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Benthic mucilage blooms threaten coralligenous reefs

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ABSTRACT

Mucilaginous aggregates produced by planktonic or benthic algae are considered ecological threats to marine systems. The study evaluated the effects of the spread of benthic mucilaginous aggregates on the structure of coralligenous assemblages. The assemblage and the quality of a site subjected to a benthic mucilage bloom were compared to those of two reference sites using a Before/After-Control/Impact (BACI) design. Results showed the α and β -diversity, ESCA and COARSE quality ecological indices and the cover of encrusting algae and bryozoans were lower at the impact site after the mucilage event than at the control sites and at the impact site before the mucilage event. An opposite pattern was observed for the necrosis of gorgonians and the cover of algal turf. This study describes for the first time the impacts of ephemeral mucilage blooms on the whole coralligenous assemblage, identifying a further threat of this habitat and the need of adequate monitoring programs.

1. Introduction

Mucilaginous aggregates consist of gelatinous organic material with colloidal properties, mainly composed of high molecular weight polysaccharides released by marine organisms (Wimpenny et al., 2000). They may be pelagic (aggregates suspended in seawater) or benthic (cloud-like aggregates adhering to solid substrates), primarily produced by planktonic or benthic algae, respectively (Innamorati, 1995; Myklestad, 1995; MacKenzie et al., 2002; Schaffelke et al., 2004; Caronni et al., 2016). Mucilaginous aggregates are considered an ecological threat to marine systems (Devescovi and Iveša, 2007; Yentur et al., 2013) and also damage tourism and fisheries (Mingazzini and Thake, 1995).

In the Mediterranean Sea, intensification of algal blooms with mucilaginous aggregates has been associated with global warming (Innamorati et al., 2001; Russo et al., 2005), because mucilage events have increased in frequency and duration (Rinaldi et al., 1995; Giani et al., 2005; Precali et al., 2005) since the second half of the nineteenth century, when sea surface temperature began to increase (Moron, 2003). In fact, the main algae producing mucilaginous aggregates are favored by warming (Schiaparelli et al., 2007).

Though less studied than pelagic events, benthic mucilaginous aggregates have become an increasing concern in many areas of the Mediterranean Sea (Sartoni and Sonni, 1992; Welker and Bressan, 1994; Calvo et al., 1995; Innamorati, 1995; Olinas et al., 1996; Hoffmann et al., 2000; Lorenti et al., 2005; Schiaparelli et al., 2007; Aktan and Topaloğlu, 2011; Caronni et al., 2014). Benthic mucilaginous

aggregates may develop over different types of substrate and a wide depth range, usually from early spring to the end of summer. They are caused by five filamentous macroalgae: free-living forms of two brown algae, *Acinetospora crinita* (Carmichael ex Harvey) Kornmann and *Tribonema marinum* J. Feldmann (Sartoni and Sonni, 1992; Sartoni et al., 1993; Giani et al., 2016), and three fast growing benthic chrysophytes *Nematochryopsis marina* (Feldmann) Billard, *Chrysonephos lewisii* (Taylor) and *Chrysophaeum taylorii* Lewis and Bryan (Sartoni et al., 1995, 2008; Caronni et al., 2016, 2017). Species composition is quite variable, although chrysophytes usually occur in spring down to a depth of 20 m, whereas *A. crinita* spreads deeper. Live bacteria, microalgae, especially diatoms, and particles of detritus are commonly embedded in the mucilage (Thornton, 2002; Faraloni et al., 2003; De Philippis et al., 2005).

Mucilaginous aggregates can seriously damage benthic organisms by overgrowth (Rinaldi et al., 1995; Giuliani et al., 2005; Schiaparelli et al., 2007), reducing light penetration (Lorenti et al., 2005) and causing benthic hypoxia due to degradation of large amounts of organic material (Cornello et al., 2005). Accumulated mucilage may suffocate sessile or less mobile organisms by clogging their siphons and burrow openings, or may determine anoxic conditions near the bottom, with the same negative effects (Rinaldi et al., 1995; Pellegrini et al., 2003). However, the effects may differ in relation to habitat: no significant alterations have been observed in seagrass meadows (Lorenti et al., 2005) while deep subtidal rocky assemblages seem the most threatened, probably due to longer lasting episodes, higher sensitivity of the organisms and different mucilage composition, mostly due to *A. crinita*

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(Mistri and Ceccherelli, 1996; Schiaparelli et al., 2007).

In the Mediterranean Sea, deep biogenic subtidal rocky habitats are characterized by coralligenous reefs consisting of calcareous structures edificed by Rhodophyta belonging to Corallinales and Peyssonneliales and by various sessile animals, mostly Cnidaria, Polychaeta and Bryozoa (Ballesteros, 2006). Coralligenous reefs have a key role in coastal systems due to their biodiversity, biomass and role in the carbon cycle (Ballesteros, 2006), but are vulnerable to global as well as local impacts (Piazzini et al., 2012; Gatti et al., 2015b). Evident signs of necrosis have been described in many benthic coralligenous taxa subject to mucilage overgrowth, such as sponges, scleractinians, encrusting coralline algae (Schiaparelli et al., 2007) and gorgonians (Mistri and Ceccherelli, 1996; Rinaldi et al., 1995; Giuliani et al., 2005). Although impacts are reported for several organisms, less is known about the effects of benthic mucilaginous aggregates on the structure and biodiversity of coralligenous assemblages.

The study aims to evaluate the effects of the spread of benthic mucilaginous aggregates on the structure of coralligenous assemblages. The assemblage of a site subject to a benthic mucilaginous aggregate was compared to those of two reference sites using Before/After-Control/Impact (BACI) design (Underwood, 1994; Benedetti-Cecchi, 2001).

2. Material and methods

The study was conducted in the Capo Carbonara-Villasimius Marine Protected Area, south-eastern Sardinia, in October 2013 and 2017. A total of three sites (Fig. 1), characterized by rocky granite bottom, were considered: two off the islands of Serpentara and Cavoli (Controls, C1 and C2) and one at the rocky shoal of Santa Caterina (Impact, I). The Santa Caterina site was subject to benthic mucilaginous aggregates of *Acinetospora crinita* in the late spring-summer 2017 (from May to July), while no aggregates were reported in the other two sites in the same period (personal observation).

In each study site, three areas of 4 m², hundreds of metres apart, were randomly selected on vertical bottoms at a depth of about 35 m. In each area, 10 photographic samples of 0.2 m² were obtained, the size (maximum height) of erect anthozoans was measured and the thickness of the calcareous concretion was evaluated with a hand-held penetrometer, taking six replicate measures per area (Gatti et al., 2012, 2015a).

Photographic samples were analysed to evaluate the percentage cover of the main taxa or morphological groups using ImageJ software (Cecchi et al., 2014). Organisms easily detected in the photographic samples were identified to the lowest possible taxonomic level, while

those not easily recognized were identified according to morphological groups (Piazzini et al., 2017b).

The diversity of the assemblages was evaluated as taxa/morphological group number per sample (i.e. α -diversity) and as heterogeneity calculated by PERMDISP analysis (i.e. β -diversity) (Primer 6 + PERMANOVA; Anderson, 2006), taking the mean distance of photographic samples from centroids as a measure of the β -diversity of the system (Anderson et al., 2006).

The ESCA index (Ecological Status of Coralligenous Assemblages; Cecchi et al., 2014; Piazzini et al., 2017b) was calculated using the formula $EQR = ((EQR_{SL} + EQR_{\alpha} + EQR_{\beta}) \times 3^{-1})$. In this case the three descriptors were: i) the overall sensitivity level (SL) of the assemblages calculated by summing the SLs of all taxa/morphological groups; ii) taxa/morphological group number per sample (α -diversity); iii) heterogeneity evaluated by PERMDISP analysis (β -diversity) (Piazzini et al., 2017b). Individual EQRs were calculated as the ratios of the values of the three descriptors to the values of the same descriptors in the reference site, which is Montecristo Island for this particular geographic region (Cecchi et al., 2014).

The COARSE index (CORalligenous Assessment by Reef Scape Estimate; Gatti et al., 2012, 2015a) was calculated for the three distinct layers characterizing coralligenous reefs: 1) basal layer, consisting of encrustations or organisms with limited (< 1 cm) vertical growth; 2) intermediate layer, composed of organisms with moderate (1–10 cm) vertical growth; and 3) upper layer, characterized by organisms with considerable (> 10 cm) vertical growth. In the basal layer, three descriptors were measured: i) percentage cover of encrusting calcified Rhodophyta, non-calcified encrusting algae, encrusting animals, turf-forming algae and sediment; ii) signs of borer species; and iii) thickness and consistency of calcareous concretions. In the intermediate layer three descriptors were assessed: i) species richness; ii) number of erect calcified organisms; and iii) sensitivity of bryozoans. For the upper layer, the three descriptors were: i) percentage cover of each species; ii) necrosis percentage of each population (even if covered by epibionts); and iii) maximum height of the tallest sessile organism. Each of the nine descriptors was scored according to Gatti et al. (2015a) and the mean value among replicate scores gave the final score for each descriptor. To obtain the quality score for each layer (Q_L) from the descriptor scores, the following formula was applied: $Q_L = (X_L \times Y_L \times Z_L) \times k^{(1-n)}$, where X_L , Y_L and Z_L are the quality scores assigned to the three descriptors, k is the maximum value of the scores (three in this case), and n is the number of descriptors considered. For each site, the mean of the three Q_L s was then used to calculate an overall quality score of the coralligenous reef (Q_O).

The variability of the number of taxa/morphological groups per sample and the percentage cover of the main taxa/morphological groups were analysed by asymmetric three-way ANOVA with Time (before vs after) and Site (one impact and two control sites) as fixed and orthogonal factors, and Area (3 levels) as random factor nested in Site. The mean square of the factor Site was partitioned into two components: i) the contrast Impact vs Controls (I vs Cs) and ii) variability between Controls (Terlizzi et al., 2005). Cochran's C-test was used before each analysis to check for homogeneity of variance (Underwood, 1997) and the data was transformed when necessary.

Variability of the two indices, the mean distance of samples from centroids and the percentage of necrosis of gorgonians were analysed by two-way ANOVA (with the crossed factors Time and Site) where the values obtained in each of the three study areas were used as replicates.

3. Results

Before the mucilage bloom, the impact site differed significantly in terms of several variables from the control sites (significant $T \times I$ vs Cs interaction term). The variables were: number of species, mean distance from centroids, ESCA and COARSE indices, necrosis of gorgonians, and abundance of encrusting algae, algal turf and erect bryozoans (Tables

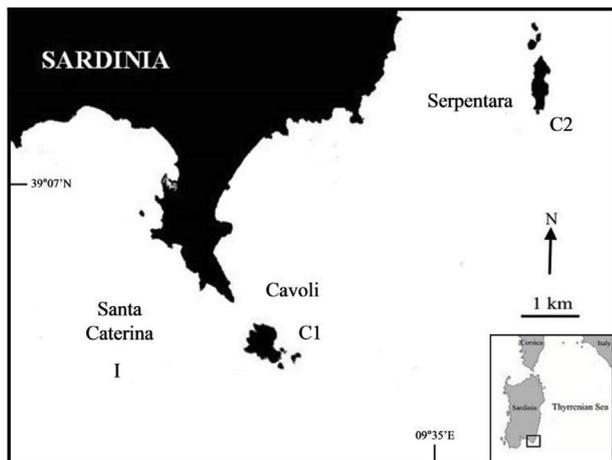


Fig. 1. Map of the study sites. I = impact site at Santa Caterina Shoals; C1 = control site at Cavoli Island; C2 = control site at Serpentara Island.

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