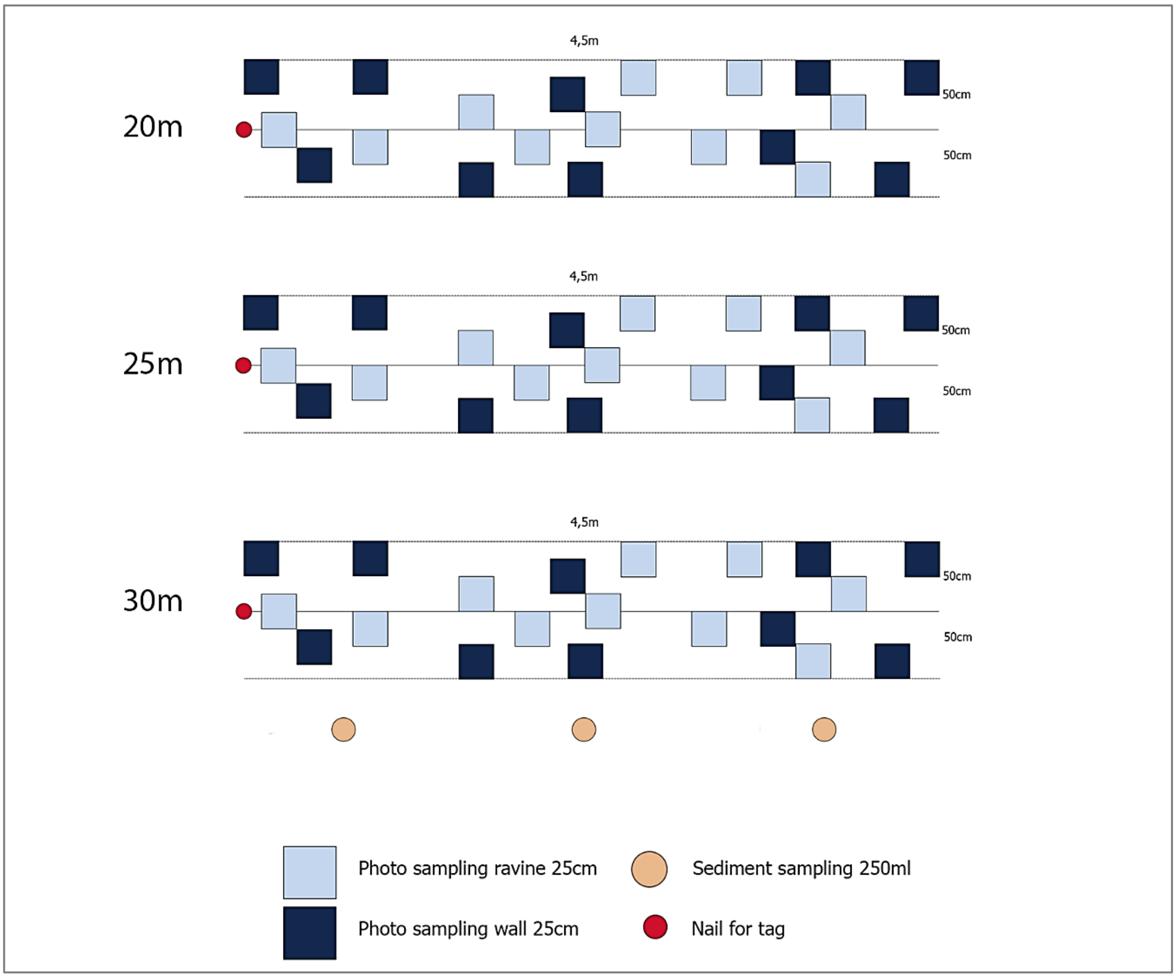

Figure 2. Sampling design.

2.3 Data management

2.3.1 Image analysis

Each photographic sample was analyzed thanks to the free software *ImageJ*, that allowed the estimation of the percentage cover of all the organisms living in the assemblage and the count of the vulnerable species, shown in the Table 2. For the index calculation, only the last one was considered.

For modular and bushy species, such as *Myriapora truncata*, distinguishing and counting the singular colony was not possible. In this case were considered a standard area ($5cm^2$) correspondent to a colony. A similar method was adopted for *Corallium rubrum*; in fact, some zones were particularly dense in terms of population and discriminating the singular specimens was difficult. Therefore, in each photographic sample was selected an area ($10cm^2$) to better determine the number of the organisms. Then, considering the total area occupied by the red coral in the photographic sample, it was possible to have an estimation of the total number of specimens. On the contrary, the hard coral *Leptosammia pruvoti* was abundant in some frames, so the count tool of the software was used, and the estimation of the total area occupied was obtained multiplying the area of the single organism by the total number of specimens.

Table 2

Fragile species considered vulnerable to mechanical impact.

Phylum	Species
Porifera	*Axinella sp.*
Bryozoa	*Myriapora truncata*
Cnidaria	*Corallium rubrum, Eunicella cavolini, Eunicella singularis, Leptosammia pruvoti*
Annellida	*Serpulidae sp.*

2.3.2 Sediments analysis

The collected sediment, in laboratory, has been sieved through a series of strainers. The meshes were in decreasing order: 500μm, 250μm, 125μm and 65μm. Every portion obtained has been dried, weighted, and catalogued. Only the coarse fraction has been sorted using a stereomicroscope to separate all the recognizable organisms. The coarse fraction was relatively fine so analyzing the whole sample was implausible. Consequently, three replicates per sample, each of 0.2g, have been extracted and sorted. For each replicate, recognizable and non- remains of calcified taxa were counted, as well as the inorganic part, to determine the composition of the sediment. Distinguished species were *Corallium rubrum,* the bryozoan *Myriapora truncata,* the foraminifer *Miniacina miniacea* and the remaining groups: gastropods, vermetidae, bivalves, annelids, coralline algae, sea urchins and bryozoans in general.

2.4 Statistical analysis

The differences of the assemblage structures among the sites were tested using the statistical software PRIMER 7 and, in particular, a distance-based permutational multivariate analysis of variance (PERMANOVA; (Anderson, 2001) The experimental designed was composed by four factors: canyon (Ca, 3 levels and random), orientation (Or, 2 levels, fixed), depth (De, 3 levels, fixed) and exposure (Ex, 2 levels, fixed), as shown in Table 3.

The analyses were based on Bray-Curtis similarities calculated on square root transformed data, and each term was tested using 9999 random permutations.

To better visualize the pattern of assemblages' variation among the sites, the results were represented through a Principal Coordinates Analysis (PCO).

The variability was tested for all the significant combination ($P < 0,05$), within the different levels of exposure (C and W), the three levels of depth (20, 25, 30 m) and the two levels of orientation of the walls (SE and NW).

At last, the most relevant species was selected using the DISTLM procedure and the differences in the density of the singular species were tested.

Table 3

Factors: name, type of factor, levels

FACTORS

Name	Abbrev.	Type	N. of levels	Levels
Canyon	Ca	Random	3	Rocca Ruja, Agnata, Canyon del Vikingo
Orientation	Or	Fixed	2	South-east (SE), north-west (NW)
Depth	De	Fixed	3	20m, 25m, 30m
Exposure	Ex	Fixed	2	Crevice (C), wall (W)

2.5 Index development

The index was developed considering the assessment of fragile species and the mechanical impact. The target species upon which is based are indicator species, as *Corallium rubrum*, *Eunicella cavolini*, annelids and erects sponges. As shown in Table 4, two vulnerability factors have been considered: the elevation from the substrate and the exposure degree (Figure 3). The first factor, elevation from the substrate, is represented by four categories, to which is assigned a score ranging from 0 to 4. The latter, exposure degree, is exemplified by the two categories, crevices and walls, which are related to a score respectively of 1 and 3. The scores were assigned considering the average value obtained in each site and the values assigned by the literature on divers impact index (Di Camillo et al., 2019). The index is represented by the sum of all the scores of the two categories:

$$Index = [elevation] + [exposure]$$

Lower values imply the presence of mechanical impact, while higher values are representative of a lower impact.

Table 4

Vulnerability factors with their categories and scores, used for the Index calculation.

Vulnerability factor	Category	Score
Elevation from the substrate	< 1	0
	1 < x < 3	1
	3 < x < 5	2
	> 5	4
Exposure degree	Crevice	1
	Wall	3

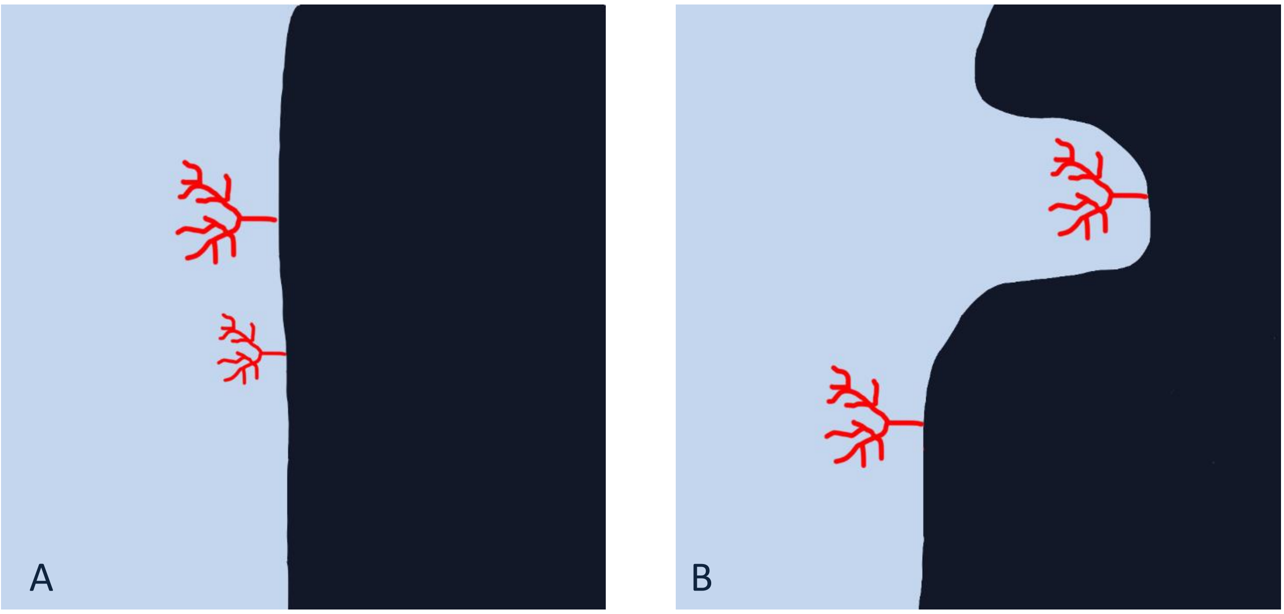

Figure 3. Different degrees of elevation from the substrate (A) and exposure of sessile organisms (B).

3. Results

3.1 Anthropic impact

The Diving Center Costa Paradiso is the only one in the area under study since 1996. Considering the trend of the total diving attendance (Figure 4), there is a negative trend of the diving activity in the area, ranging from 2500 to 1000 dives in total from 2011 to 2020. The lack of previous data is due to the absence of a database in those years. The flux fluctuated from 2011 to 2014. By 2014 the fluctuation stopped, and the attendance sharply declined. The lowest number of visitors is reached in 2016, then it steady increased until 2019. A new fall was observed in 2020, likely due to the COVID-19 pandemic and the consequent restrictions of tourism flux

The observed negative trend is similar in the three sites under exam (Figure 5); however, the lowest value was recorded in 2018. The most frequented site during the years is Rocca Ruja, probably because of the presence of a great abundance of the red coral *Corallium rubrum* in the canyon. It is followed by Canyon del Vikingo, characterized by a narrow canyon and gorgonians like *Eunicella cavolini* and the last, in terms of attendance, is the site Agnata. To limit the mechanical impact and avoid anchoring, the attendance of each diving site by the diving boats is allowed only through specific fixed buoys.

In Figure 6 is evident that the level of diving qualification of scuba divers visiting the diving center increased during the years from 2011 to 2020. There is a dramatic fall of OWD from 2011 to 2013. The levels fluctuated until the 2018 and then slightly increased in the last years.

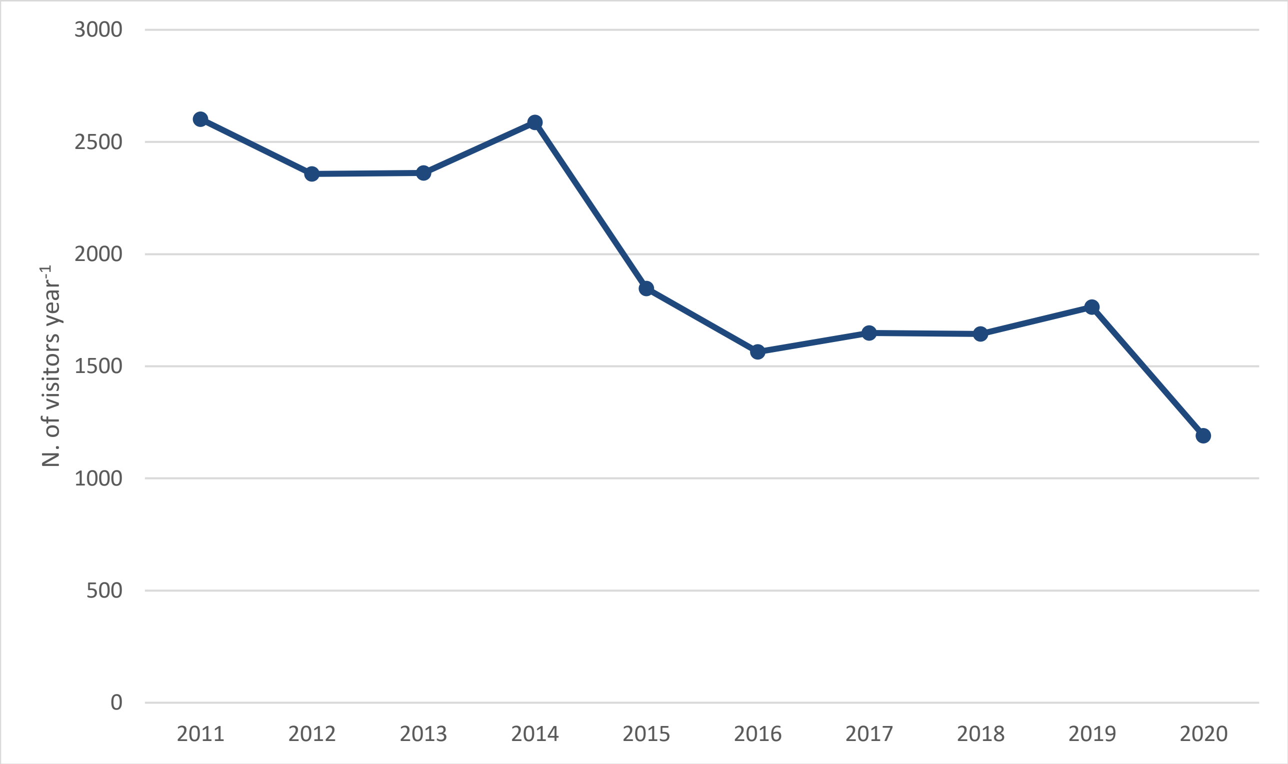

Figure 4. Temporal trend of the diving flux expressed as number of visitors per year in all the dive sites of the area.

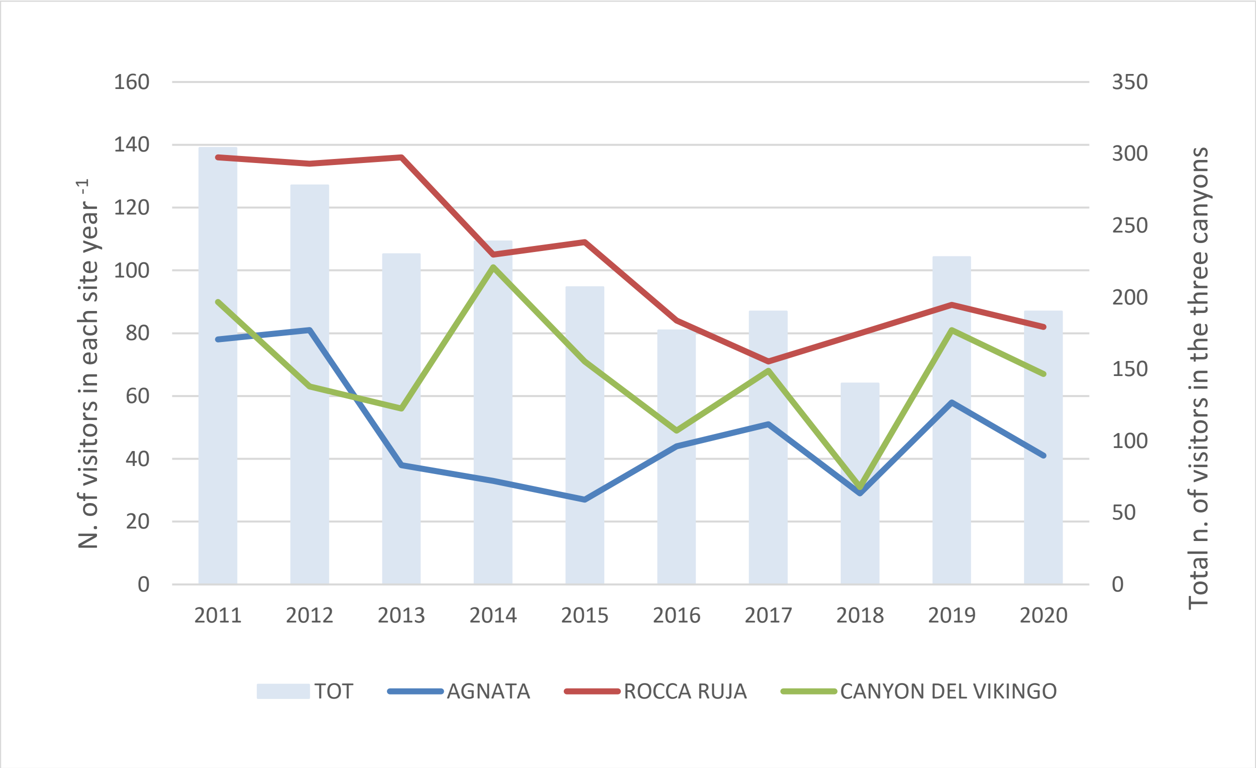

Figure 5. Temporal trend of the diving flux in each site, expressed as number of visitors per year.

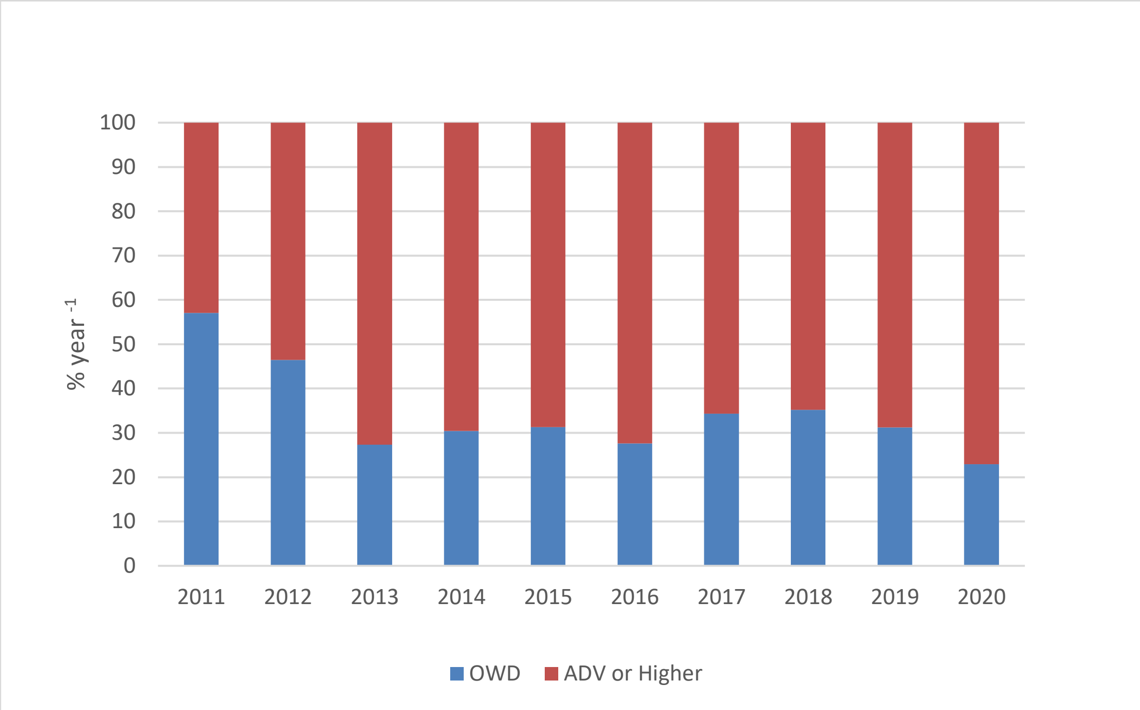

Figure 6. Scuba diver levels expressed in terms of percentage of Open Water Divers and Advanced Open Water Divers or higher per year.

3.2 Fragile community in the study sites

The three study sites are characterized by a similar benthic community. The main fluctuation is relative to the abundance of the two main carbonate organisms (Figure 7): in the sites Agnata, Canyon del Vikingo and in the NW wall of Rocca Ruja the assemblages are principally constituted by the hard coral *Leptosammia pruvoti* (Figure 8 A, B, D, E and F). On the contrary, the SE wall of Rocca Ruja is almost dominated by *Corallium rubrum* colonies (Figure 8 C). In quantitative terms, the red coral population showed a medium density of 381.6 ± 309.7 colonies m^{-2} in the SE wall of Rocca Ruja, whereas 24.3 ± 24.3 colonies m^{-2} in the NW wall (Table 5). In Canyon del Vikingo the red coral has been found only in the NW wall with a low density of 1.3 ± 1.3 colonies m^{-2} in Canyon del Vikingo, while is absent in Agnata. The densities of *L. pruvoti* in the walls of Rocca Ruja were 3.5 ± 3.5 corallites m^{-2} (SE wall) and 120.3 ± 85.0 corallites m^{-2} (NW wall). The other two sites did not reveal such a difference between the walls and the average densities in Agnata and Canyon del Vikingo are respectively 121.9 ± 91.1 corallites m^{-2} (SE wall) and 288.9 ± 216.0 corallites m^{-2} (NW wall); 287.7 ± 215.3 corallites m^{-2} (SE wall) and 177.9 ± 88.5 corallites m^{-2} (NW wall). Concerning the gorgonians, *Eunicella cavolini* and

Eunicella singularis are present only in the sites Canyon del Vikingo and Rocca Ruja; in particular, *E. singularis* has been observed only in the former. The bryozoan *Myriapora truncata* is present in every site with similar densities. Other erect species observed were some annelids and some erect sponges.

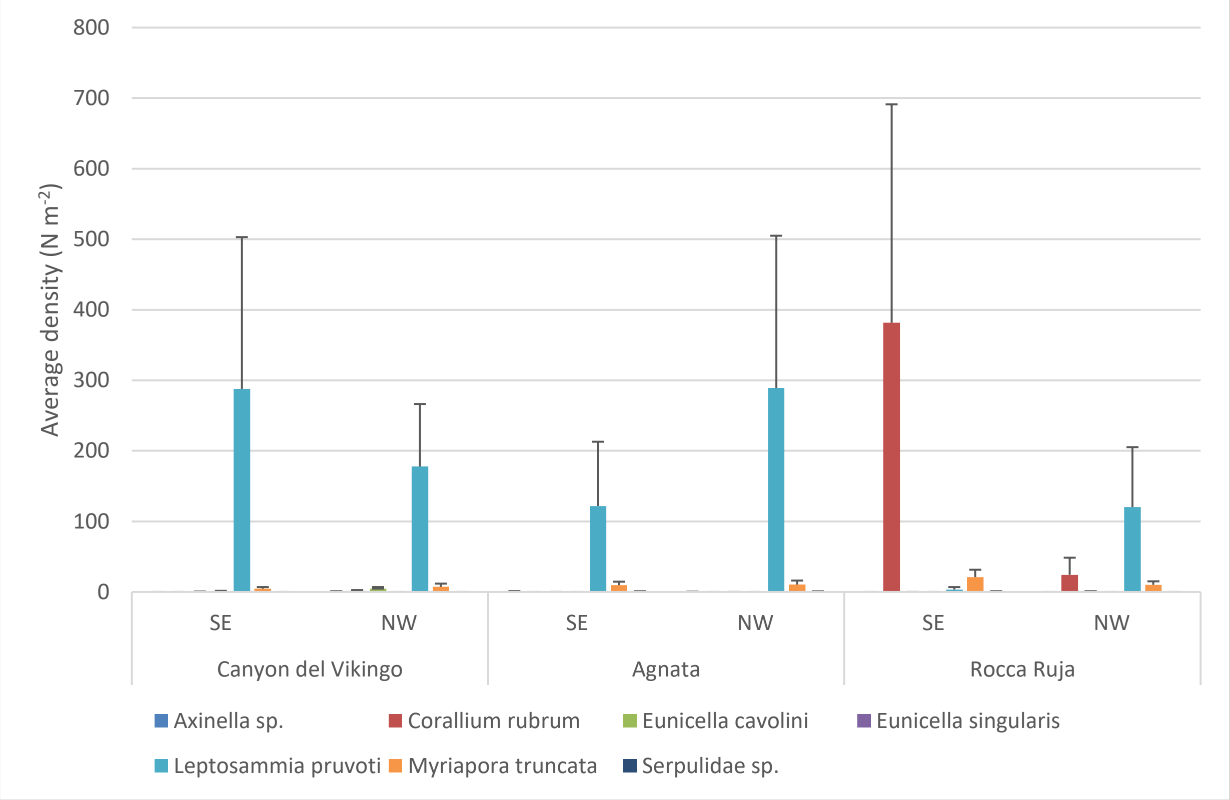

Figure 7. Comparison of the average densities of the species between the two different walls of the three study sites.

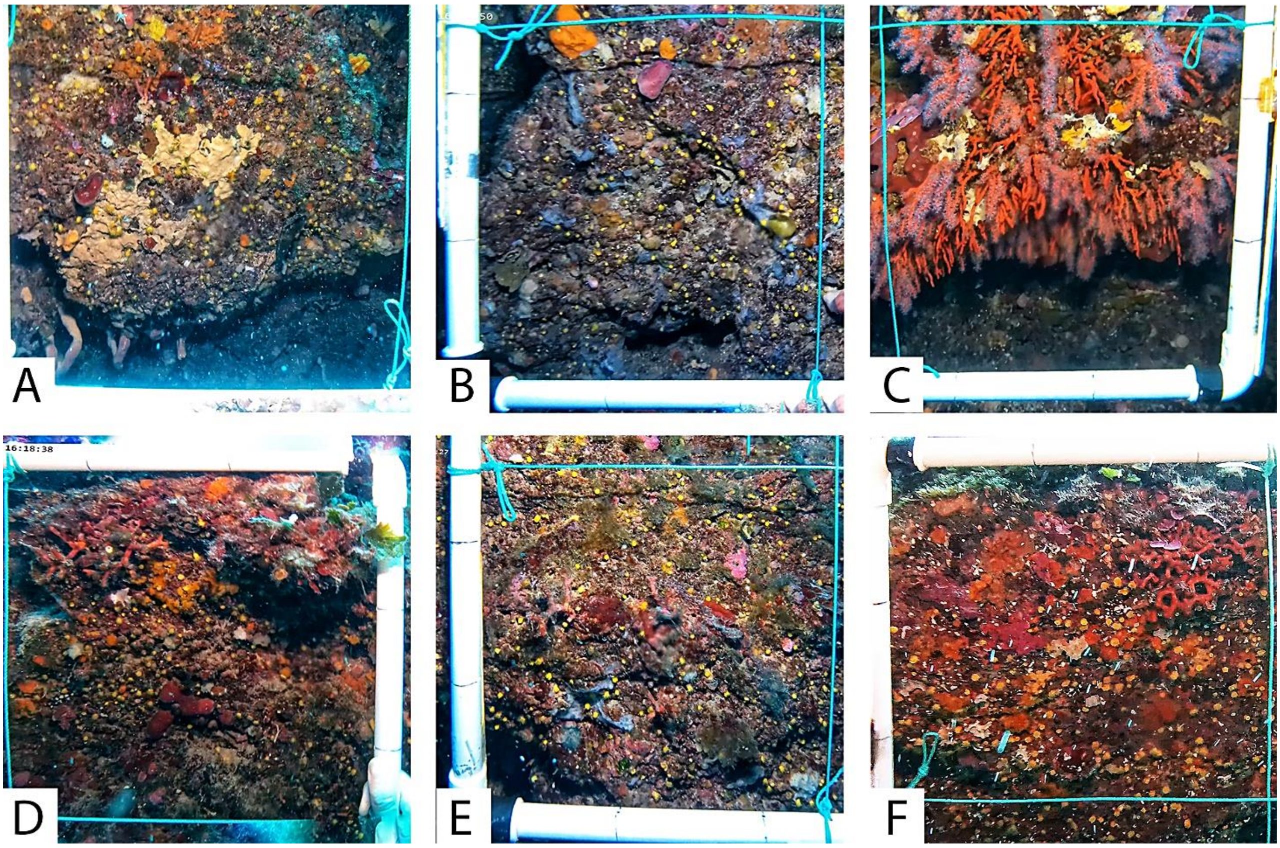

Figure 8. Different characteristics of the assemblages in the Costa Paradiso study sites. (A, D) Canyon del Vikingo (SE and NW walls), the community is characterized mostly by Leptosammia pruvoti. (B, E) Agnata (SE and NW walls), the assemblage is constituted by a rich population of L. pruvoti. (C) Rocca Ruja (SE wall), the assemblage is almost entirely composed by Corallium rubrum colonies. (F) Rocca ruja (NW wall), L. pruvoti population is prevalent.

Table 5

Average densities (± SE) of the target species in the three examined site and relative walls with different orientation (N m^{-2}).

	Canyon del Vikingo			Agnata			Rocca Ruja		
	SE	NW	SITE	SE	NW	SITE	SE	NW	SITE
Axinella sp.	na	0.5 ± 0.5	0.3 ± 0.3	0.8 ± 0.4	0.2 ± 0.2	0.5 ± 0.2	na	na	na
C. rubrum	na	1.3 ± 1.3	0.7 ± 0.7	na	na	na	381.6 ± 309.7	24.3 ± 24.3	202.9 ± 157.6
E. cavolini	0.3 ± 0.3	4.8 ± 2.2	2.5 ± 1.3	na	na	na	na	0.5 ± 0.5	0.3 ± 0.3
E. singularis	0.8 ± 0.8	na	0.4 ± 0.4	na	na	na	na	na	na
L. pruvoti	287.7 ± 215.3	177.9 ± 88.5	232.8 ± 112.2	121.9 ± 91.1	288.9 ± 216.0	229.5 ± 130.6	3.5 ± 3.5	120.3 ± 85.0	61.9 ± 44.2
M. truncata	4.5 ± 2.4	7.2 ± 4.6	5.9 ± 2.5	9.6 ± 5.0	10.5 ± 5.6	10.9 ± 3.8	21.1 ± 10.4	10.1 ± 5.0	15.6 ± 5.7
Serpulidae sp.	na	na	na	0.5 ± 0.5	0.5 ± 0.5	0.5 ± 0.4	0.5 ± 0.5	na	0.3 ± 0.3

3.3 Statistical analyses

The assemblage structure showed a spatial distribution pattern with significant differences among the canyons (P = 0.001). Significant differences were observed among the two exposures and the three considered depths. Concerning the exposure, assemblage structure inside crevices and on walls showed a different distribution at all depths in every canyon ($P < 0.005$). Moreover, differences were relevant among the crevices at all depths ($P < 0.001$), on the contrary there was not a significant variation among the walls. The orientation is the third factor in terms of relevance in structuring the assemblages. In this case the assemblages at the Rocca Ruja canyon presented some significant differences between the SE and NW walls ($P < 0.001$), while the other two canyons did not show a significant variability.

DISTLM indicated that the contribution of all the species considered in the study were significant, except the annelids. The most relevant species are: *Leptopsammia pruvoti*, *Myriapora truncata* and *Corallium rubrum.*

The PCO (Figure 9) gives a better representation of the variability of the assemblages. All the considered species are mainly present in the crevices. *L. pruvoti* is predominant especially in the canyons of Agnata and Vikingo, while *M. truncata* and *C. rubrum* are dominant in Rocca Ruja.

The individual analysis of the more relevant species revealed a site-specific pattern of density, especially concerning *Leptopsammia pruvoti* and *Corallium rubrum*. Conversely, the density of *Myriapora truncata* is less variable among the sites. All the analyzed species showed a difference in terms of density among the levels of exposure ($P < 0.05$). Additionally, even the depth is an important factor: there is a variability in the density of the colonies in the crevices, especially between 20m and 30m depths ($P < 0.05$).

Corallium rubrum is present almost exclusively in the canyon of Rocca Ruja, showing a great local variability. The analysis demonstrated a significant difference between the orientations (SE and NW) of the canyon walls ($P < 0.001$).

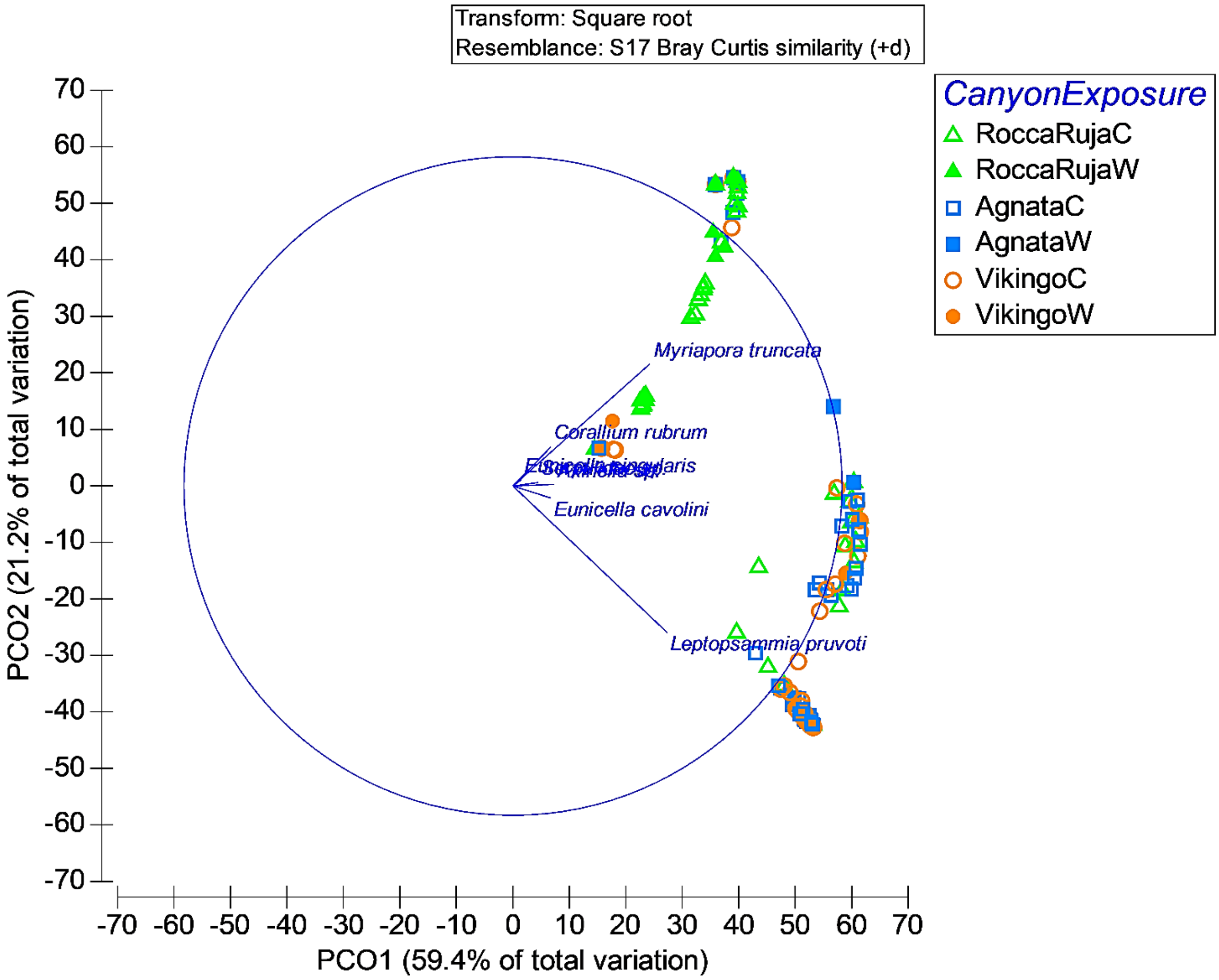

Figure 9. PCO of distances among centroids based on Bray-Curtis dissimilarities of square rout-transformed data. Symbols represent the exposure in each site and labels indicate the predominant species.

3.4 Vulnerability index

The results of the analysis are presented in Figure 10. The calculation of the index showed that the most disturbed site was the site Canyon del Vikingo (Index value = 115), followed by Agnata (Index value = 148) and Rocca Ruja (Index value = 163).

Canyon del Vikingo has been characterized by the lowest value of the index (115). It is characterized by the presence of crevice hosting fragile species: the bryozoan *Myriapora truncata* and *Corallium rubrum*.

The site Agnata, with its bottleneck structure, presented an intermediate value (148). The trail is characterized by a less presence of vulnerable species. In addition, the elevation of the organisms from the substrate is limited.

Rocca Ruja showed the highest value of the index (163), reporting the highest scores for both the vulnerability factors. This is due to the feature of the canyon; this is the most width canyon analyzed. The trail is abundant in vulnerable species, but the main are in crevices protected by the diving activity.

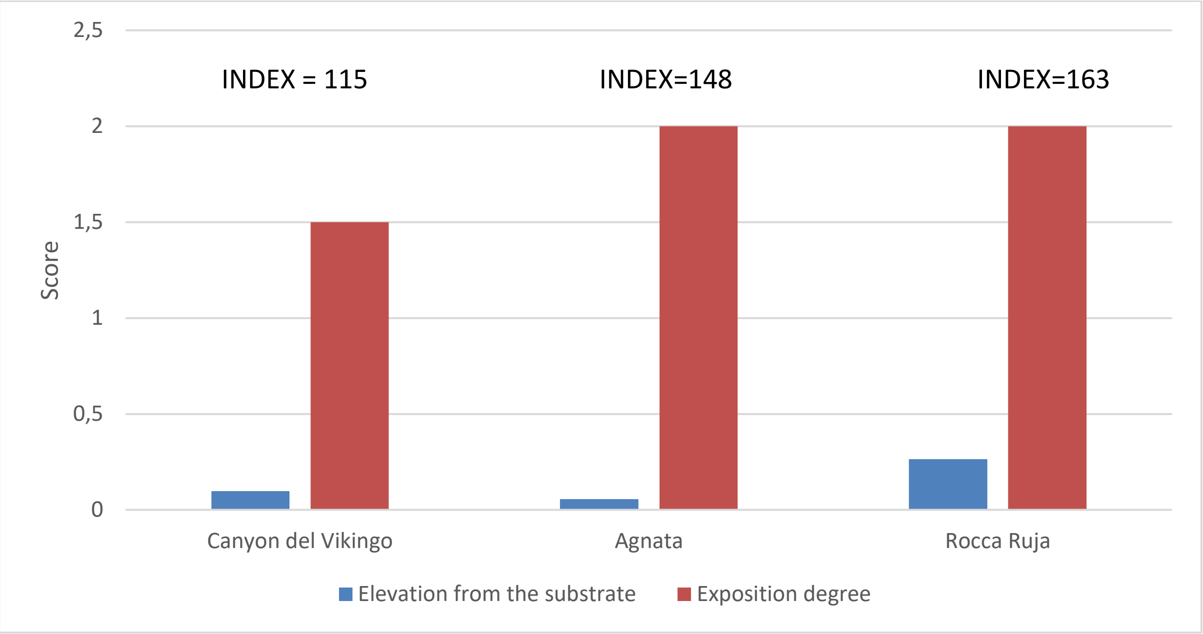

Figure 10. Index values and different scores for the two vulnerability factors for the three study sites.

3.5 Sediments

The weighted sediments present a quite uniform composition in terms of granulometry in the sites. The coarse fraction represents the main part, except for the site Agnata, which is characterized by a dominance of the fine part (Figure 11). The sediments are mainly composed by biogenic detritus in all the sites, as we can see in Figure 12. Although, no fresh fragments have been observed. Moreover, from the 60 to the 80% of the biogenic fraction of the sieved sediment were too small and smooth to identify the taxonomic groups (Figure 13).

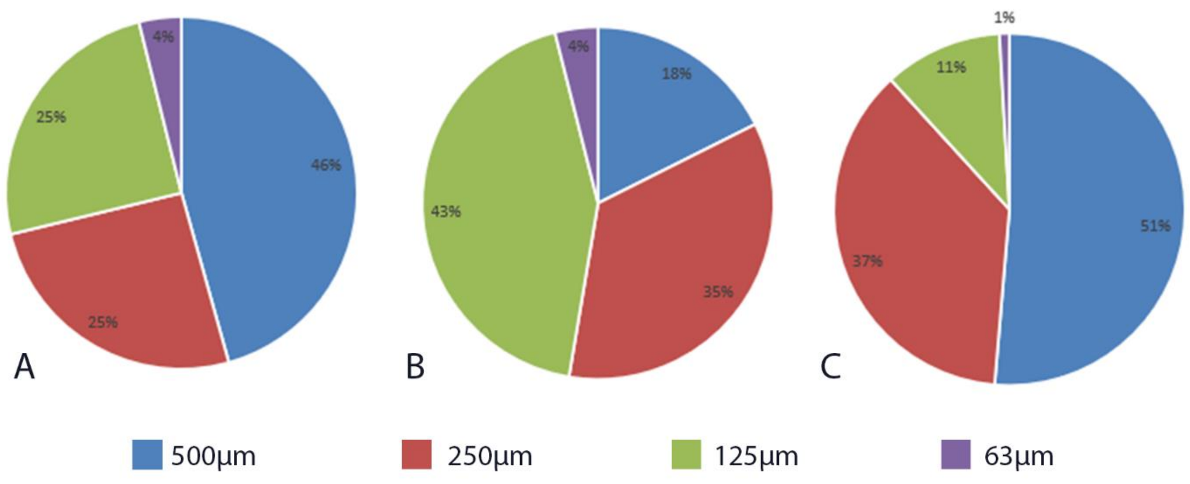

Figure 11. Percentage of the fractions of sediments with different granulometry. (A) Canyon del Vikingo. (B) Agnata. (C) Rocca Ruja.

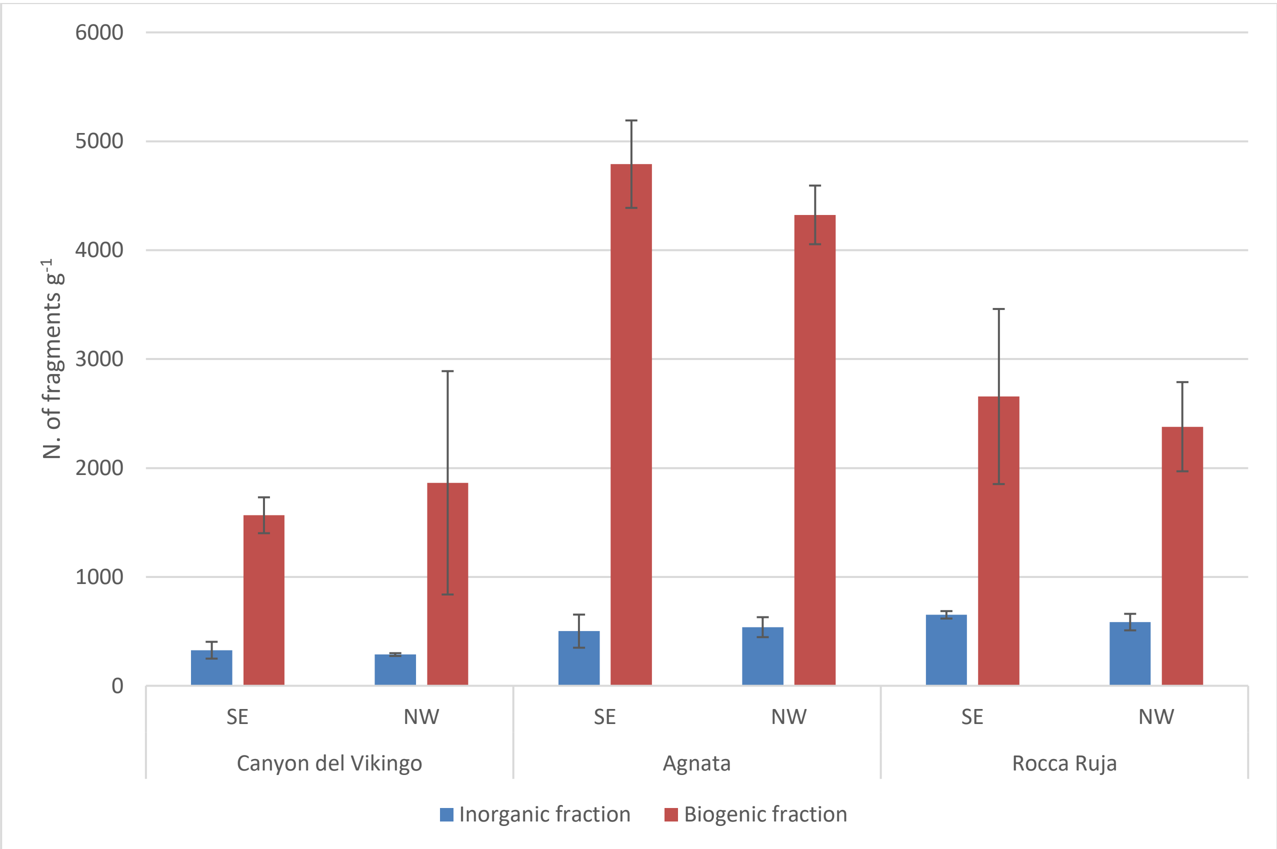

Figure 12. Composition of the sediments: inorganic and biogenic fraction.

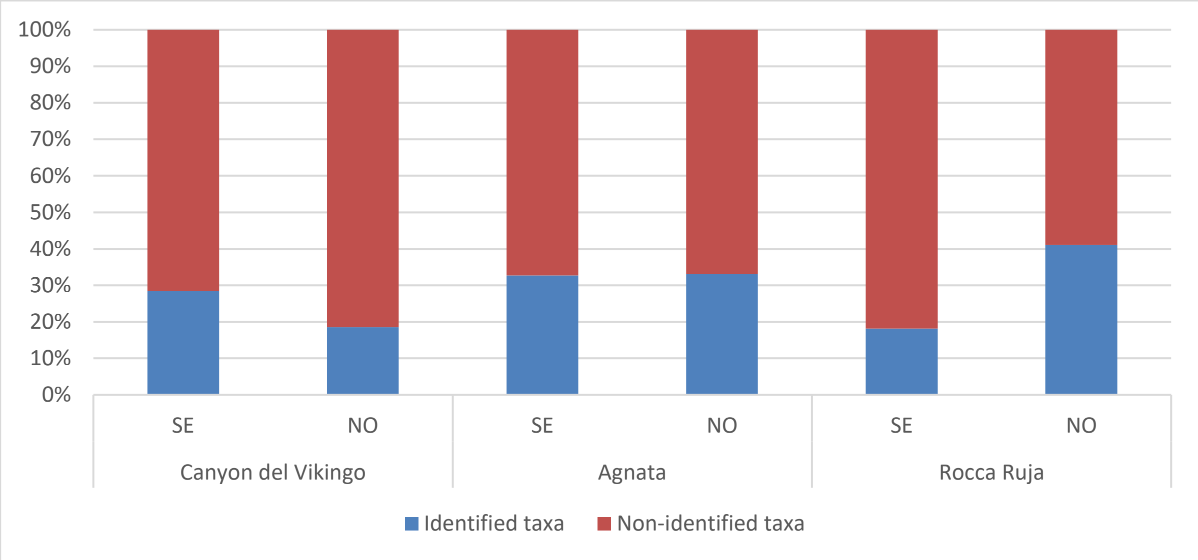

Figure 13. Percentage of identified and non-identified taxa in the two walls of the sites.

Quantitative data are reported in Table 6 and in Figure 14 to be better visualized. Concerning fragile species, little fragments of *Corallium rubrum* (Figure 15 B*)* and *Myriapora truncata* (Figure 15 D) have been found, the most of them were consumed, denoting an old detachment. The densities of red coral fragments were higher below the SE wall of the site Rocca Ruja, reflecting the high density of the species in the assemblages, and lower below the NW wall (respectively, 21.0 ± 7.6 and 4.5 ± 1.8 N/g). In Table 6 we can see that lower values have been found even for the other sites, except for the NW wall of Canyon del Vikingo where fragments of the red coral were not recorded. *Myriapora truncata* presents similar densities in all the sites, without a relevant difference between the walls of the canyons, according to the respective abundance in the assemblages. The highest density has been found in Agnata (20.0 ± 5.2 below the SE wall and 13.5 ± 3.6 below the NE wall). The more abundant species in every site have been bryozoans (Figure 15 A), remains of the foraminifer *Miniacina miniacea* (Figure 15 E) and coralline algae, especially *Ellisolandia elongata* (Figure 15 C). Remains of bryozoans have been found in the sediments of every site. The highest density has been found in Agnata (500.5 ± 7.1 N/g), while lower in the other sites, 133.0 ± 64.7 and 113.8 ± 12.6 N/g respectively for Rocca Ruja and Canyon del Vikingo. *Miniacina miniacea* presented high abundance in all the sites' sediments with densities of 77.0 ± 1.8 N/g for Canyon del Vikingo, 284.8 ± 29.2 N/g for Agnata and 159.8 ± 14.7 N/g for Rocca Ruja. Another well represented group was the coralline algae which was almost entirely composed by fragments of the species *Ellisolandia elongata*, with densities of 67.8 ± 12.6 N/g, 471.3 ± 10.4 and 293.5 ±

83.4 respectively for Canyon del Vikingo, Agnata and Rocca Ruja. Other components of the biogenic fraction belonged to the groups of other Foraminifera, gastropods and Vermetidae, bivalves, polichaetes (Figure 15 F) and echinoderms, prevalently sea urchins.

Table 6

Average densities (± SE) of the species composing the biogenic fraction of the sediments in the three examined site and relative walls with different orientation (N g^{-1}).

	Canyon del Vikingo			Agnata			Rocca Ruja		
	SE	NW	SITE	SE	NW	SITE	SE	NW	SITE
Foraminifera	9.0 ± 3.7	5.0 ± 1.9	7.0 ± 1.4	43.0 ± 15.3	12.5 ± 3.0	27.8 ± 10.8	8.0 ± 2.7	13.0 ± 4.2	10.5 ± 1.8
M. miniacea	79.5 ± 22.3	74.5 ± 16.0	77.0 ± 1.8	326.0 ± 76.9	243.5 ± 36.3	284.8 ± 29.2	139.0 ± 26.1	180.5 ± 29.4	159.8 ± 14.7
Gastropods	70.5 ± 22.4	47.5 ± 7.9	59.0 ± 8.1	79.0 ± 15.7	92.0 ± 13.5	85.5 ± 4.6	63.0 ± 12.6	68.0 ± 9.6	65.5 ± 1.8
Vermetids	13.5 ± 3.7	20.0 ± 5.1	16.8 ± 2.3	44.5 ± 13.4	33.5 ± 7.2	39.0 ± 3.9	10.0 ± 3.5	30.0 ± 6.7	20.0 ± 7.1
Bivalves	13.5 ± 3.5	17.0 ± 4.3	15.3 ± 1.2	23.5 ± 5.1	21.0 ± 5.2	22.3 ± 0.9	4.5 ± 1.7	11.5 ± 3.2	8.0 ± 2.5
M. truncata	10.0 ± 2.5	13.5 ± 2.6	11.8 ± 1.2	20.0 ± 5.2	13.5 ± 3.6	16.8 ± 2.3	10.0 ± 3.9	7.0 ± 2.1	8.5 ± 1.1
Bryozoans	131.5 ± 31.6	96.0 ± 14.5	113.8 ± 12.6	510.5 ± 203.8	490.5 ± 143.6	500.5 ± 7.1	41.5 ± 7.3	224.5 ± 41.4	133.0 ± 64.7
C. rubrum	6.0 ± 3.7	na	3.0 ± 2.1	2.5 ± 1.1	1.5 ± 0.7	2.0 ± 0.4	21.0 ± 7.6	4.5 ± 1.8	12.8 ± 5.8
Polichaetes	8.0 ± 3.2	14.0 ± 3.4	11.0 ± 2.1	26.5 ± 12.8	13.0 ± 3.5	19.8 ± 4.8	4.5 ± 1.5	18.5 ± 4.6	11.5 ± 4.9
Coralline algae	85.5 ± 25.9	50.0 ± 11.6	67.8 ± 12.6	456.5 ± 127.4	486 ± 90.8	471.3 ± 10.4	175.5 ± 44.6	411.5 ± 79.5	293.5 ± 83.4
Echinodermds	19.0 ± 9.5	8.0 ± 2.3	13.5 ± 3.9	33.0 ± 7.0	20.5 ± 4.6	26.8 ± 4.4	6.0 ± 2.2	8.5 ± 3.2	7.3 ± 0.9

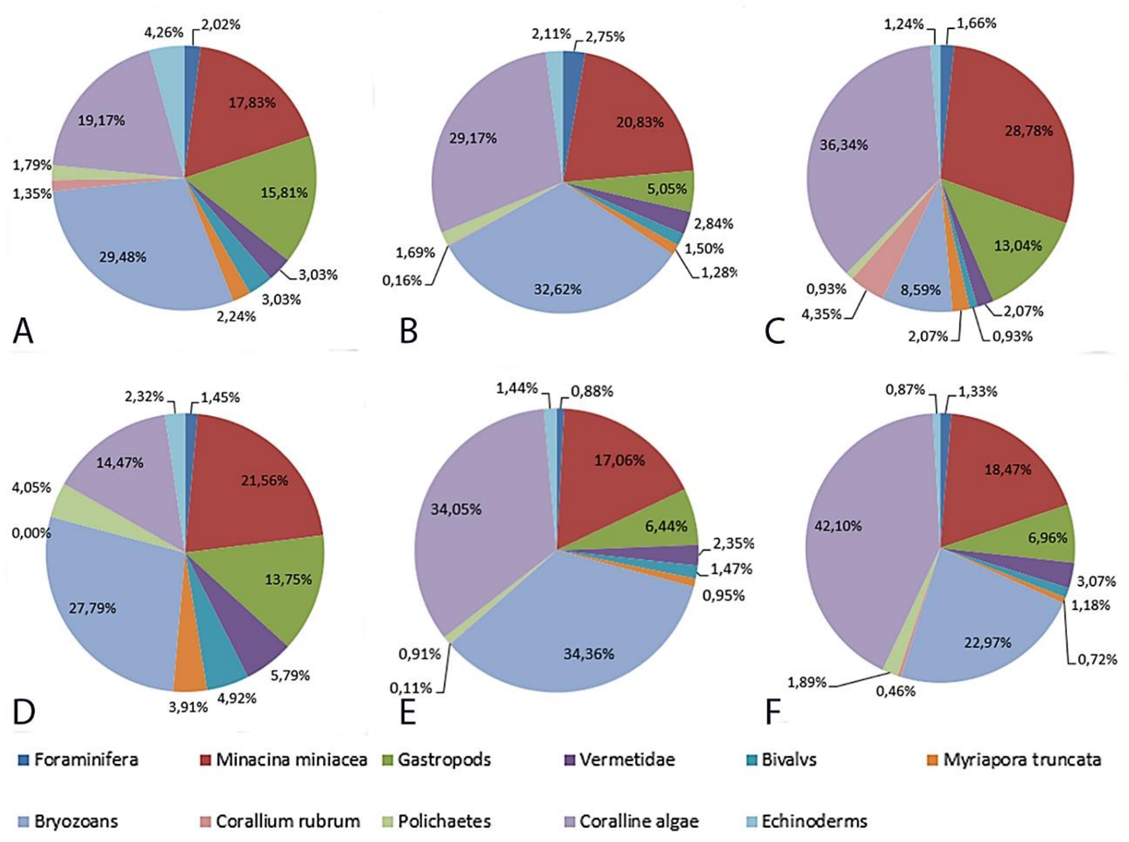

Figure 14. Species composition of the biogenic fraction of the two walls of the sites. (A, D) Canyon del Vikingo (SE wall and NW wall). (B, E) Agnata (SE wall and NW wall). (C, F) Rocca Ruja (SE wall and NW wall).

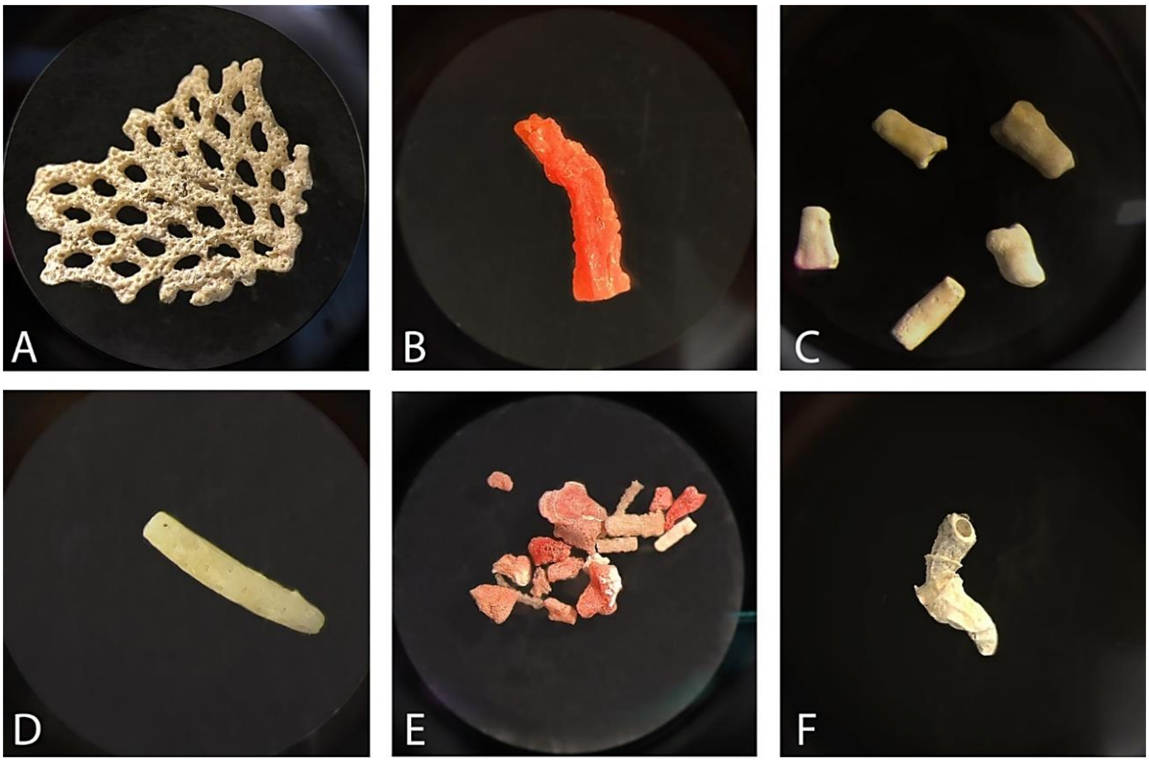

Figure 15. Examples of fragments found in the collected sediments at the steromicroscope. (A) Old portion of bryozoan. (B) Small fragment of Corallium rubrum. (C) Smooth pieces of Ellisolandia elongata. (D) Fragment of Myriapora truncata. (E) Pieces of the foraminifer Miniacina miniacea and some bryozoans. *(F) Little tube of a polichaete.*

4. Discussion

The distribution of the densities of the more abundant species among the investigated canyons had a site-specific variability, which may be due to different factors, such as morphological and hydrological conditions, irradiance, but also anthropic impact. The environmental factors in an heterogeneous system, as the coralligenous habitat could greatly change at local and geographical scale; therefore, their influence is poorly known and hard to quantify (Ballesteros, 2006; Ponti et al., 2011). *Leptopsammia pruvoti* is dominant in the sites of Agnata and Canyon del Vikingo, while *Corallium rubrum* is abundant in Rocca Ruja, especially in the SE wall. *Myriapora truncata* showed a more homogeneous distribution among the sites. The statistical analyses revealed a great difference in terms of pattern of the assemblages concerning the two exposures. In particular, the PCO showed the presence of fragile species mainly in the crevices. The individual species analysis confirmed the higher presence of these organisms in the crevices instead of the walls. One of the main factors that may influence this mechanism could be the lower exposure to the light, another characteristic of crevices. *L. pruvoti* and *C. rubrum* showed a significant difference of distribution between 20 and 30m depths, having higher densities at higher depths. In fact, especially the red coral is known to prefer dim light habitats (Casas-Guëll et al., 2016). This anthozoan usually lives in cracks, crevices, overhangs, and boulders between 7 and 1016m depth (Knittweis et al., 2016; Mallo et al., 2019; Rossi et al., 2008). The larval behavior of *C. rubrum* is not fully described, but laboratory observations (Weinberg, 1979) and genetic studies (Abbiati et al., 1993) seem to indicate that larvae released may be trapped at the ceiling of the crevices and overhangs due to their geonegative/photonegative behavior (Virgilio et al., 2006). Similarly, *L. pruvoti* is one of the most common organisms in semi-enclosed rocky habitats, under overhangs, in caves and small crevices between 0 and 70m depth (Goffredo et al., 2010). *M. truncata* appears to be the most ubiquitous species. Even though it showed less differences in the distribution among the three canyons, it still prefers crevices rather than walls. Normally this species is found in a variety of habitats, from shallow sheltered sites to circalittoral rocky environment (Zabala, 1986).

As a matter of fact, crevices offer a lower risk of exposure to mechanical impact. It is demonstrated that populations in sites frequented by divers tend to occupy more cryptic locations (Sala et al., 1996).

Besides, higher densities of sessile invertebrates on the undersides of crevices and overhangs are consistent with the results of several experimental studies showed a greater recruitment and survival of invertebrates on down-facing surfaces (Virgilio et al., 2006).

Analyzing sediments, nowadays fragile species appear to be only moderately impacted by diving activity and other possible mechanical impacts, suggesting a greater impact in the past. An important constituent of the studied cliffs is the red coral, *Corallium rubrum*. This species is very attractive for the divers (Betti et al., 2019; Bramanti et al., 2011) increasing the chances of damage. Moreover, the delicate carbonate skeleton and the erect morphology make the red coral particularly vulnerable to occasional contacts, especially along vertical exposed cliffs (Betti et al., 2019).

The fragments found in the sediments were small and smooth and the number of fresh ones was limited, revealing the presence of a low mechanical impact at present. This may be due to the fact that there were few fragile species on the canyons' walls; moreover, a lower frequentation of the sites in the current year caused by the COVID-19 pandemic and the consequent restrictions of the tourism flux (Redazione ANSA, 2020), may have furtherly reduced the change of breakage. However, the fall of the tourism flux in the study sites in 2020 is not as dramatic as the fall considering all the sites of the area; the reason can be the fact that selected sites are particularly interesting for scuba divers in terms of species and morphology, thus they would be preferred during this unfortunate moment. Anyway, the attendance decreased by 30% since 2011 in the considered dive sites. Furthermore, the percentage of more expert divers, with an ADV or higher diving qualification, increased in the last years, being up to 4 times higher than the OWD. In terms of other potential natural causes of mechanical stress, no severe storms occurred in the months before the sampling period, excluding this factor as source of impact. The more abundant taxa found in the analyzed sediments are fragments of bryozoans, the forams' tests of *Miniacina miniacea* and the coralline algae *Ellisolandia elongata*, whose abundances do not reflect that in the cliffs. The only species of bryozoan found in the assemblages is *Myriapora truncata*. The great abundance of fragments in the sediments of different taxa of bryozoans may indicate a huge mechanical impact in the past. These species have fragile skeletons and low turnover rates (Ballesteros, 1992; Coma, 1994; Sala et al., 1996; Zabala & Ballesteros, 1989), making them particularly vulnerable to mechanical impacts.

Consequently, they might face an impact derived by the high frequentation of less expert and less learned divers in the past. Erect bryozoans are a good indicator for the evaluation and monitoring of coralligenous reefs and the different taxa demonstrate a different sensitivity to human disturbance, including the diving activity (Casoli et al., 2020). In particular, *M. truncata* is known to be the less sensitive species among bryozoans: it has often been reported in highly degraded situations (Casoli et al., 2020; Perez et al., 2002). Concerning the foraminifer, *Miniacina miniacea*, a relevant number of remains has been found in all the sites. Above all the cliffs, at 20m depth or less, there is the presence of an important *Posidonia oceanica* meadow. *M. miniacea* is well known to be associated to *P. oceanica*, in particular to the rhizomes (Casieri et al., 1993). The presence of this huge abundance of the foraminifer in the sediments may derive from the fragmentation of the ones associated to the meadows. An evidence of this kind of process is the formation of the Spiaggia Rosa (Budelli Island, Sardinia) which owe the pink sand color to the presence of this foraminifer living in the facing *P. oceanica* meadow (Ragazzola et al., 2005). Another important component of the sites' sediments is the coralline algae *Ellisolandia elongata*. This species is an articulated thallus that frequently inhabits the intertidal environment (Egilsdottir et al., 2016) and the fragmented calcified thalli may easily be transported to the sediments at higher depths. The sources of biogenic fraction of the sediments are shown in Figure 16.

The index is based on the approach applied by Di Camillo et al. (2019) adapted to the current study area. It considers two easy measurable vulnerability factors, elevation of the organisms from the substrate and exposure degree. The index values reflect well the impact in the sites. In fact, the higher the width of the canyon, the higher the index value, indicating a lower impact. The highest index value has been obtained for Rocca Ruja, resulting the less impacted site. This is the study site with dive trails characterized by the highest abundance of attractive species, in particular *C. rubrum*, which leads to the highest divers' frequentation. Intuitively this might suggest a significant level of vulnerability. On the other hand, the canyon is the first in terms of width. This crucial feature allows the scuba divers to maintain a certain distance from the wall, reducing the risk of involuntary contact with the organisms. Besides, fragile species are generally in the crevices, which decrease the exposure degree to mechanical impacts. On the contrary, the lower index value has been obtained for the narrowest, Canyon del Vikingo. It is about two meters width and the number of fragile erected species is limited even in the crevices, indicating a higher mechanical impact.

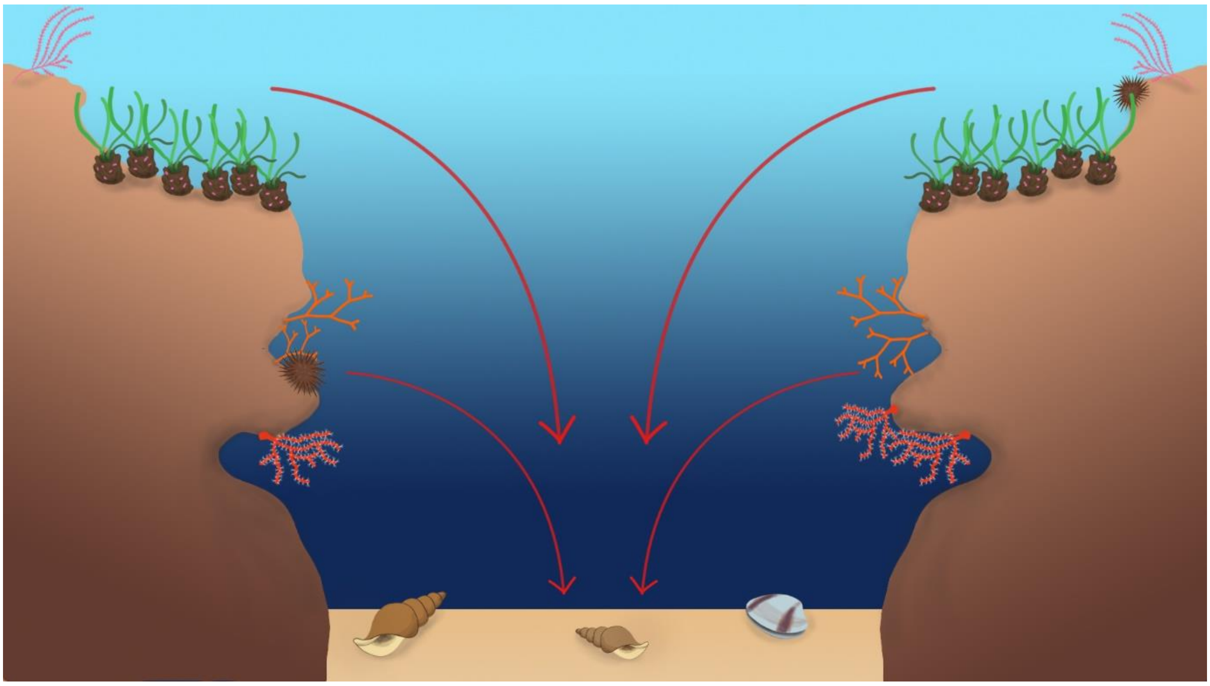

Figure 16. Sources of biogenic fraction of the sediments.

5. Conclusions

Fragile sessile erected species can be an appropriate indicator to assess the human impact in the coralligenous habitat. Though, they can be sensitive to different natural and anthropic pressures, such as storms or fishing activity. This is an essential issue to consider, to avoid mistakes in the environmental evaluation. The observations in the current study suggest the SCUBA divers' pressure as the main source of impact.

The results obtained from the sediment analysis suggest the presence of a huge mechanical impact in the past, probably due to the higher frequentation of less educated divers and/or to other forms of impact. This is an evidence of the importance of an accurate briefing before starting the dives, underling the presence of fragile species and specifying the appropriate behavior. This study proved that sediments, gathering fragments of all the past and present taxa of the site, are an important repository of information about the story of the biodiversity of the area.

The index reflects well the mechanical impact in the different sites. It has been developed to be an easy way to assess the mechanical impact on the coralligenous habitat. The main advantage is that trained people can easily repeat the sampling and the analysis. In fact, despite both the photographic sampling and the sediment sampling are fast in terms of underwater work, the sediment analysis is longer and requires an higher degree of expertise (Di Camillo et al., 2019). The approach and the application of the index must be adapted to the area under study; the establishment of the vulnerability factors may vary depending on different features, such as the species present in the area. Due to the lack of knowledge on the past condition of the area, the index do not give us information on the ecological status in an absolute way; this may be a limit of the approach. However, it can be considered an easy applicable method to assess the current physical impact on the coralligenous habitat by non-expert trained people. In this way it can be a valid tool to help in the evaluation of the habitat condition and in its protection, managing and mitigating the divers' impact if needed.

After all the considerations, the low impact reported in the study area may possibly be the result of a poor year in terms of visitors. For this reason, it would be noteworthy to repeat the study at the end of a richer summer season.

Acknowledgements

This study was carried out thanks to the support of the Diving Center Costa Paradiso; their directions were really appreciated.

References

Abbiati, M., Santangelo, G., & Novelli, S. (1993). Genetic variation within and between two Tyrrhenian populations of the Mediterranean alcyonarian Corallium rubrum. *Marine Ecology Progress Series*, *95*, 245–250. https://doi.org/10.3354/meps095245

Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, *26*(1), 32–46. https://doi.org/10.1046/j.1442-9993.2001.01070.x

Angel, D. L., Krost, P., & Silvert, W. L. (1998). Describing benthic impacts of fish farming with fuzzy sets: theoretical background and analytic methods. *Journal of Applied Ichthyology*, *14*(1–2), 1–8. https://doi.org/10.1111/j.1439-0426.1998.tb00606.x

Ballesteros, E. (1992). Els vegetals i la zonaciò litoral: espècies, comunitats i factors que influeixen en la seva distrbuciò. *Arxius Secció Ciències I.E.C.*, *101*.

Ballesteros, E. (2006). Mediterranean coralligenous assemblages: a synthesis of present knowledge. *Oceanography and Marine Biology*, *44*, 123–195.

Bavestrello, G., Bertolino, M., Betti, F., Nike Bianchi, C., Bo, M., Montefalcone, M., & Morri, C. (2016). New perspectives in the study of Mediterranean coralligenous assemblages. *Biologia Marina Mediterranea*, *23*, 170–173.

Betti, F., Bavestrello, G., Fravega, L., Bo, M., Coppari, M., Enrichetti, F., Cappanera, V., Venturini, S., & Cattaneo-Vietti, R. (2019). On the effects of recreational SCUBA diving on fragile benthic species: The Portofino MPA (NW Mediterranean Sea) case study. *Ocean & Coastal Management*, *182*(August), 104926. https://doi.org/10.1016/j.ocecoaman.2019.104926

Bramanti, L., Vielmini, I., Rossi, S., Stolfa, S., & Santangelo, G. (2011). Involvement of recreational scuba divers in emblematic species monitoring: The case of Mediterranean red coral (Corallium rubrum). *Journal for Nature Conservation*, *19*(5), 312–318.

https://doi.org/10.1016/j.jnc.2011.05.004

Casas-Guëll, E., Cebrian, E., Garrabou, J., Ledoux, J. B., Linares, C., & Teixidó, N. (2016). Structure and biodiversity of coralligenous assemblages dominated by the precious red coral Corallium rubrum over broad spatial scales. *Scientific Reports*, *6*(October). https://doi.org/10.1038/srep36535

Casieri, S., Frezza, V., Mancini, S., & Carboni, M. G. (1993). Living sessile epiphytic foraminifera from Posidonia oceanica meadows of Ischia and Ponza Islands. *1*, 5–7.

Casoli, E., Piazzi, L., Nicoletti, L., Jona-Lasinio, G., Cecchi, E., Mancini, G., Belluscio, A., & Ardizzone, G. (2020). Ecology, distribution and demography of erect bryozoans in Mediterranean coralligenous reefs. *Estuarine, Coastal and Shelf Science*, *235*(July 2019), 106573. https://doi.org/10.1016/j.ecss.2019.106573

Cecchi, E., Gennaro, P., Piazzi, L., Ricevuto, E., & Serena, F. (2014). Development of a new biotic index for ecological status assessment of Italian coastal waters based on coralligenous macroalgal assemblages. *European Journal of Phycology*, *49*(3), 298–312. https://doi.org/10.1080/09670262.2014.918657

Chung, S., Au, A., & Qiu, J.-W. (2013). Understanding the Underwater Behaviour of Scuba Divers in Hong Kong. *Environmental Management*, *51*(4), 824–837. https://doi.org/10.1007/s00267-013-0023-y

Coma, R. (1994). Evaluaciòn del metabolismo de dos suspensivoros bentònicos marinos: Othopyxis crenata y Paramuricea clavata. Universitat de Barcelona, Barcelona.

Coma, R., Pola, E., Ribes, M., & Zabala, M. (2004). Long-term assessment of temperate octocoral mortality patterns, protected VS unprotected areas. *Ecological Applications*, *14*(5), 1466–1478. https://doi.org/10.1890/03-5176

Davis, D., & Tisdell, C. (1995). Recreational scuba-diving and carrying capacity in marine protected areas. *Ocean and Coastal Management*, *26*(1), 19–40. https://doi.org/10.1016/0964-5691(95)00004-L

Deter, J., Descamp, P., Ballesta, L., Boissery, P., & Holon, F. (2012). A preliminary study toward an index based on coralligenous assemblages for the ecological status assessment of Mediterranean French coastal waters. *Ecological Indicators*, *20*(2012), 345–352. https://doi.org/10.1016/j.ecolind.2012.03.001

Di Camillo, C. G., Bavestrello, G., Betti, F., Pantaleo, U., Scinto, A., & Cerrano, C. (2019). *Estimation methods of scuba divers' impact in submerged littoral caves*.

Di Franco, A., Ferruzza, G., Baiata, P., Chemello, R., & Milazzo, M. (2010). Can recreational scuba divers alter natural gross sedimentation rate? A case study from a Mediterranean deep cave. *ICES Journal of Marine Science*, *67*(5), 871–874. https://doi.org/10.1093/icesjms/fsq007

Di Franco, A., Marchini, A., Baiata, P., Milazzo, M., & Chemello, R. (2009). Developing a scuba trail vulnerability index (STVI): a case study from a Mediterranean MPA. *Biodiversity and Conservation*, *18*(5), 1201–1217. https://doi.org/10.1007/s10531-008-9461-x

Egilsdottir, H., Olafsson, J., & Martin, S. (2016). Photosynthesis and calcification in the articulated coralline alga Ellisolandia elongata (Corallinales, Rhodophyta) from intertidal rock pools. *European Journal of Phycology*, *51*(1), 59–70. https://doi.org/10.1080/09670262.2015.1101165

Ferrigno, F., Russo, G. F., & Sandulli, R. (2017). Coralligenous Bioconstructions Quality Index (CBQI): a synthetic indicator to assess the status of different types of coralligenous habitats. *Ecological Indicators*, *82*(July), 271–279. https://doi.org/10.1016/j.ecolind.2017.07.020

Garrabou, J., & Harmelin, J.-G. (2002). A 20-year study on life-history traits of a harvested long-lived temperate coral in the NW Mediterranean: insights into conservation and management needs. https://doi.org/10.1046/j.1365-2656.2002.00661.x

Gatti, G., Montefalcone, M., Rovere, A., Parravicini, V., Morri, C., Albertelli, G., & Nike Bianchi, C. (2012). Seafloor integrity down the harbor waterfront: The coralligenous shoals off Vado Ligure (NW Mediterranean). *Advances in Oceanography and Limnology*, *3*(1), 51–67. https://doi.org/10.1080/19475721.2012.671190

Gatti, G., Nike Bianchi, C., Morri, C., Montefalcone, M., & Sartoretto, S. (2015). Coralligenous reefs state along anthropized coasts: Application and validation of the COARSE index, based on a rapid visual assessment (RVA) approach. *Ecological Indicators*, *52*, 567–576. https://doi.org/10.1016/j.ecolind.2014.12.026

Giglio, V. J., Luiz, O. J., & Ferreira, C. E. L. (2020). Ecological impacts and management strategies for recreational diving : A review. *Journal of Environmental Management*, *256*(December 2019), 109949. https://doi.org/10.1016/j.jenvman.2019.109949

Goffredo, S., Caroselli, E., Mattioli, G., & Zaccanti, F. (2010). Growth and population dynamic model for the non-zooxanthellate temperate solitary coral Leptopsammia pruvoti (Scleractinia, Dendrophylliidae). *Marine Biology*, *157*(12), 2603–2612. https://doi.org/10.1007/s00227-010-1522-5

Guarnieri, G., Terlizzi, A., Bevilacqua, S., & Fraschetti, S. (2012). Increasing heterogeneity of sensitive assemblages as a consequence of human impact in submarine caves. *Marine Biology*, *159*(5), 1155–1164. https://doi.org/10.1007/s00227-012-1895-8

Knittweis, L., Aguilar, R., Alvarez, H., Borg, J., Evans, J., Garcia, S., & Al., E. (2016). New depth record of the precious red coral Corallium rubrum for the Mediterranean. *41st Congress of the Mediterranean Science Commission (CIESM)*.

Linares, C., Doak, D. F., Coma, R., Díaz, D., & Zabala, M. (2007). Life history and viability of a long-lived marine invertebrate: the octocoral Paramuricea clavata. *Ecology*, *88*(4), 918–928. https://doi.org/10.1890/05-1931

Lloret, J., Marín, A., Marín-Guirao, L., & Francisca Carreño, M. (2006). An alternative approach for managing scuba diving in small marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *16*(6), 579–591. https://doi.org/10.1002/aqc.734

Mallo, M., Ziveri, P., Reyes-García, V., & Rossi, S. (2019). Historical record of Corallium rubrum and its changing carbon sequestration capacity: A meta-analysis from the North Western Mediterranean. *PLoS ONE*, *14*(12), 1–20. https://doi.org/10.1371/journal.pone.0223802

McCool, S. F., & Lime, D. W. (2001). Tourism Carrying Capacity: Tempting Fantasy or Useful Reality? *Journal of Sustainable Tourism*, *9*(5), 372–388. https://doi.org/10.1080/09669580108667409

Meese, R., & Tomich, P. A. (1992). Dots on the rocks: A comparison of percent cover estimation methods. https://doi.org/10.1016/0022-0981(92)90289-M

Milazzo, M., Chemello, R., Badalamenti, F., Riggio, R. C., & Riggio, S. (2002). The impact of human recreational activities in marine protected areas: What lessons should be learnt in the Mediterranean sea? *Marine Ecology*, *23*(SUPPL. 1), 280–290. https://doi.org/10.1111/j.1439-0485.2002.tb00026.x

Montefalcone, M., Morri, C., Bianchi, C. N., Bavestrello, G., & Piazzi, L. (2017). The two facets of species sensitivity: Stress and disturbance on coralligenous assemblages in space and time. *Marine Pollution Bulletin*, *117*(1–2), 229–238. https://doi.org/10.1016/j.marpolbul.2017.01.072

Perez, T., Harmelin, J. G., Vacelet, J., & Sartoretto, S. (2002). La bioévaluation de la qualité littorale par les peuplements de substrats durs: spongiaires, gorgonaires et bryozoaires comme indicateurs de pollution.

Personnic, S., Boudouresque, C. F., Astruch, P., Ballesteros, E., Blouet, S., Bellan-Santini, D., Bonhomme, P., Thibault-Botha, D., Feunteun, E., Harmelin-Vivien, M., Pergent, G., Pergent-Martini, C., Pastor, J., Poggiale, J.-C., Renaud, F., Thibaut, T., & Ruitton, S. (2014). An Ecosystem-Based Approach to Assess the Status of a Mediterranean Ecosystem, the Posidonia oceanica Seagrass Meadow. *PLoS ONE*, *9*(6), e98994. https://doi.org/10.1371/journal.pone.0098994

Piazzi, L., Balata, D., Pertusati, M., & Cinelli, F. (2004). Spatial and temporal variability of Mediterranean macroalgal coralligenous assemblages in relation to habitat and substratum inclination. *Botanica Marina*, *47*(2). https://doi.org/10.1515/BOT.2004.010

Ponti, M., Fava, F., & Abbiati, M. (2011). Spatial-temporal variability of epibenthic assemblages on subtidal biogenic reefs in the northern Adriatic Sea. *Marine Biology*, *158*(7), 1447–1459. https://doi.org/10.1007/s00227-011-1661-3

Ragazzola, F., Cossu, A., Mulargia, M., Pala, D., & Plastina, G. (2005). Extension and conservation of Posidonia oceanica delile meadow in front of the Spiaggia Rosa (Budelli Island). *Biologia Marina Mediterranea*, *12 (1)*, 151–154.

Rastorgueff, P., Bellan-Santini, D., Bianchi, C. N., Bussotti, S., Chevaldonné, P., Guidetti, P., Harmelin, J.-G., Montefalcone, M., Morri, C., Perez, T., Ruitton, S., Vacelet, J., & Personnic, S. (2015). An ecosystem-based approach to evaluate the ecological quality of Mediterranean undersea caves. *Ecological Indicators*, *54*(July 2019), 137–152. https://doi.org/10.1016/j.ecolind.2015.02.014

Redazione ANSA. (2020). Flessione del turismo in Sardegna nell’estate nera del Covid. https://www.ansa.it/sardegna/notizie/2020/09/09/flessione-del-turismo-in-sardegna-nellestate-nera-del-covid_c2b38009-0a18-4d51-ad90-c0b178be76a1.html

Rossi, S., Tsounis, G., Orejas, C., Padrón, T., Gili, J.-M., Bramanti, L., Teixidó, N., & Gutt, J. (2008). Survey of deep-dwelling red coral (Corallium rubrum) populations at Cap de Creus (NW Mediterranean). *Marine Biology*, *154*(3), 533–545. https://doi.org/10.1007/s00227-008-0947-6

Rouphael, A. B., & Inglis, G. J. (1997). Impacts of recreational SCUBA diving at sites with different reef topographies. *Biological Conservation*, *82*(3), 329–336. https://doi.org/10.1016/S0006-3207(97)00047-5

Ruitton, S., Personnic, S., Boudouresque, C., & Nike Bianchi, C. (2014). An ecosystem based approach to assess the status of the mediterranean coralligenous habitat. November. https://doi.org/10.13140/2.1.1502.6887

Sala, E., Ballesteros, E., Dendrinos, P., Di Franco, A., Ferretti, F., Foley, D., Fraschetti, S., Friedlander, A., Garrabou, J., Güçlüsoy, H., Guidetti, P., Halpern, B. S., Hereu, B., Karamanlidis, A. A., Kizilkaya, Z., Macpherson, E., Mangialajo, L., Mariani, S., Micheli, F., … Zabala, M. (2012). The Structure of Mediterranean Rocky Reef Ecosystems across Environmental and Human Gradients, and Conservation Implications. *PLoS ONE*, *7*(2), e32742. https://doi.org/10.1371/journal.pone.0032742

Sala, E., Garrabou, J., & Zabala, M. (1996). Effects of diver frequentation on Mediterranean sublittoral populations of the bryozoan Pentapora fascialis. *Marine Biology*, *126*, 451–459.

Sartoretto, S., Schohn, T., Bianchi, C. N., Morri, C., Garrabou, J., Ballesteros, E., Ruitton, S., Verlaque, M., Daniel, B., Charbonnel, E., Blouet, S., David, R., Féral, J. P., & Gatti, G. (2017). An integrated method to evaluate and monitor the conservation state of coralligenous habitats: The INDEX-COR approach. *Marine Pollution Bulletin*, *120*(1–2), 222–231. https://doi.org/10.1016/j.marpolbul.2017.05.020

Smith, C. J., & Rumohr, H. (2005). Imaging Techniques. In *Methods for the Study of Marine Benthos* (pp. 87–111). Blackwell Science Ltd. https://doi.org/10.1002/9780470995129.ch3

Talge, H. (1990). *Impact of recreational divers on coral reefs in the Florida keys*. University of South Florida, Florida.

Thompson, A., & Mapstone, B. (1997). Observer effects and training in underwater visual surveys of reef fishes. *Marine Ecology Progress Series*, *154*, 53–63. https://doi.org/10.3354/meps154053

Virgilio, M., Airoldi, L., & Abbiati, M. (2006). Spatial and temporal variations of assemblages in a Mediterranean coralligenous reef and relationships with surface orientation. *Coral Reefs*, *25*(2), 265–272. https://doi.org/10.1007/s00338-006-0100-2

Weinberg, S. (1979). The Light-Dependent Behaviour of Planula Larvae of Eunicella Singularis and Corallium Rubrum and its Implication for Octocorallian Ecology. *Bijdragen Tot de Dierkunde*, *49*(1), 16–30. https://doi.org/10.1163/26660644-04901002

Zabala, M. (1986). Fauna dels Briozous dels Països Catalans. *Arxius Secció Ciències I.E.C.*, *84*, 1–833.

Zabala, M., & Ballesteros, E. (1989). Surface-dependent strategies and energy flux in benthic marine communities or, why corals do not exist in the Mediterranean. *Scientia Marina*, *53 (1)*, 3–17.