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Caratterizzazione dei popolamenti coralligeni della Sardegna nord-orientale e determinazione di specie indicatrici di impatto meccanico

Characterization of north-east Sardinia's coralligenous populations and determination of mechanical impact-indicator species

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Summary

Riassunto

L'habitat coralligeno rappresenta un "hot spot'' di diversità nel Mar Mediterraneo e può essere soggetto a impatti meccanici determinati dall'attività di pesca, il ghost-fishing e la subacquea ricreativa, che possono causare modificazioni nella struttura e nel funzionamento della sua comunità.

La subacquea ricreativa è un settore del turismo marino in veloce crescita e tra gli impatti meccanici è il meno conosciuto.

Questo studio ha l'obiettivo di caratterizzare i popolamenti coralligeni della Sardegna nord-orientale e di determinare le possibili specie indicatrici di impatto meccanico.

Per caratterizzare i popolamenti sono stati scelti tre canyon a cui è stato applicato un transetto orizzontale lungo tre profondità fisse (20 m, 25 m, 30 m) utilizzando la tecnica dei photo-quadrats (25x25 cm). Dalle fotografie ottenute è stata estrapolata la percentuale di ricoprimento di ogni specie.

I risultati hanno mostrato differenze tra i popolamenti dei tre canyon, la composizione in specie tra i siti è particolarmente legata al tipo di esposizione e al canyon stesso.

Integrando i risultati con le dive routes di ogni canyon e i dati di frequentazione del diving, un impatto meccanico legato allo SCUBA diving sembra altamente possibile e Canyon del Vikingo pare essere il sito più impattato.

1. Abstract

Coralligenous habitat represent a “hot spot’’ of species diversity in the Mediterranean Sea and can be affected by mechanical impacts such as fishing activity, ghost-fishing and recreational diving, which can lead to modifications in its communities’ structure and functioning.

Recreational diving is a fast-growing activity in the marine tourism sector and among the mechanical impacts is the less known.

This study aims to characterize the coralligenous assemblages in north-east Sardinia and to assess possible mechanical impact-indicator species.

To characterize the assemblages, three canyons were chosen and a horizontal transect with fixed depth (20 m, 25 m, 30 m) was performed, using photo-quadrats (25x25 cm) applied to two exposure type (crevices, walls). Pictures allowed to extrapolate the percentage cover data for each species.

Results showed differences between the canyons’ assemblages, species composition between sites resulted mainly related to the exposure type and the canyon itself.

Integrating the results with dive route of each canyon and diving frequentation data, a mechanical impact related to SCUBA diving seems highly possible and Canyon del Vikingo appears as the most impacted site.

2. Introduction

2.1 Coralligenous habitat

Coralligenous habitat is a rocky habitat typical of the Circalittoral Mediterranean zone, it is originated from the accumulation of calcareous encrusting algae able to grow at low irradiance, mainly Corallinales and Peyssonneliales (Enric Ballesteros 2006).

Due to the dim light condition all the organisms thriving in coralligenous habitat are sciaphilic (Enric Ballesteros 2006).

This habitat also includes animal builders, bioeroders, several epi- and endo-faunal species and host a rich crypto-fauna (Hong JS., 1982), therefore is considered a “hot spot’’ of species diversity in the Mediterranean Sea (Boudouresque 2004).

Several species of commercial interest live, feed or breed in association with coralligenous bioconstructions and many of them are considered vulnerable or endangered (Cavanagh and Gibson, 2007).

Coralligenous reef occurs between 20 and 120 m in depth along the Mediterranean coast (Laborel 1987).

Morphology and inner structure of coralligenous frameworks depend mainly on depth, topography and the nature of prevailing algal builders (Laborel 1961).

According to Pérès & Picard (1964), coralligenous habitat is defined into two main categories: assemblages over littoral rock or rims (e.g. vertical cliffs, overhangs and outer part of marine caves), and coralligenous banks or platform outcrops, which develop on the continental shelves over consolidated sediments, coalesced rhodoliths or pre-existing rocks (Laborel 1987).

Coralligenous assemblages are maintained by the delicate equilibrium between bio-construction and bio-erosion, which can easily be altered by environmental changes (Garrabou and Ballesteros 2000; Sartoretto and Francour 1997).

Stable environmental conditions are a key factor for the development and survival of coralligenous habitat (Piazzi, Gennaro, and Balata 2012), since it hosts species highly sensitive to human disturbance, such as *Corallium rubrum* (Linnaeus, 1758) and the fan corals *Eunicella cavolini* (Koch, 1887) and *Paramuricea clavata* (Risso, 1826) (Brown and Macfadyen 2007). Therefore, is protected by several international protection agreements such as the Habitat Directive 92/43/CEE, in which is considered, together with *Cystoseira* association and deep corals biocenosis, as one of the component of the reef habitat (Gennaro et al. 2011).

Coralligenous habitat is also monitored through the European Marine Strategy Framework Directive (MSFD,2008/56/EC), which allows to study, protect and monitor this ecosystem and its biodiversity.

Among the environmental factors influencing coralligenous habitat, light condition and water movement are particularly relevant.

Light is the most important factor because influences the distribution of benthic organisms along the rocky bottoms of the continental shelf (Ballesteros 1992, Martí et al. 2004) and the development and growth of coralligenous frameworks, as the calcareous macroalgae need enough light to grow but cannot withstand high levels of irradiance (Pérès & Picard 1964, Laubier 1966). The irradiance at which coralligenous communities are able to develop is between 0.05% and 3% of the surface irradiance. However, light levels reaching different microenvironments of coralligenous communities can differ by at least two orders of magnitude (Enric Ballesteros 2006).

At the depth of coralligenous development, the predominant water movement is represented by flowing currents (Riedl 1966) but, the movement generated by waves with heights > 1 m can be significant even at 50 m depth (E. Ballesteros et al. 1993; Garrabou 1997). However, due to the coralligenous morphology, water movement can differ among microenvironments as it happens for light levels (Laubier 1966).

2.1.1 Biodiversity in coralligenous structure

Environmental factors can significantly vary among different parts of the same coralligenous concretion, creating a great environmental heterogeneity which allows several different assemblages to coexist in a reduced space (Enric Ballesteros 2006).

The main coralligenous builders are coralline algae, whose framework is reinforced by other organisms, mostly Peyssonneliaceae, serpulid worms and bryozoans (Sartoretto 1996).

As reported by Sartoretto et al. 1996, *Peyssonnelia* (Decaisne, 1841) can be abundant as a living encrusting algae in the north-western Mediterranean but almost completely absent from the fossil record, because its carbonate content is lower than the average in Corallinales and it also calcifies as aragonite rather than calcite, preventing a good fossilization (James et al. 1988).

Across the Mediterranean, algal populations in coralligenous habitat differ greatly on geographical scales (Boudouresque 1973), this explain why, even if the species diversity at one site is rather constant, the overall algal richness of coralligenous habitats on a Mediterranean wide scale can be huge (Enric Ballesteros 2006).

In shallow water banks, encrusting algae are generally covered by the green algae *Halimeda tuna* ((J.Ellis & Solander) J.V.Lamouroux, 1816) and *Flabellia petiolata* ((Turra) Nizamuddin, 1987) (*Lithophyllo-Halimedetum tunae*), which can reach a density enough to hide calcareous algae (Enric Ballesteros 2006).

Recently, the role of substrate's mineral composition in determining structure and dynamics of the benthic communities have been investigated (Canessa, Bavestrello, Bo, et al. 2020).

Cerrano et al. 1999 have demonstrated the ability of benthic organisms, mainly during the settling process, to recognize, select, react and possibly exploit different rocky substrates, with important consequences in the definitive community structure.

The role of lithology in driving the structure and dynamics of the coralligenous communities has never been carefully investigated (Canessa, Bavestrello, Bo, et al. 2020) but significant differences within coverage, species richness and biomass were found among communities developing on silica enriched substrata and the ones developing on carbonate rocks.

According to Canessa and Bavestrello et al. 2020, in Tavolara Punta Coda Cavallo MPA, coralligenous assemblages growing on carbonate appeared richer and more complex than the ones developing on granite. This difference in the building capacity of *Lithophyllum* (Philippi, 1837) could be explained by the growth of different lineages on the two type of rock. Moreover, quartz, which is one of the main mineral in granite, can inhibit several sessile species due to its oxidant and hydrophobic proprieties (Canessa et al. 2019).

As reported by Canessa et al. 2020, lithology, in particular the substrate stability, is one of the primary drivers of colonization. Besides, the epilithic corallines seems to favour calcareous substrates and their settling may affect the other colonization's phases, stabilizing the limestone and preserving it from dissolution (Canessa, Bavestrello, Trainito, et al. 2020).

According to Hong (1982), four different categories of invertebrates can be distinguished within the coralligenous structure in relation to their position and ecological significance:

- Fauna contributing to build-up (e.g. bryozoans, serpulids, corals and sponges)
- Crypto-fauna colonising small holes and crevices (e.g. molluscs, crustaceans and polychaetes)
- Epifauna and endofauna

▪ Eroding species (browsers, microborers and macroborers);

Coralligenous communities constitute one of the most important "hot spot" of species diversity in the Mediterranean (Boudouresque 2004) and due to their great diversity of organisms (Figure 1), are one of the favoured diving spots for tourists (Harmelin 1993).

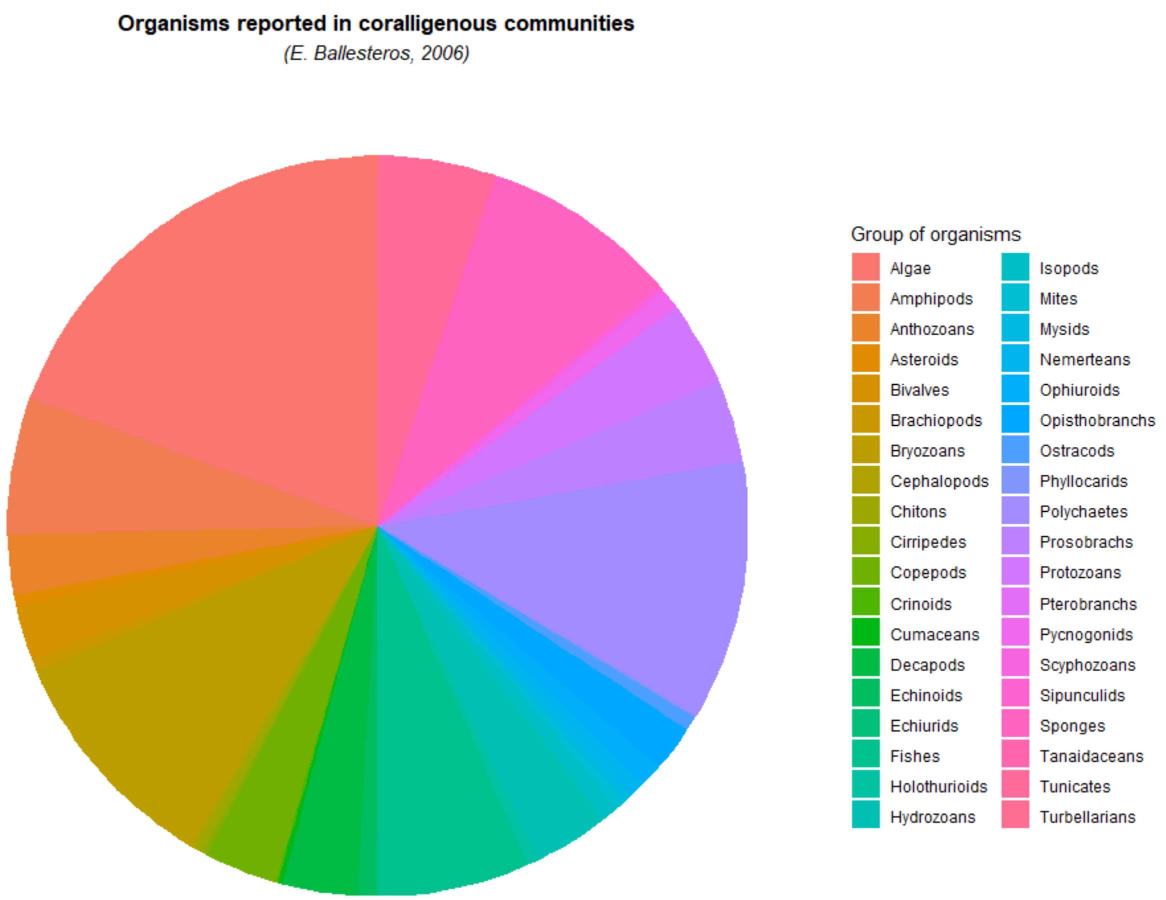


Fig. 1: Approximate number of species reported from coralligenous communities (E. Ballesteros, 2006)

2.2 Mechanical impacts on coralligenous

Many anthropic activities have negative effects on hard bottom benthic communities (Collie et al., 2000). Coralligenous habitat can be affected by fishing activity, ghost-fishing, anchoring, dredging and recreational diving.

2.2.1 Fishing impact

Fishing activity can lead to modifications in communities' structure and functioning, causing a shift in species composition towards opportunistic communities composed by rapid growth rates species (Daskalov et al. 2007; Schiaparelli, Chiantore, and Cattaneo-vietti 2001).

According to Boudouresque et al. 1990, trawling, one of the most destructive fishing methods, caused the degradation of large areas of coralligenous concretions.

Its effects on coralligenous have been highlighted by Palanques et al. 2001, which defined two type of effects, one through direct physical damage, by breaking down the coralligenous structure and rolling its blocks, and the other through the increase in turbidity and sedimentation rates, which negatively affect the photosynthetic production of encrusting and erect algae, when trawling is applied to adjacent sedimentary bottoms.

Both traditional and recreational fishing also have an effect on coralligenous communities, although they mainly affect the target species (Enric Ballesteros 2006), leading to a significant decrease in mean specific number of fish species and producing changes in community's composition (Bell 1983) (Garcia-Rubies & Zabala 1990).

While professional fishing practiced on the bottom, such as trawling, may affect deep coralligenous banks scattered on it (Ferrigno et al. 2018), lost gears of artisanal fishing (e.g. longlines, hooks) mainly affect coralligenous assemblages on rocky cliffs and shoals, where fishes are gathered (Sbrescia et al., 2008).

In coralligenous assemblages, the most endangered organisms by fishing gears are erect and branched species with calcareous skeletons and those that are large, such as bryozoans and fan corals (Ferrigno et al. 2018). Their damaged colonies often show necrosis due to mechanical friction, leading to their being overgrown by epibionts (Hall-Spencer et al., 2002; UNEP, 2009; Bo et al., 2014a; Angiolillo et al., 2015).

Regarding dredging and anchoring operations, their potential impact concerns destruction of habitat and increase in sedimentation, as well as removal of arborescent species, although these effects are known only at a very local scale (Enrichetti et al. 2019).

2.2.2 SCUBA diving impact

Recreational diving is one of the fastest-growing types of marine wildlife tourism activities (Garrod and Gossling, 2008) and is especially important in marine protected areas (MPAs) where the particularly high biodiversity attracts many visitors, making of diving tourism a relevant socio-economic component (Parsons and Thur 2008; Sorice, Oh, and Ditton 2007).

Diving tourism may contribute to enhance the public awareness towards marine ecosystems (De Brauwer et al. 2017), however it must be effectively managed to ensure that any impacts caused to ecosystems do not outweigh the positive effects of the MPAs (Giglio, Luiz, and Ferreira 2020).

2.3 Purpose of the study

The present study aims to characterize the coralligenous assemblages in granitic sites of the north-east Sardinia (Italy) and to define the possible species that can be used as indicators of mechanical impact, focusing especially on recreational diving. Furthermore, the creation of fixed monitoring stations is considered (Figure 2).

Issues	Objectives	Research questions	Hypothesis	N.	Methods
Scuba diving can have an impact on fragile benthos altering characteristics of the organisms (morphology, dimension, health) and resulting in the decrease in abundance of vulnerable species This can lead to habitat degradation, aesthetic damage and reduction in ecosystem services. This impact could be higher in cramped sites such as submerged caves, tunnels and canyons. Costa Paradiso (Sardinia, Italy) is one of the coastal locality most frequented by scuba divers and their impact on benthic community could be relevant. Moreover, there are a few studies on the coralligenous developing on granitic substrates.	To increase knowledge about species composition in submerged canyons on granitic sites (case study: Costa Paradiso, Sardinia)	Does species composition change in canyons among different type of exposure (walls/crevices) and along depth?	Different environmental conditions between wall and crevices determine a difference in the species' assembleges.	1	**Vertical transect** on 3 sites (canyons) along the two sides of the canyons at 3 depths (30-25-20 m) with 20 photo quadrats (25x25 cm) at each depth, 10 for each exposure. **Analysis of the photos** with a programme (ImageJ)
			Species composition changes along depth and among canyons' side.	2	**Sampling (1)**
	To identify the mechanical impact- indicator species in submerged canyons in Costa Paradiso	Which are the species that can be used as indicators?How does diving impact influence the specific abundance of indicator species?	Impact due to scuba diving has different intensity in relation to these factors: - Frequentation - Sites - Sides of the canyons - Depth	2	**Sampling (1)** **Analysis of scuba data reports** to know the number of scuba divers per year and per season. **Analysis of the 'dive route'** per each site to understand how the scuba diver damages the benthic communities (with fins? with arms? Snorkels? Are there 'shelves' trapping air bubbles? Which depth range is more frequented?).
				3	**Evaluation of factors influencing the distribution/abundance** of indicator species (one of the wall is not or less frequented by scuba divers (see 'dive route'); different exposure to light or water motion; different morphology of the wall...).
			Scuba diving is the major pressure on fragile bethic communities	4	Collection of information about **direction of prevalling seastorms** in each site. **Video transects** to detect presence/absence of fishing lines/fishing nets/lures etc... in each site.
			Different level of experience of scuba divers influences underwater behavior	5	**Analysis of scuba data reports to profile scuba divers** frequenting the area considering dive licences.
	To supply data useful to management of submerged canyons to regulate their frequentation	What consequences can have the reduction in coverage and abundance of species on the coralligenous habitat and the ecosystem services that this type of habitat can provide?	The decrease in coverage and aboundance of vulnerable species can modify the landscape leading to the loss of "animal forest effect"	7	**Sampling (1)** **Collection from the literature** of data about clearance rates, associated organisms, sediment trapping...to quantify reproduction/filtration/predation efficiency in animals and in photosyntethic capacity and calcification in algal species.
	To create fixed monitoring stations	If SCUBA diving impact is present, does its frequency change during time? Does other impacts (es. fishing) change their frequency as well?	Fixed monitoring station should be able to detect a change in the frequency of a specific impact and the presence of new impacts.	8	Sampling (1) on **fixed transects**

Fig. 2 Logframe of the study.

3. Materials and methods

3.1 Review on recreational diving impact

The bibliographic research was conducted on three different platforms (ResearchGate, Elsvier' s Scopus database, Google Scholar) using as keywords "diving impact", "recreational diving", "diving impact" AND "coralligenous", "diving impact" AND "Mediterranean".

All the queries used resulted only in 27 articles (no review counted). The studies were divided within ecosystem (coralligenous, coral reef, others) and focus of the research (diver's behaviour, mechanical damages).

Regarding the Mediterranean Sea, papers were further differentiated within type of study area (protected, unprotected, both) and type of coralligenous assemblage (horizontal or vertical surface).

3.2 Study area

The area chosen for the study is Costa Paradiso, in the north-west Sardinia (Italy) (Figure 3). The coastal area, which is between Isola Rossa and P. ta di Li Frances, is characterized by the presence of granitic rocks of the Sardinia's Hercynian basement, mainly monzogranites (35%≤ K- feldspar ≤ % 65), that outcrops along the coast (Mannoni, Soriga, and Costa 2012).

The coastline presents sea-cliffs, pocket beaches and little islands, all typical structures of a rías coast, whose origin is attributable to the marine ingression in fluvial valleys due to the end of the last glacial period of Würm glaciation (Mannoni, Soriga, and Costa 2012).

Costa Paradiso is mainly affected by Mistral, a north-west wind which develops from south-eastern France and can extend into the western and central Mediterranean, reaching Sardinian coasts through Bonifacio Strait (Jiang, Smith, and Doyle 2003).

Mistral creates high sea states throughout the entire region, and contributes to the Mediterranean deep-water formation by cooling the sea surface (Schott et al. 1996).

In order to study the mechanical impacts on the area of Costa Paradiso, three sites, all canyons, were chosen: Agnata, Canyon del Vikingo and Rocca Ruja.

Fig. 3 Study area with indication of the three sampling sites and the diving center.

3.2.1 Characterization of the canyons

The sites are all canyons developing from south-west to north-east, whose sides are characterized by a highly structured morphology. This made essential to distinguished two type of exposure, “wall” and “crevice”. The first one identifies the portion on the same level of the canyon’ side, while the second one is referred to its fissures.

The sites were chosen to be as far as possible similar, they extends from 18-20 m to 30-32 m depth and are initially narrow (~1.5–2 m) and then become wider (> 3 m), except for Rocca Ruja, whose sides are particularly distant (~ 6–7 m).

The distance from the coast is 165 m for Canyon del Vikingo, 200 m for Agnata and 300 m for Rocca Ruja.

3.2.2 Sampling activity

The sampling method consisted in taking 20 photo-quadrats (25x25 cm) along a 4.5 m transect. The transect was developed on three depths (20 m, 25 m, 30 m) within the canyons. Ten photos were taken on walls and ten on crevices, making a total of 20 photos for each depth. In each site both canyon’ sides were sampled, the north-west (side A) and the south-east (side B). Video-transect was used to record the presence of eventual fishing gears along the transects.

In all the photos were identified the species, and for each species was calculated the percentage cover on an area of 625 cm^2.

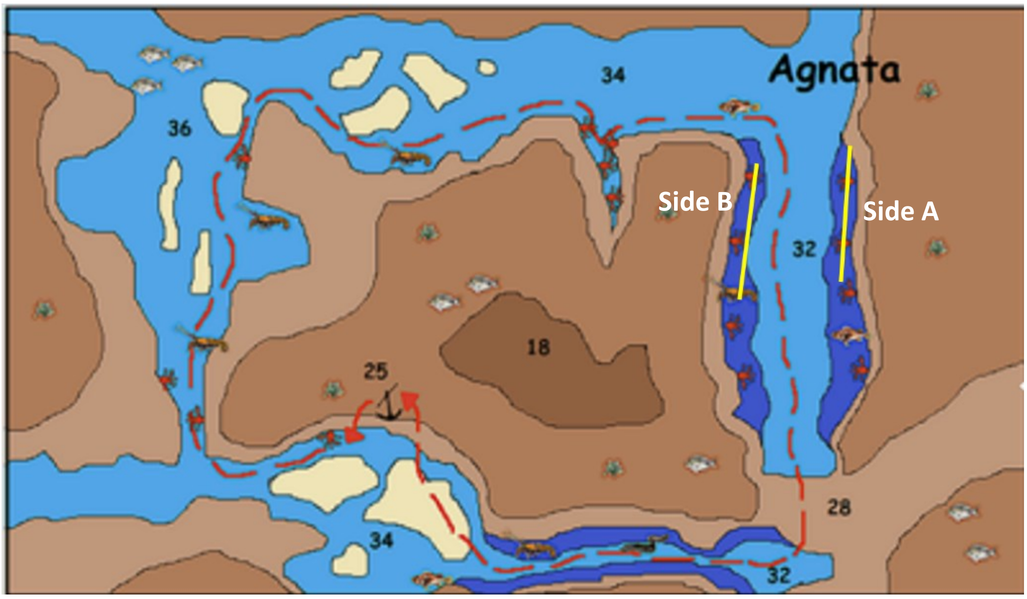
3.2.3 Dive routes in the canyons

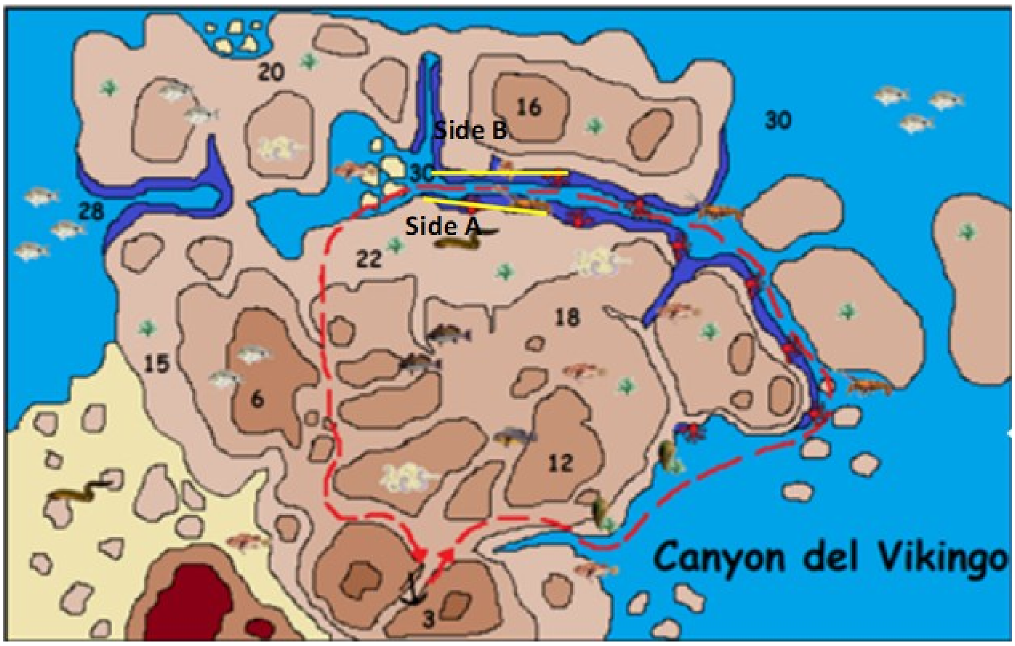
In all the considered diving sites the dive route involves crossing the canyons (Figure 4).

In Agnata the canyon is crossed at 30 m depth as a consequences of its topography, which becomes tighter from the entrance towards the end between 20 and 25 m depth. Thus, swimming near the substrate is the only way to pass through this canyon.

In Rocca Ruja during the dive, visitors are taken at 30 m depth to the south-east side of the canyon, in order to admire red coral.

Instead, Canyon del Vikingo is expected to be crossed between 25-30 m depth. At this range in the sampled area the canyon' sides get particularly close to each other, increasing the likelihood of being hit by divers with a bad buoyancy control.





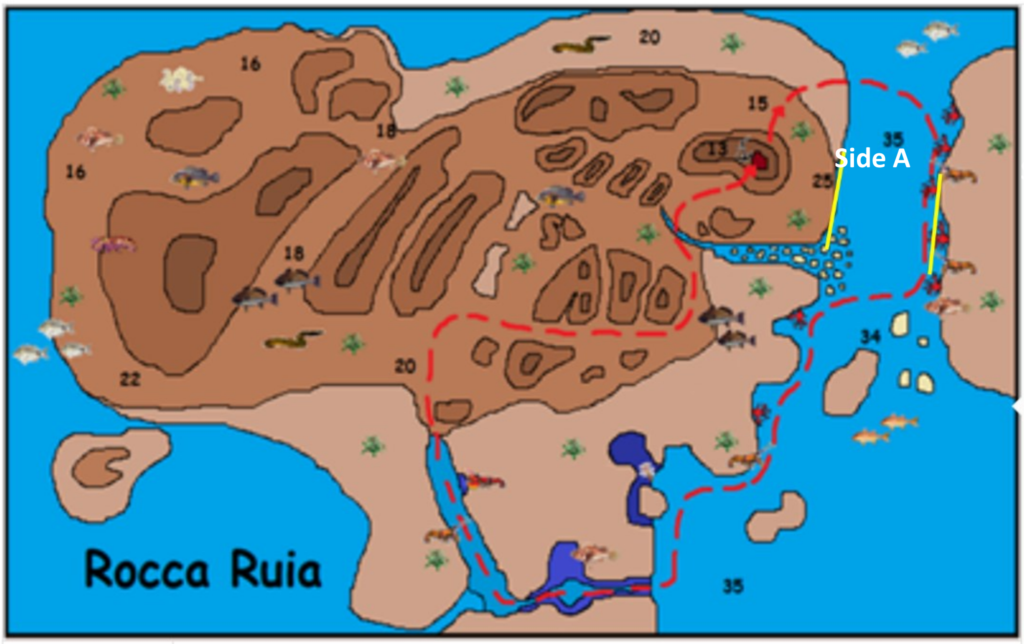


Fig. 4 Schematic representation of the diving route of each canyon. Pictures taken by Costa Paradiso Diving Center website (www.divingcentercostaparadiso.it).
Note: depth and distances are approximative and do not correspond to reality.

3.3 Statistical analysis

Data was analysed performing PERMANOVA analysis (Anderson MJ, ter Braak CJF, 2003) with PRIMER v. 6 software, setting Canyon as random factor and Orientation (i.e. canyon' side), Depth and Exposure (i.e. crevices or walls) as fixed factors (Table 1).

For multivariate analysis, data was transformed using square root to reduce the effect of the most abundant species and Bray-Curtis similarity index was applied as measure of similarity.

Factors

Names	**Abbrev.**	**Type**	**Levels**
Canyon	Ca	Random	3
Orientation	Or	Fixed	2
Depth	De	Fixed	3
Exposure	Ex	Fixed	2

Tab. 1 Factors used in the PERMANOVA analysis and their levels.

4. Results

4.1 SCUBA diving impact in literature

Scuba divers may affect organisms in several ways, both intentionally and unintentionally. The damage can be done through direct physical contact (e.g. fins, body and scuba gears), air bubbles trapped within caves or overhangs and sediment resuspension affecting sessile organisms (Milazzo et al. 2002).

Previous studies, until now, have focused on the assessment of SCUBA diving impact between sites with different level of frequentation (Hawkins and Roberts 1992; Zakai and Chadwick-Furman 2002) and on direct observation of divers' behaviour (Barker and Roberts 2004; Luna, Pérez, and Sánchez-Lizaso 2009; Medio, Ormond, and Pearson 1997). Most of the researches are conducted in tropical ecosystems, mainly coral reef (Figure 5).

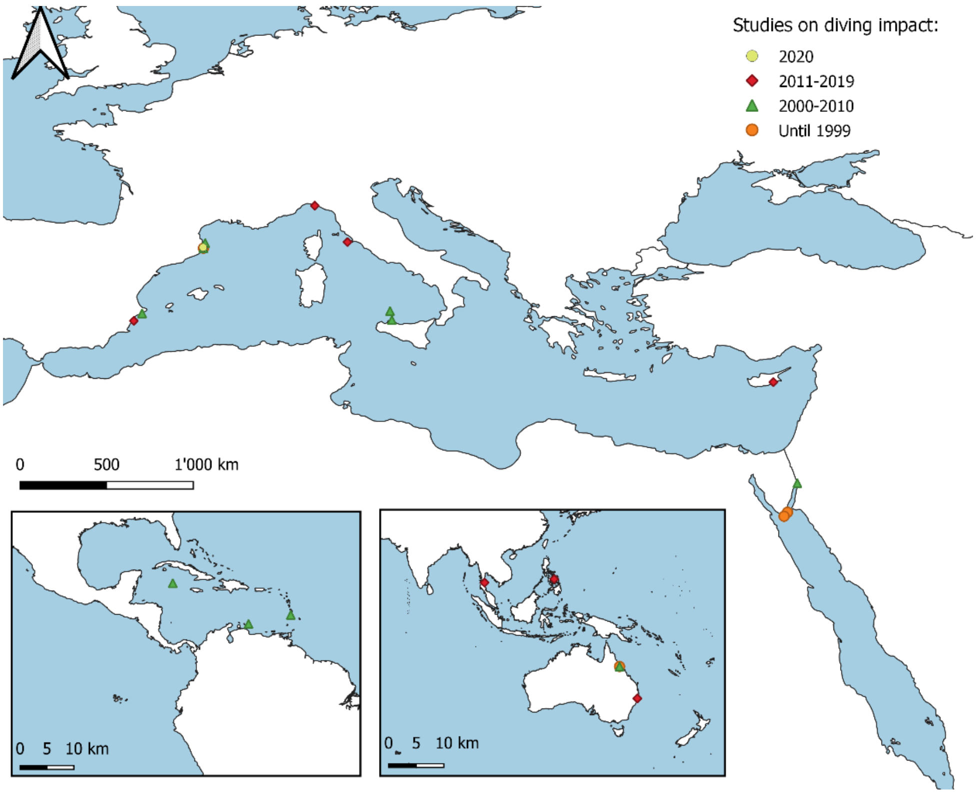


Fig. 5 The map shows the places in Mediterranean, Red Sea, Caraibbean Sea, Australia and Indochina where the studies about recreational diving impact have been conducted.

According to Di Franco et al. 2009, there is a lack of knowledge about the effects of recreational diving in Mediterranean Sea, especially on coralligenous assemblages, which are highly vulnerable to this type of impact (E. Sala, J. Garrabou 1996).

In literature, previous studies about SCUBA diving effects on coralligenous habitat in Mediterranean Sea, shows that the study areas interested by these works were chosen mostly within protected areas such as marine parks, reserves and MPAs (Figure 6.a).

Only few studies considered both, protected and unprotected areas (view Coma et al., 2004).

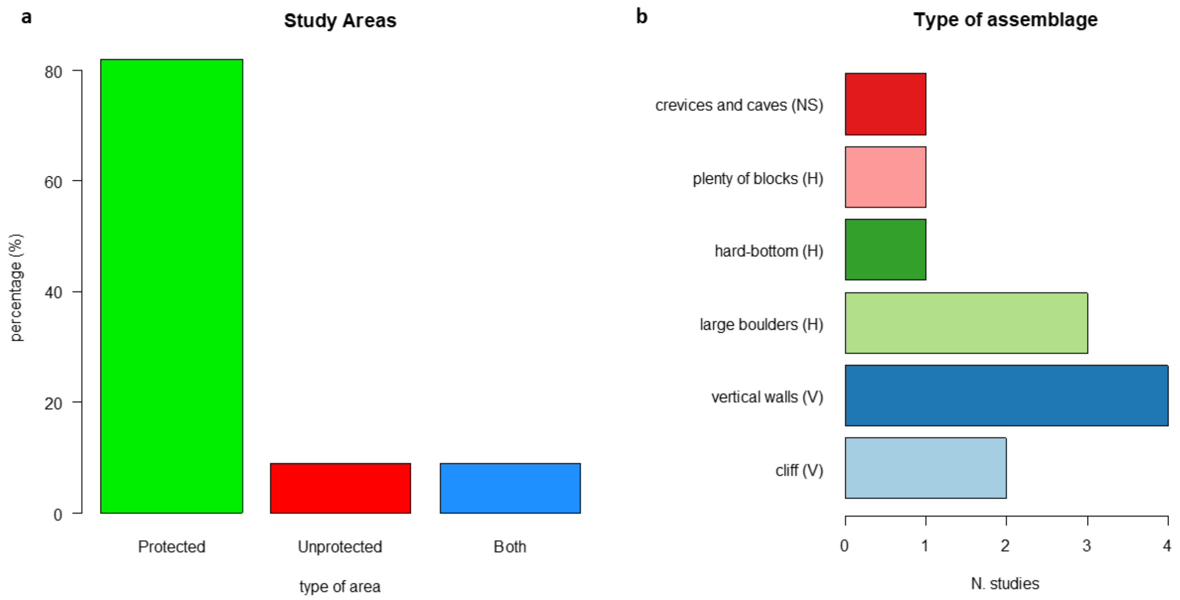


Fig. 6 The barplot (a) shows the percentage of studies within the different levels of protection of the chosen areas. The barplot (b) represent the type of coralligenous assemblages chosen for the studies, "H" identifies the horizontal structures while "V" the vertical ones.

Considering that coralligenous habitat can shows different forms, it is important to distinguish the literature on the basis of the assemblage's type. According to this, most of the studies happen to be applied on vertical surfaces and large boulders, only few were related to horizontal surfaces (Figure 6.b).

In order to evaluate this impact, most of the studies have focused on target species particularly vulnerable to SCUBA diving (Figure 7), mainly reef builders or fragile organisms such as gorgonians (Coma et al. 2004) and bryozoans (E. Sala, J. Garrabou 1996; Pagès-Escolà et al. 2020).

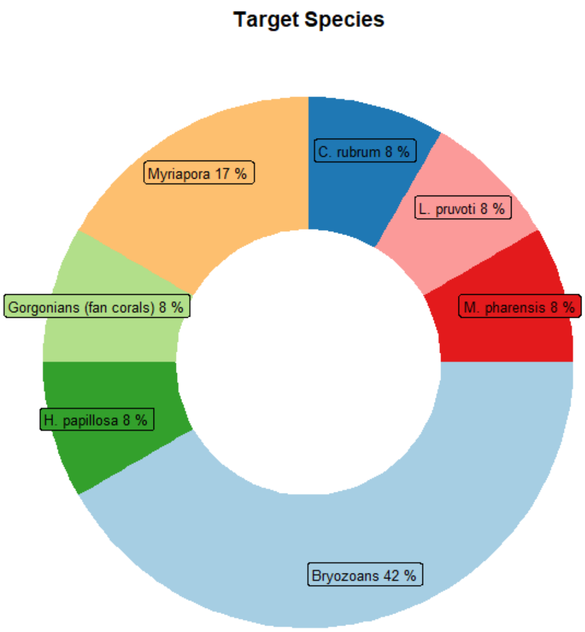


Fig. 7 The radial chart shows the most used target species to evaluate the SCUBA diving impact on coralligenous habitat.
Considered species: the bryozoans *Myriapora*, *Leptopsammia pruvoti* (*L. pruvoti*), the red coral *Corallium rubrum* (*C. rubrum*), the scleractinian *Madracis pharensis* (*M. pharensis*), other species of bryozoans (Bryozoans), the tunicate *Halocynthia papillosa* (*H. papillosa*) and several species of Gorgonians (Gorgonians (fan corals)).

Sala et al. 1996, to evaluate a possible negative effect of diving activity on coralligenous assemblages in Medes Islands Protected Area (north-west Mediterranean), compared frequented and unfrequented sites focusing on *Pentapora fascialis* (Pallas, 1766)' population.

In both sites were calculated density, degree of exposure, size and the relationship between these lasts. Results clearly showed that colonies' size and density were significantly lower in frequented sites, were *Pentapora fascialis*' populations tended to occupy more cryptic positions, than in the unfrequented ones were tended to be more exposed.

The same study was repeated by Pagès-Escolà, et al. 2020, whose results evidenced an impact on colonies' abundance and size. However, no differences were registered in partial mortality and growth rates between frequented and non-frequented sites (Pagès-Escolà et al. 2020).

Erect bryozoans are useful for the evaluation and monitoring of SCUBA diving impact on coralligenous habitat, in particular *Pentapora fascialis* and *Reteporella grimaldii* (Jullien, 1903) are good candidates as indicators of physical stress and should be taken into consideration in the coralligenous habitat status' assessment, as requested by MSFD (Casoli et al. 2017).

Some studies about diving activity monitoring have shown that one of the most frequently effect produced by divers is raising of sediment, followed by contact with fragile organisms (Garrabou et al. 1998; Luna, Pérez, and Sánchez-Lizaso 2009; Zakai and Chadwick-Furman 2002).

The excessive sediment deposition may affect benthic organisms, clogging filtering apparatus and inhibiting recruitment, growth and metabolic processes (E. Sala, J. Garrabou 1996; Garrabou et al. 1998).

Luna-Pérez et al. 2010 investigated the possible role of the ascidian *Halocynthia papillosa* (Linnaeus, 1767) as indicator of SCUBA diving impact. The results, collected during two years of sampling, showed a lower density and size in the frequented sites, where was also observed a decrease in the abundance after the diving season's peak.

According to previous studies, some of the possible consequences of SCUBA diving can be the decrease in density and size, shift to cryptic positions as well as increase in mortality of fragile organisms (Figure 8).

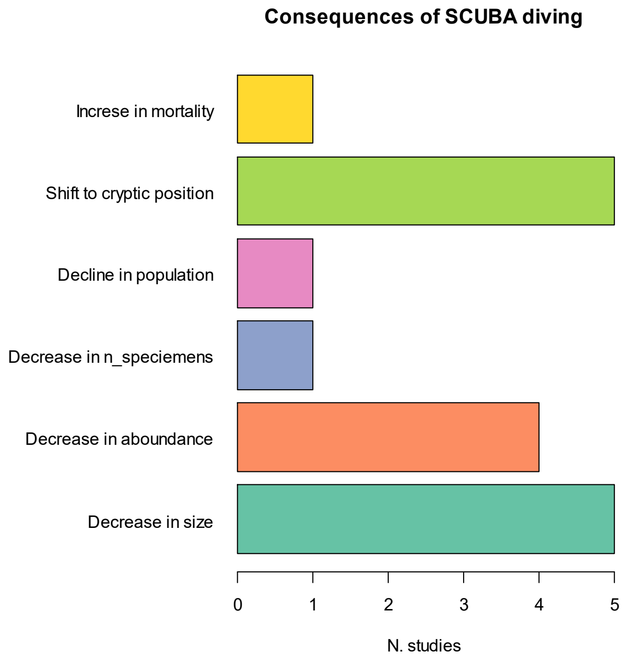


Fig. 8 The barplot shows the consequences of SCUBA diving on coralligenous habitat in previous studies. Eight studies were considered

In addition to these studies, which highlighted the use of target species to evaluate the impact and its consequences, some researches focused more on divers' behaviour during the dive in order to determine the sources of damage and its quantification (view Di Franco et al., 2010; Medio et al., 1997).

Most of these studies consist in a temporary observation of divers to report the number of contacts, both intentionally and unintentionally, the body portion or the equipment of the diver who made the contact, and their consequences.

Repetitive contact by divers or their equipment is one of the principal mechanism for chronic impact on benthic life forms (Harriott 2002).

According to B. Luna et al. 2009, who carried out the study in Sierra Helada Marine Park (Spain), flapping was the most frequent type of contact, especially the one involving fins, which mainly caused trampling of organisms, resuspension of sediment, and removal of algae.

Even though, most studies reported that less experienced or beginner divers create the most impact (Zakai and Chadwick-Furman 2002), this is not always true. Most open water divers, if well supervised in water by the diving instructor, make less contact than more experienced divers, including dive-masters (Hammerton and Bucher 2015).

Rates of contact recorded by A. Di Franco et al. 2009 in Mediterranean Sea were particularly elevated in caves and encrusted walls, which represent two of the habitats mostly vulnerable to SCUBA diving activity (Lloret et al. 2006). In caves, high level divers were responsible of the highest contact rate, probably due to an excess of confidence.

Since diver certifications do not require periodic renewal, diver training level may not be a good indicator of current diving skills (Luna, Pérez, and Sánchez-Lizaso 2009). The identification of different factors describing divers' behaviour and its environmental effects, may help to prevent or reduce the incidence of damaging behaviours through the development of more effective training procedures, pre-dive briefings and site regulations (Rouphael and Inglis 2001).

Dive companies often give briefings that last only a few minutes and in many instances those briefings do not include how to avoid damaging the reef (Barker and Roberts 2004).

As reported by Baker & Roberts 2004, briefings and underwater intervention by a dive leader were highly effective at reducing the average impact of flapping and contact by diver’s body portions. Many divers, particularly the less experienced, model their in-water behaviour basing on how the dive guide conduct them underwater (Townsend 2000).

Divers with cameras have been reported to cause significantly more damage than their counterparts without cameras (Rouphael and Inglis 2001). According to Hammerton & Bucher 2015, photographers made a great number of intentional contacts with their hands and knees due to the need of using the reef to stabilise themselves.

The cumulative effects of large numbers of divers can be significant, and can have long-term consequences (Dearden, Bennett, and Rollins 2007).

In heavily used sites, diving impacts may render the reef less able to recover from bigger stressors such as hurricanes, storms and disease (Hawkins and Roberts 1992). Therefore, it can lead to detectable changes to the coral communities, and eventually, a change to the aesthetics of the reef if diving intensity is high enough (Hawkins and Roberts 1992).

The loss of aesthetic value in ecosystems such as coral reef or coralligenous habitat may has a negative effect on their appeal to tourism.

Coralligenous assemblages are one of the most important and largely appreciated Mediterranean seascape accessible to SCUBA divers, comparable to the one made by barrier reefs in tropical ecosystems (Chimienti et al. 2017).

According to Tribot, A. S. et al. 2016, aesthetic experience induces a social motivation for ecosystem conservation, therefore landscape seems to be a good vehicle for educating the general public on environmental issues (Jorgensen 2011).

Education through the concept of "functional beauty", based both on ecological understanding and aesthetic experience, could be a solution to better converge ecology and beauty (Swaffield and McWilliam 2013).

Besides educational measures, design and implementation of management strategies to reduce conflicts between recreation and conservation are needed (Davis and Tisdell 1995).

According to V.J. Giglio et al. 2020, one of the most important management strategies is the establishment of a limit to diver visitation estimating the ecological carrying capacity (ECC) of a site. This approach expresses the ECC as the number of divers per dive site per year, measuring the number of divers each site can tolerate without becoming degraded (Davis and Tisdell 1995).

Management initiatives about dive tourism should not rely only on promoting a responsible use of natural resources but also need to consider the socio-economic context of stakeholders, to be integrated with the community and to promote a satisfying diving experience (Wongthong and Harvey 2014).

In this contest the sustainable tourism development's principles (STD) and the integrated costal management (ICM) approach, if combined, can emphasize the importance of the ecological component as well as the social, economic and managerial elements of sustainability (Wongthong and Harvey 2014).

4.2 Diving frequentation's data

Diving frequentation data for each site and diving license's data from 2011 to 2020 were collected (Figure 9, Figure 11).

Diving frequentation was measured as number of dives per each site per year, while diving license data were collected from both Costa Paradiso Diving Center and Isola Rossa seat and expressed as percentages. The level of experience was considered as two categories: “Open Water” and “Advance or higher level”.

At first glance appears evident the gap in number of dives between Rocca Ruja and the other diving sites, which are less frequented.

According to data, Rocca Ruja and Agnata show a decreasing trend in frequentation starting from 2011, respectively with 136 and 105 as the highest number of dives.

On the contrary, Canyon del Vikingo seems to have an instable trend, reaching a maximum peak of 81 dives in 2014.

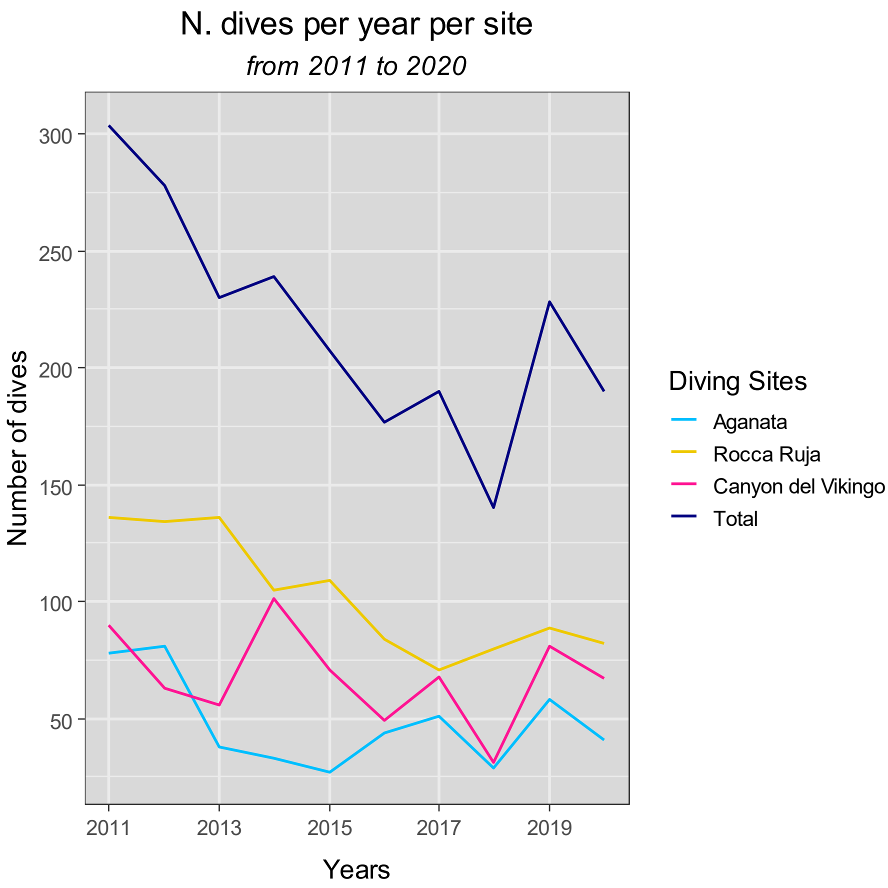


Fig. 9 The graph shows the number of dives in each site and the total number of dives considering the three site together in a period of time from 2011 to 2020.

Considering the total number of dives, there is a decreasing trend form 2011 to 2018 with a recovery starting in 2019. Unfortunately, 2020 brought an ulterior decline with a loss of -1.3% in frequentation from 2019.

It is important to underline that in 2015 was opened another seat in Isola Rossa, and from 2015 to 2019 the number of dives per year in Costa Paradiso decreased. Furthermore, in both diving centres the frequentation drastically declined in 2020 probably due to COVID-19 pandemic (Figure 10). According to ANSA, Sardinia registered a decline of tourism in 2020 (www.ansa.it).

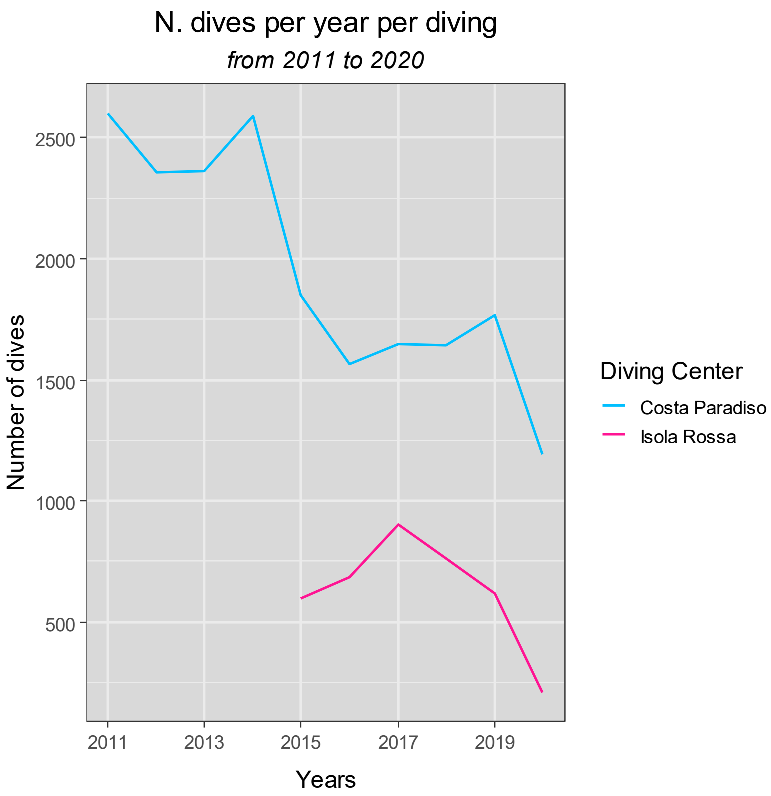


Fig. 10 The barplot shows the number of dives in each diving center (from 2015 to 2020) considering all of their diving spots.

The level of scuba divers frequenting Costa Paradiso became progressively higher, data shows an increasing trend in divers with Advanced or a higher level and a respectively decrease in Open Water divers with an average of 35% for OWD and 65% for ADW/+ (Figure 11).

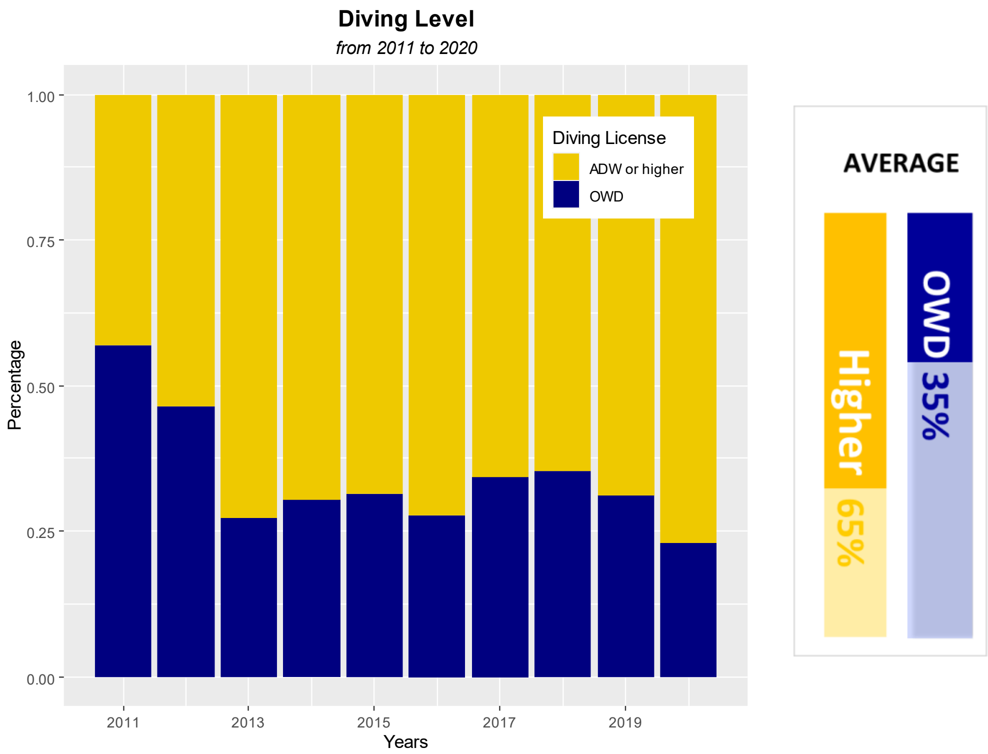


Fig. 11 The barplot shows the level of SCUBA divers who frequented the diving from 2011 to 2020 expressed in percentage.

4.3 Species composition of the canyons

The percentage cover data for each species with value ≥ 0.5 % were reported in four stacked barplots for each canyon (Figure 12). *Peyssonnelia* sp. was represented by itself due to its values, much more higher if compared with the other species.

Observing the representation of Agnata's data, it is possible to notice some differences in the species composition between exposure (C/W). Encrusting sponges, such as *Halisarca dujardinii*, *Spirastrella cuncatrix*, *Fasciospongia* cfr. *cavernosa* and *Petrosia ficiformis*, appear to be more abundant in crevices than in walls. Furthermore, data suggests the bryozoan *Leptopsammia pruvoti*, well represented in crevices, to be plentiful at 30 m depth. As well, massive algae (e.g

Codium) and foliaceus algae (e.g. *Flabellia petiolata*, *Halopteris scoparia* and *Halimeda tuna*) seem to reach higher levels in walls than in crevices.

The same pattern is observed in Canyon del Vikingo's data, where *Spirastrella cuncatrix* reaches the highest value (10%) at 20 m depth.

Moreover, in both sites the percentage cover of red coral (*Corallium rubrum*) is minimum.

Observing Rocca Ruja's data representations, appears immediately evident the elevated presence of red coral at 30 m depth in crevices of the south-east side of the canyon (side B), while the north-west side (side A) appears particularly poor. Furthermore, algae such as *Halimeda tuna* seems particularly abundant on both walls of this canyon if compared to the other sites. This species reach the highest level of coverage (40%) on the B side, where is equally distributed at 20 and 25 m depth.

During the sampling of Rocca Ruja was reported a fishing line on the side B at 25 m depth.

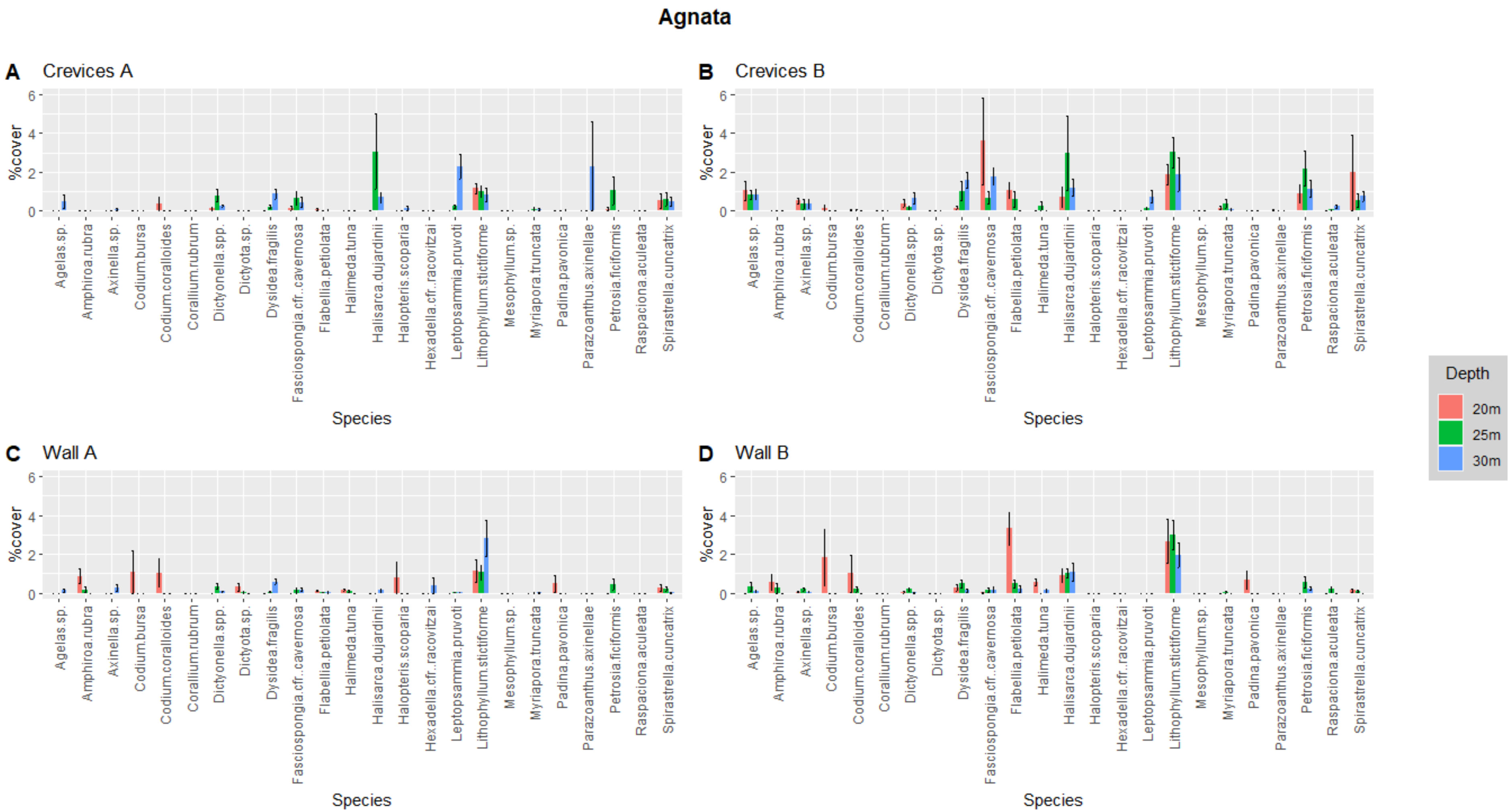
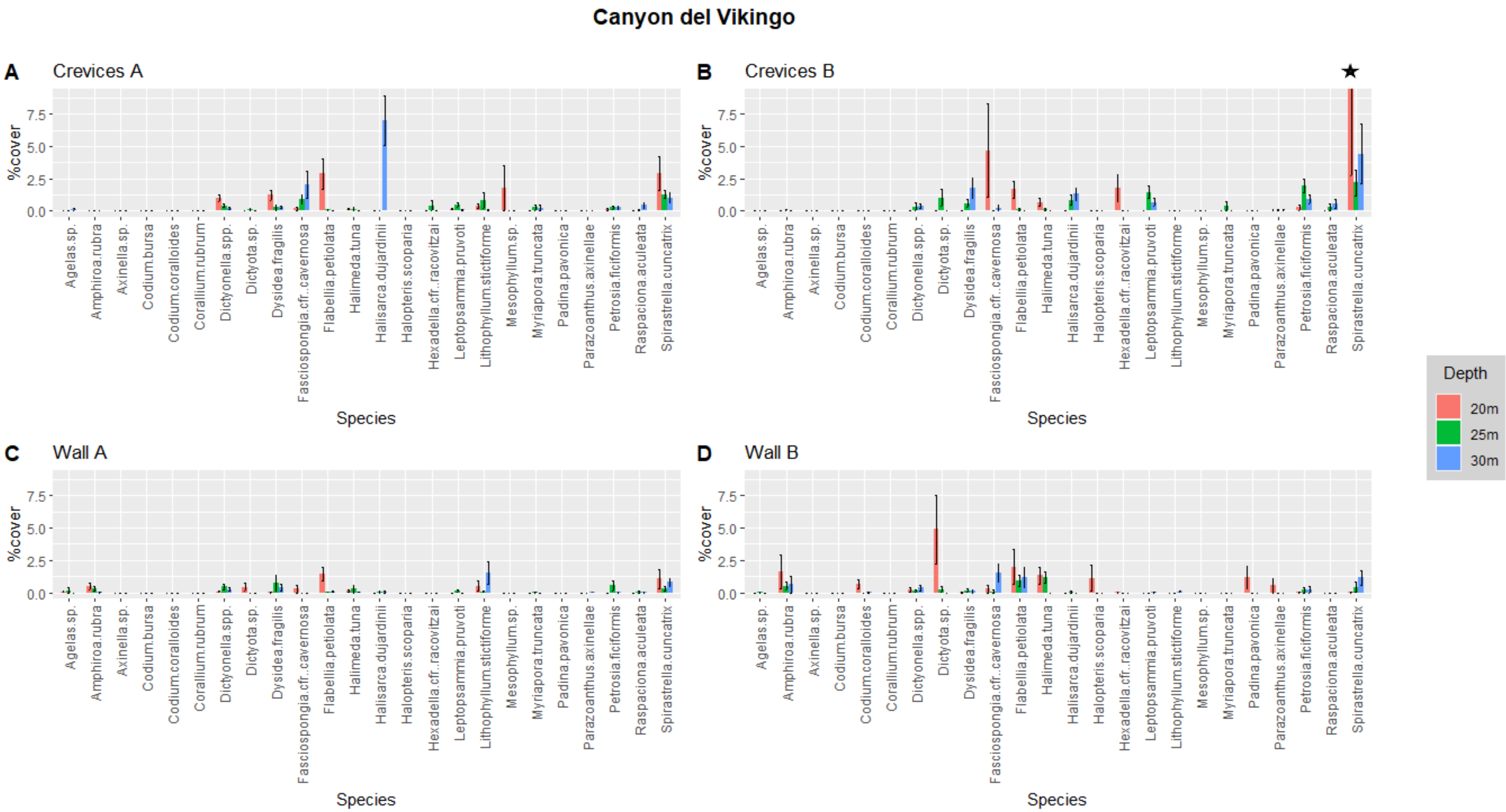
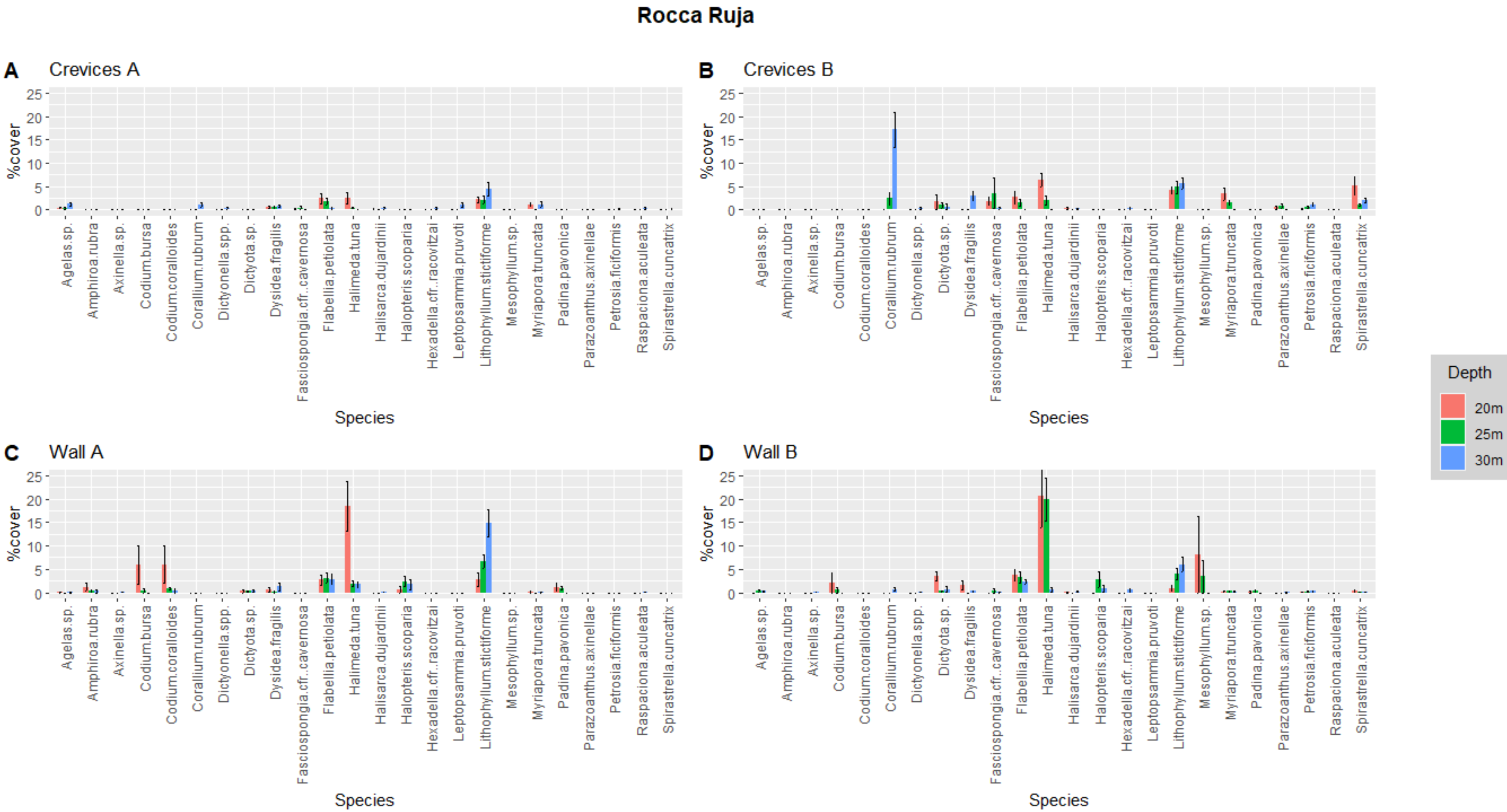


Fig. 12 The barplots represent the percentage cover of different species within exposure and canyon' side in the three sites (Agnata, Canyon del Vikingo, Rocca Ruja). Each bar shows the percentage cover of the species among three different depths (20 m, 25 m, 30 m).
Note: Each site has a different scale.



Note: error bar of *Spirastrella cuncatrix* in Crevices B reaches 18%. The symbol "★" means that the bar was cut in order to fit the scale and well represent the data in all four the graphs.



Note: error bar of *Halimeda tuna* in Wall B reaches 27%.

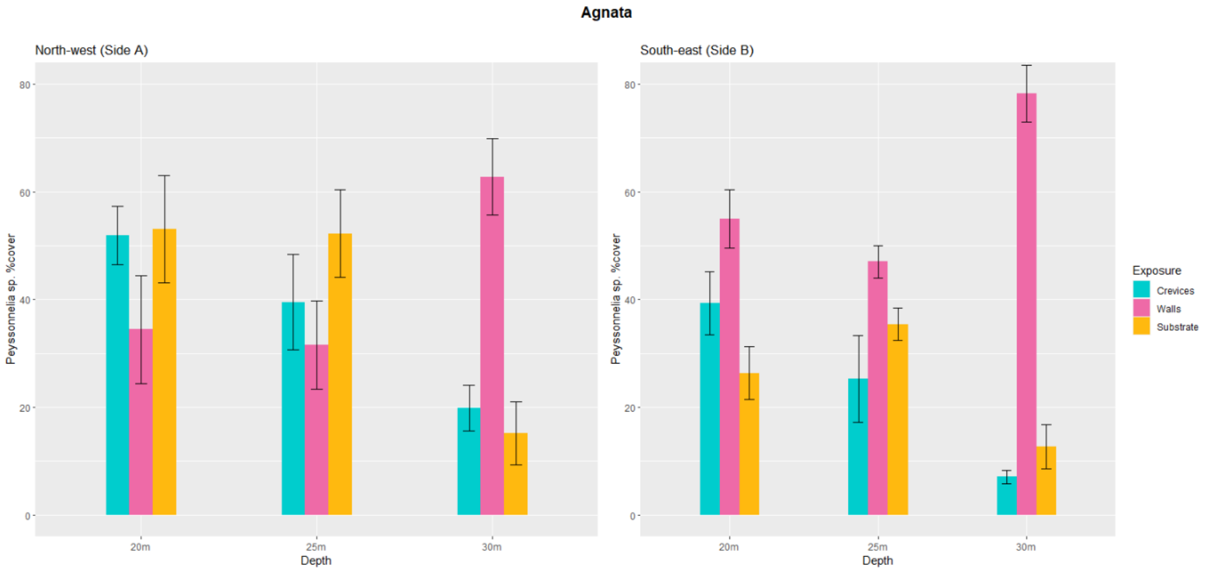
Peyssonnelia sp.' s percentage cover data were analysed apart due to the high abundance of the species (Figure 13).

It is important to highlight that, during the photo analysis, the epiphytic species covering encrusting algae on walls were referred as "Substrate" because, even though *Peyssonnelia* sp. seems to be the most abundant building-species in these canyons, sometimes epiphytes were so abundant that it was not possible to exclude the presence of *Lithophyllum* sp..

In Agnata, *Peyssonnelia* sp. shows a decreasing trend with depth in crevices, while in walls appears more abundant at 30 m. Actually, considering together the substrate and the walls' values, the encrusting algae reaches the highest percentage cover in walls, where also shows a decrease with depth.

The same pattern is observed in Canyon del Vikingo's crevices. Instead, on walls, the trend seems to be stable between depth, if "Walls" and "Substrate" are considered together, otherwise it shows a decrease.

In Rocca Ruja, crevices of the north-west side shows a different trend than the ones of the other sites, *Peyssonnelia* sp. seems particularly abundant at 25 m depth. Concerning walls, both sides shows an increase in the coverage with depth, even without considering epiphytes.



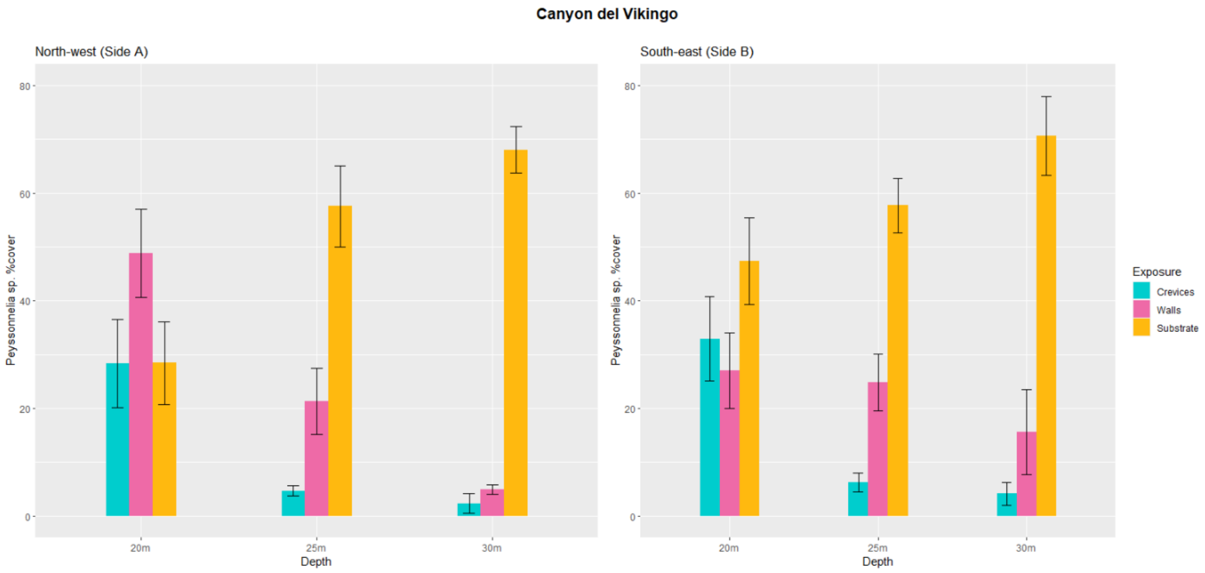


Fig. 13 Each pair of barplot shows the %cover of *Peyssonnelia sp.* along depth (20-25-30 m) considering the two type of exposure (Crevices/Walls) in both canyon' side. It is also considered the "Substrate" associated with "Walls"
Note: "Substrate" stands for the epiphytic species covering the encrusting algae on walls.

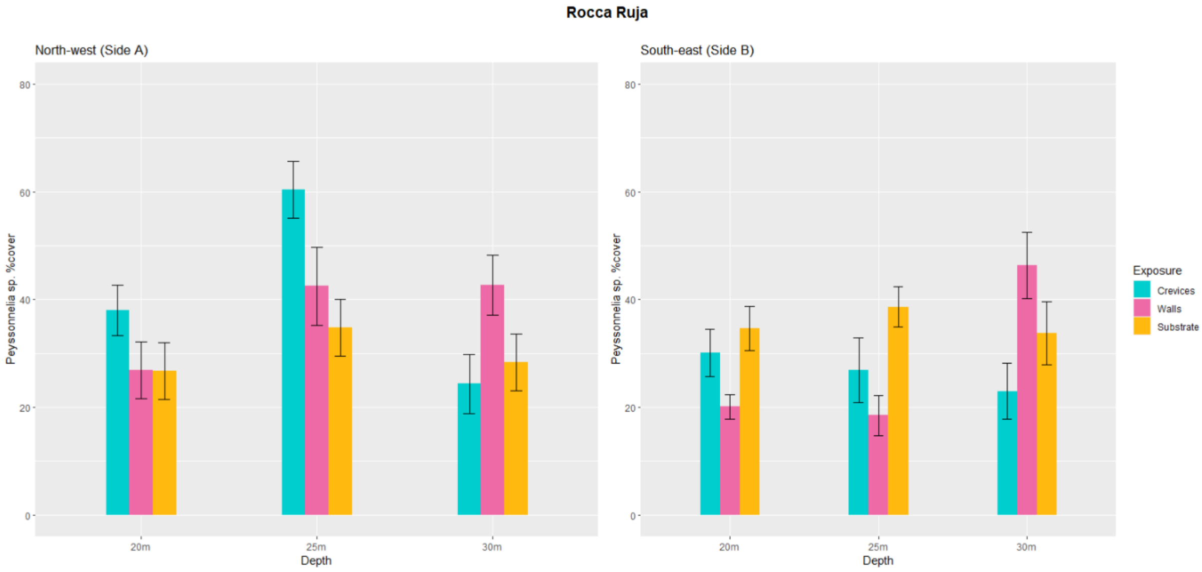


Fig. 13 Each pair of barplot shows the %cover of *Peyssonnelia sp.* along depth (20-25-30 m) considering the two type of exposure (Crevices/Walls) in both canyon' side. It is also considered the "Substrate" associated with "Walls"
Note: "Substrate" stands for the epiphytic species covering the encrusting algae on walls.

4.4 Statistical results

Applying PERMANOVA test on the complete dataset, with data transformed using square root, the interaction between all the factors (Ca*Or*De*Ex) resulted as highly significant (Table 2).

Source	df	SS	MS	Pseudo-F	$p_{[perm]}$	Unique perms	P(MC)
Ca	2	92068	46034	45.187	0.000	9928	0.0001
Or	1	8900	8899.6	1.087	0.370	38	0.4336
De	2	37728	18864	2.637	0.082	6180	0.0142
Ex	1	46215	46215	6.243	0.098	38	0.0033
Ca x Or	2	16369	8184.5	8.034	0.000	9916	0.0001
Ca x De	4	28619	7154.8	7.023	0.000	9887	0.0001
Ca x Ex	2	14807	7403.4	7.267	0.000	9912	0.0001
Or x De	2	7871	3935.7	1.78	0.149	9940	0.0855
Or x Ex	1	5077	5076.9	0.971	0.456	2086	0.4972
De x Ex	2	17261	8630.6	1.933	0.138	9953	0.0597
Ca x Or x De	4	8847	2211.6	2.171	0.000	9894	0.0004
Ca x Or x Ex	2	10461	5230.5	5.134	0.000	9922	0.0001
Ca x De x Ex	4	17858	4464.4	4.382	0.000	9894	0.0001
Or x De x Ex	2	6325	3162.5	1.648	0.213	9946	0.1148
Ca x Or x De x Ex	4	7677	1919.3	1.884	0.002	9890	0.0026
Res	324	330080	1018.8				
Total	359	656160					

Tab. 2 PERMANOVA table of results. Ca (Canyon), Or (Orientation), De (Depth), Ex (Exposure). PERMANOVA was based on S17 Bray-Curtis similarity and square root-transformed coverage data.

Considering each factor individually, Canyon represents the most relevant source of variation (375.13), followed by Exposure (251.09) and the interaction Ca*De*Ex (172.28).

Therefore, species composition shows a highly overall heterogeneity and is mostly influenced by two factors: Canyon and Exposure (Figure 14).

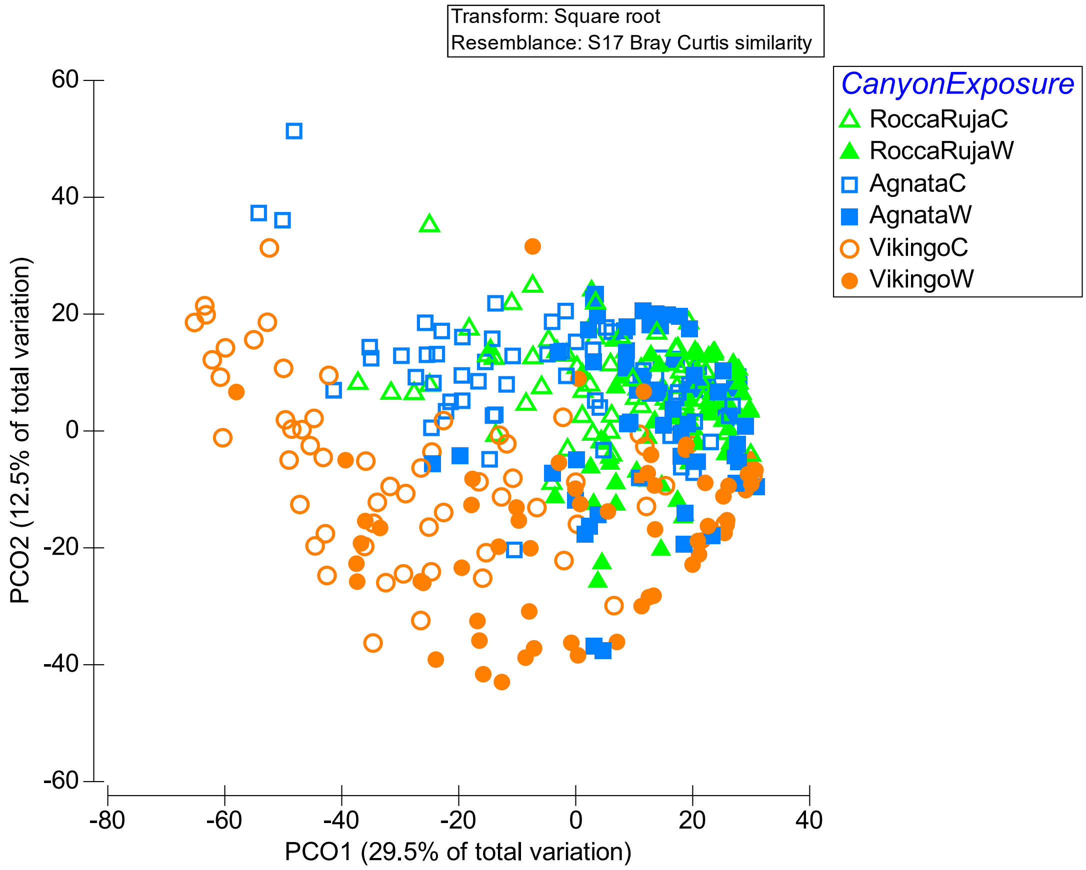


Fig. 14 PERMANOVA results considering all the factors and their interactions. In the graph are shown only the factors Canyon (Ca) and Exposure (Ex).

Pair-wise test was applied to understand how the species composition in the two type of exposure changes along depth. Nearly always there are significant differences between crevices and walls among depths.

The main species responsible of the differences between species composition in the two exposures are shown in Figure 15.

Encrusting sponges and *Leptopsammia pruvoti* characterize the assemblage in crevices, while encrusting algae and *Flabellia petiolata* are typical in walls.

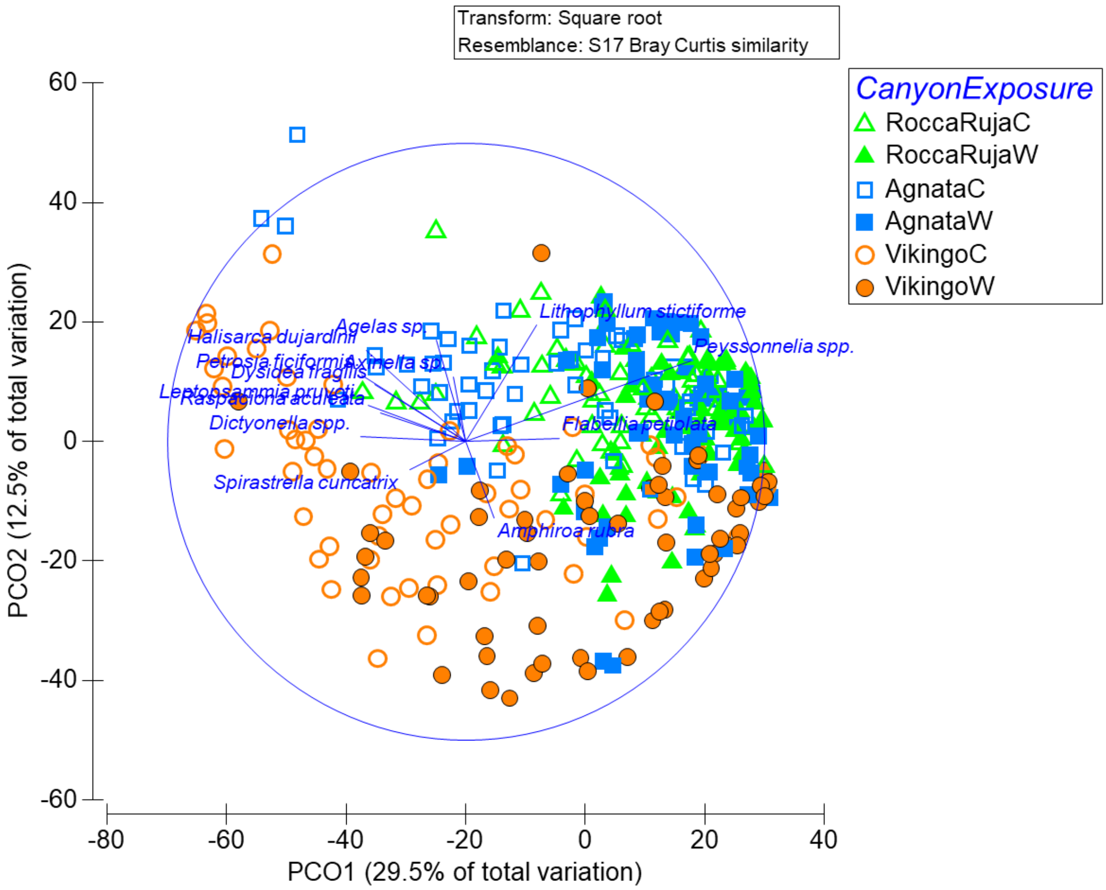
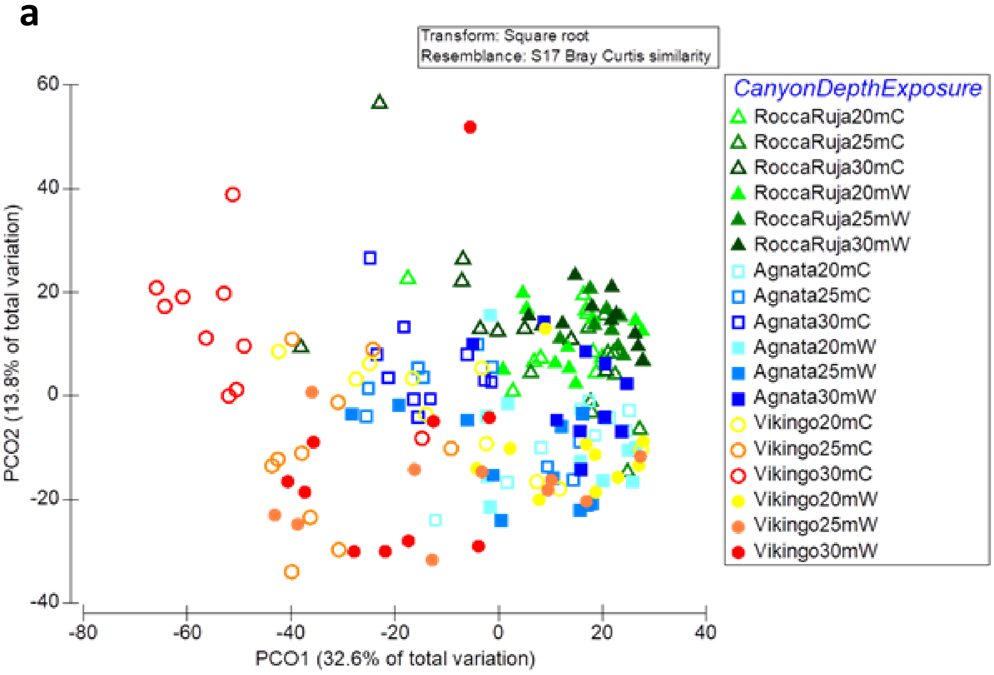


Fig. 15 Main species responsible of the differences between the two exposures.

Main test was applied to highlight possible differences between canyons considering the same orientation (Figure 16).

In both, north-west and south-east, results are highly significant (p = 0.0001), and assemblages among canyons nearly always differ but with different intensity according to which orientation is considered.

a



b

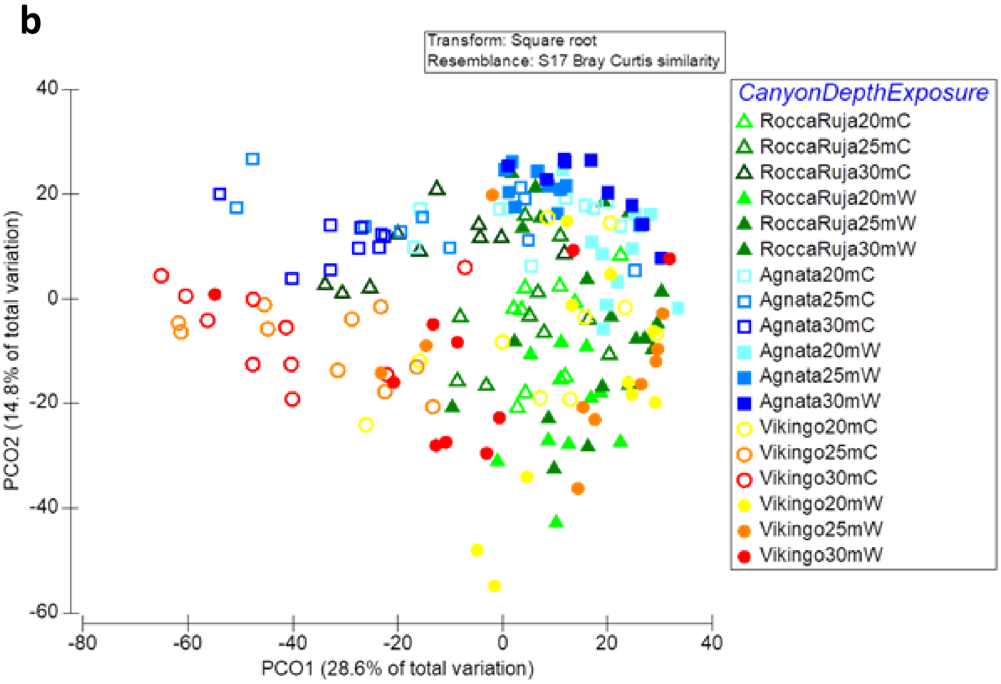


Fig. 16 Main-test results considering all the canyons with same orientation. (a) North-west orientation, (b) South-east orientation.

5. Discussion

Coralligenous habitat represent a “hot spot’’ of species diversity in the Mediterranean Sea and is maintained by the delicate equilibrium between bio-construction and bio-erosion. Stable environmental conditions are a key factor for the development and survival of this habitat, since it hosts species highly sensitive to human disturbance (e.g. *Corallium rubrum* (Linnaeus, 1758), *Eunicella cavolini* (Koch, 1887)).

Mechanical impacts such as fishing activity, ghost-fishing, anchoring, dredging and recreational diving can affect coralligenous habitat leading to modifications in its communities’ structure and functioning.

In this study, coralligenous assemblages in north-west Sardinia (Italy) were characterized and possible mechanical impact-indicator species were investigated, focusing especially on recreational diving impact.

At date, impacts caused by SCUBA diving are poorly studied and most of the researches are conducted in MPAs using target species to monitor the mechanical impact.

Ideal indicator-species to evaluate mechanical impacts on coralligenous habitat are fragile species (e.g fan corals) and those who are erected and branched with calcareous skeletons (e.g. bryozoans).

The area of Costa Paradiso is highly frequented by divers. In 2019 it reached more than 1750 dives, and among the chosen canyons, Rocca Ruja is the most frequented.

Even though the diving sites of Costa Paradiso are highly visited, over time it was observed an increase in the license level of SCUBA divers. In 2019 almost 70% were Advanced divers or divers with higher level.

According to PERMANOVA results, species composition shows a highly overall heterogeneity mostly related to the type of exposure and the canyon itself.

In all the three canyons, coverage data has shown differences in population between the two type of exposure: walls are dominated by algae, while crevices are abundant in *Leptopsammia pruvoti* and encrusting sponges.

Assemblages among canyons nearly always differ with different intensity according to which orientation is considered.

Species composition in Canyon del Vikingo seems to always deviate from the other sites'. Since, there are not particularly differences in topography and environmental conditions between this site and the other canyons, especially Agnata, these differences could be related to a recreational diving impact. In fact, according to the dive routes, the canyons are crossed at different depths.

Canyon del Vikingo, which is crossed between 25–30 m, is particularly exposed to diver's kicks if they have bad buoyancy control.

In Agnata, divers cross the canyon really close to the substrate, increasing the risk in sediment resuspension.

These conditions can affect filter-feeding organisms, since sediment particles can damage their filtering apparatus, but also fragile organisms, which can be hurt by fin kicks and bubbles. Since bubbles tend to go up, their effects can even involve organisms at lower depths on the canyon' sides, reflecting on their distribution along depth.

Considering the dive routes, Canyon del Vikingo is more exposed to direct damages, while Agnata and Rocca Ruja are particularly subjected to indirect damages. This difference could explain why species composition in Canyon del Vikingo always deviates from the other sites, resulting as the most impacted among canyons.

Concerning Rocca Ruja, the canyon presents a massive presence of red coral in the south-east side, and a higher abundance of algae, particularly *Lithophyllum* sp. and *Halimeda tuna*, if compared with the other sites.

These characteristics of Rocca Ruja could be ascribed to the morphology of this canyon. Even though the sites were chosen as far as possible similar, Rocca Ruja' sides are more distant than in other canyons, allowing more light to penetrate. This can explain the high coverage in the foliaceus algae *Halimeda tuna* and *Flabellia petiolata*. Some authors identify this coverage as "facies of *Halimeda tuna*", a coralligenous depletion phase with seasonal cycle. It prevails at late summer or autumn while it is minimal in winter (Bressan G, Babbini L., Ghirardelli L. 2001).

According to this, the higher percentage cover of *Halimeda tuna* and *Flabellia petiolata* found in Rocca Ruja can be the result of a synergy between the sampling period (early September) and the canyon's topography.

Concerning *Corallium rubrum*, its low presence on the north-west side of Rocca Ruja could be related to a cumulative mechanical impact, since topography and light condition between the two sides of the canyon do not seem particularly different.

Among the chosen canyons, Rocca Ruja appears to be the most frequented diving site, with almost 140 dives in 2011 and 2012, when more than 50% of divers had an Open Water license in the past.

Since it is known that cumulative effects of large numbers of divers can be significant, leading to long-term consequences, species composition in the north-west side of Rocca Ruja could be the result of a persistent mechanical impact.

In conclusion, considering that these canyons are not close enough to the coast (d= 150–300 m) and at a depth easily reachable by people to justify an impact, and since the area is mostly frequented by Costa Paradiso Diving Center, recreational diving seems to be the only cause able to explain the differences in species composition among canyons, if we exclude the own variability of each site. Of course, considering the presence of fishing lines in one of the transect in Rocca Ruja, impact from ghost fishnets cannot be excluded.

Due to its narrow passage, Canyon del Vikingo seems be the most impacted site, since it's the most exposed to direct damages and its assemblages always deviate from the ones of the other canyons.

The assessment of SCUBA diving impact should be done through the evaluation of the coverage and distribution of particular species.

These mechanical impact-indicator species should be chosen between:

(I) Fragile species (e.g. gorgonians, red coral): these species are particularly vulnerable to mechanical impact and tend to move to more cryptic position if subjected to repeated impacts. Therefore, the type of exposure they take up should also be reported (e.g. overhangs, crevices, holes, caves).

(II) Sessile filter-feeders (e.g. ascidians, bryozoans): these organisms are sensitive to sediment resuspension and should be monitored, especially in areas close to the substrate, where divers can raise sediment causing, in the worst case scenario, their death due to choking.

Together with the evaluation of target species' conditions, an analysis of the sediment, if possible, should be considered because it can give information about the entity of the mechanical impact and its date (old impact/recent impact).

In addition, the creation of fixed monitoring station should allow to detect a change in the frequency of the recreational diving impact, as well as the presence of new impacts. Therefore it should be considered.

Farther, if the study area allows it, three canyons with the same characteristics of the chosen ones should be added to the experimental design as control sites in order to statistically evaluate the presence of SCUBA diving impact.

Acknowledgements

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