



Effects of benthic mucilagenous aggregates on the hermatypic Mediterranean coral *Cladocora caespitosa*

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Abstract

In the temperate Mediterranean Sea, *Cladocora caespitosa* is the unique species of zooxanthellate reef-building coral and it threatened by different kinds of human pressure. The present study aims at evaluating the effects of a benthic mucilagenous aggregates bloom on a bed of *Cladocora caespitosa*. Colony density, cover and necrosis of the bed before and after the benthic mucilagenous aggregates bloom were compared. After the event there was an increase in necrosis which caused a decrease in colony density and cover. The study quantified the damage as an increase of necrosis of about 55% and an overall loss of percentage cover of about 85% of living *C. caespitosa*, suggesting that benthic mucilagenous aggregates may be a serious threat for this endemic Mediterranean hermatypic coral.

Introduction

In the temperate Mediterranean Sea, the long-living *Cladocora caespitosa* (Linnaeus, 1767) is the unique species of zooxanthellate reef-building coral, as most of hermatypic corals disappeared at the end of Miocene (Vertino et al. 2014). This ecosystem engineer has been recorded in areas with contrasting environmental characteristics, from shallow waters to deeper subtidal (Morri et al. 1994; Kersting and Linares 2012). Allelochemical defense mechanisms coped with its ability to up-regulate heterotrophy are valid explanations of *C. caespitosa* spread in different habitats (Hoogenboom et al. 2010; Ferrier-Pagès et al. 2011; Kersting et al. 2014a). Hydrodynamic conditions, type of substratum and sea floor morphology may determine different types of spatial development and colony morphology (Chefaoui et al. 2017; Kersting et al. 2017). *C. caespitosa* normally occurs in scattered colonies but, in some cases,

can form aggregates of large number of distinct subspherical colonies, named beds, and, in some others, can develop large colonies, reaching several decimeters in height, able to colonize wide areas forming the so called banks (Peirano et al. 1998). However, large bioconstructions have become rare in the Mediterranean Sea probably because they are threatened by different kinds of human pressure (Kružić and Benković 2008; Kersting and Linares 2012). Sea water thermal anomalies, for example, are causing worrying mass mortalities of *C. caespitosa* at increasing rate (Rodolfo-Metalpa et al. 2005; Kersting et al. 2013; Kružić et al. 2014; Jiménez et al. 2014). Further effects related to anthropic disturbances, such as pollution and spreading of invasive species (Zuljevic and Nikolic 2008; Kersting et al. 2014a, 2015; El Kateb et al. 2017) may also interact causing drastic negative consequences on this endangered species. In relation to its ecological role (Koukouras et al. 1998; Peirano et al. 2001; Pitacco et al. 2014) and sensitivity to human impacts, *C. caespitosa* has been included as endangered in the IUCN Red List (Casado-Amezúa et al. 2015).

Among the threats that can potentially affect *C. caespitosa* population, benthic mucilaginous aggregates have been recently recorded in the eastern Adriatic Sea (Kružić and Požar-Domac 2007). Mediterranean benthic mucilaginous aggregates (BMA) are constituted by different algal species and by organic matter, mostly containing polysaccharides, released by these algae (Giani et al. 2016). The development of BMA may be caused by the free-living Phaeophyceae *Acinetospora crinita* (Carmichael ex Harvey) Kornmann,

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and the fast-growing benthic Pelagophyceae *Nematochrysis marina* (Feldmann) Billard, *Chrysonephos lewisii* (Taylor) and *Chrysophaeum taylorii* Lewis and Bryan (Sartoni and Sonni 1991; Sartoni et al. 1995; Caronni et al. 2014; Giani et al. 2016). The specific composition of BMA is quite variable, as more species can co-occur and living bacteria, microalgae and detrital particles are commonly embedded (Sartoni et al. 2008). In the last decades, blooms by BMA increased in frequency and duration (Lorenti et al. 2005; Caronni et al. 2014; Piazzini et al. 2018), and they have been associated to global warming that might enhance the spread of the main algae producing mucilage (Innamorati et al. 2001). BMA can seriously damage benthic organisms by overgrowing (Giuliani et al. 2005; Schiaparelli et al. 2007), reducing light penetration (Lorenti et al. 2005) and causing benthic hypoxia as a consequence of the degradation of large amounts of organic material (Cornello et al. 2005). Although negative effects of BMA on *C. caespitosa* can be predictable and the problem is widely recognized and discussed, quantitative investigations are lacking. In fact, BMA events are not foreseeable, preventing the researchers from planning adequate monitoring programs.

The present study aims to quantify the effects of a BMA bloom on a *C. caespitosa* bed using data before and after the event to compare density, cover and necrosis of the bed.

Material and methods

The study was carried out in Meloria Shoals, a rocky platform located in front of the Tuscany coast (Italy), in the north-western Mediterranean Sea. The Shoals were included in a Marine Protected Area since 2010. The area colonized by *C. caespitosa* covers a calcareous sandstone bottom of about 0.05 km² between 6.5 and 7.5 m depth. All the colonized area was subjected to BMA mostly due to *Acinetospora crinita* in summer 2019 (from July to September).

The surveys were performed in summer 2018 and in summer 2020, before and after the occurrence of BMA. In 2019, the presence of BMA, which completely covered the substrate and colonies of *C. caespitosa*, prevented any survey. Two different methods were used to monitor the *C. caespitosa* bed: visual surveys along belt transects and permanent photo quadrates.

For the visual survey, three sites of about 5000 m² were selected within the area colonized by *C. caespitosa*, and in each site three transects 25 m long were sampled. For each transect the number of living colonies were counted in a stretch of substrate 1 m wide; moreover, the diameter of each colony was measured and the percentage of necrosis was visually estimated. The abundance of colonies was expressed as density (number of colonies m⁻²). The density of colonies and the percentage of necrosis were analyzed

by a permutational analysis of variance (Primer6+ PERMANOVA, Anderson 2001) based on the Euclidean Distance matrix. A two-way model was used with the factor Time (before vs. after) fixed and the factor Site (three levels) random and orthogonal. Three replicate transects were considered for each site.

For the photographic sampling, three plots of 1 m² surface were marked and photographed in each year (2018 and 2020). The percent cover of living colonies was evaluated through the software ImageJ. The differences in percent cover of living colonies between before and after the BMA event were analyzed with one-way PERMANOVA.

Results and discussion

A total of 251 colonies of *Cladocora caespitosa* were recorded with a density of 3.4 ± 1.8 (mean \pm SE, $n = 3$) colonies m⁻² (Fig. 1A); colonies' size was similar among study sites with a mean diameter of 12.9 ± 1.3 cm. After the BMA events, the percentage of necrosis significantly increased (Pseudo-F_{1,2} = 1239.6, P(Perm) = 0.015) from 24.1 ± 5.2 to 79.7 ± 2.2 (Fig. 1B) and the density significantly decreased to 2.1 ± 1.3 colonies m⁻² (Pseudo-F_{1,2} = 8.2, P(Perm) = 0.033) (Fig. 1A). In the permanent quadrates, the percent cover of living colonies significantly dropped (Pseudo-F_{1,4} = 224.2, P(Perm) = 0.002) after the BMA event from 16.3 ± 0.9 to 2.2 ± 0.6 (Fig. 2, Fig. 3).

The study confirmed some previous observations on the effects of BMA on *C. caespitosa* (Kružić and Požar-Domac 2007; Schiaparelli et al. 2007) and quantified the damage as an overall loss of percentage cover of about 80%. This result identifies the BMA as a worrying, serious threat for this endemic Mediterranean hermatypic coral. Parallel to other tridimensional organisms (Giuliani et al. 2005; Schiaparelli et al. 2007), *C. caespitosa* can represent a suitable substrate for the development of BMA, especially when it

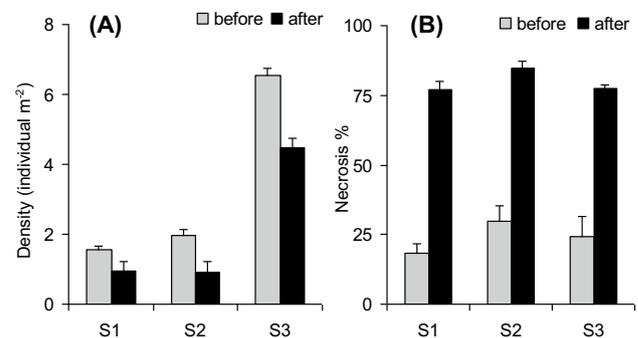


Fig. 1 Density **a** and necrosis **b** of colonies between before and after the occurrence of benthic mucilaginous aggregates (mean \pm SE, $n = 3$)

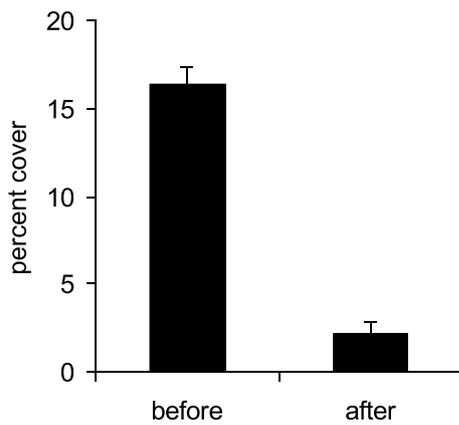


Fig. 2 Percent cover of living colonies between before and after the occurrence of benthic mucilaginous aggregates by photographic samples (mean \pm SE, $n=3$)

constitutes beds or banks. Recovery of *C. caespitosa* populations from this sort of impact can be possible, as polyps subjected to stress may be able to adopt a transitory resistance phase, to reduce their size and to grow re-colonizing dead colony areas (rejuvenation process, Kersting and Linares 2019). However, eventual recovery process needs several years (Kersting and Linares 2019) and the increasing frequency of BMA events and/or climatic anomalies that can affect already damaged individuals, could prevent the colonies from a recovery that would have been possible under undisturbed conditions. In fact, the current climate-change scenario, with increasing water temperature, may act as synergic factor that interferes negatively (Kružić et al.

2012) on the slow growth rates of this species (Peirano et al. 2001; Rodolfo-Metalpa et al. 2008) and its ability of recovery (Kersting et al. 2014b). *C. caespitosa* resilience may be further reduced by adding source of impacts. In fact, the resistance of colonies to disturbances, for instance the spread of invasive organisms, depends on their state of health and on the wideness of the necrotized portions that can be easily colonized by allochthonous algae (Zuljevic and Nikolic 2008; Kersting et al. 2014a, 2015).

Severe negative consequences have been highlighted comparing a *C. caespitosa* bed before and after a BMA event, even this correlative study does not allow evaluating the occurrence of other additive or synergetic factors, such as climatic anomalies. Moreover, the percentage of necrosis before the BMA event showed that this population had been affected by other mortality events in the past, but the lack of previous monitoring programs allows only speculations about these supposed events. It is well known that a longer monitoring period would be necessary to completely evaluate the damage of BMA to *C. caespitosa* having this specie a long recovery time. Despite the absence of long-term observations, this kind of threat needs to be seriously taken into account for the conservation of *C. caespitosa*. Furthermore, BMA do not occur as a response to a direct human pressure and MPAs or other local protection measures are not effective to reduce this threat. In this contest, it is important to identify the occurrence of *C. caespitosa* populations and to monitor the phenomenon trying to avoid synergisms with other local human induced impacts that can lead to very severe effects on this endemic Mediterranean hermatypic coral.

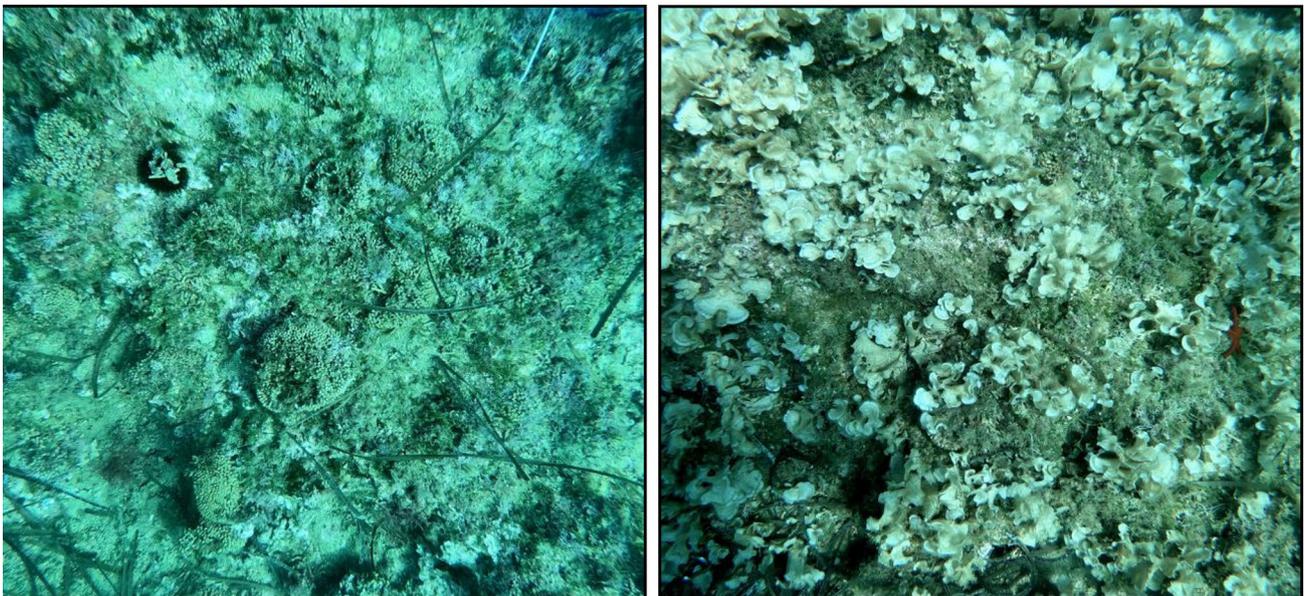


Fig. 3 Images of *Cladocora caespitosa* bed before (left) and after (right) the occurrence of benthic mucilaginous aggregates

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Author contributions DBAM: conceptualization, formal analysis, roles/writing—original draft, revision. PL: conceptualization, investigation, methodology. PM: conceptualization, investigation, methodology. PC: conceptualization, roles/writing—original draft. PL: conceptualization, formal analysis, investigation, methodology, roles/writing—original draft, revision.

Data availability All data generated or analyzed during this study are included in its supplementary information files.

The authors declare that the study was performed in compliance with ethical standards. This article does not contain any studies with animals performed by any of the authors.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The authors declare that the study was performed in compliance with ethical standards. This article does not contain any studies with animals performed by any of the authors.

References

- Anderson MJ (2001) A new method for a non-parametric multivariate analysis of variance. *Austral Ecol* 26:32–46. <https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x>
- Caronni S, Delaria MA, Navone A, Panzalis P, Sechi N, Ceccherelli G (2014) Relevant scales of variability of the benthic allochthonous microalga *Chrysosphaera taylorii*. *Mar Biol* 161:1787–1798. <https://doi.org/10.1007/s00227-014-2461-3>
- Casado-Amezúa P, Kersting D, Linares CL, Bo M, Caroselli E, Garrabou J, Cerrano C, Ozalp B, Terrón-Sigler A, Betti F (2015) *Cladocora caespitosa*. The IUCN Red List of Threatened Species. <https://doi.org/10.2305/IUCN.UK.2015-2.RLTS.T133142A75872554.en>
- Chefaoui RM, Casado-Amezúa P, Templado J (2017) Environmental drivers of distribution and reef development of the Mediterranean coral *Cladocora caespitosa*. *Coral Reefs* 36:1195–1209. <https://doi.org/10.1007/s00338-017-1611-8>
- Cornello M, Boscolo R, Giovanardi O (2005) Do mucous aggregates affect macro-zoobenthic community and mussel culture? A study in a coastal area of the Northwestern Adriatic Sea. *Sci Total Environ* 353:329–339. <https://doi.org/10.1016/j.scitotenv.2005.09.022>
- El Kateb A, Stalder C, Neururer C, Pisapia C, Spezzaferri S (2017) Correlation between pollution and decline of Scleractinian *Cladocora caespitosa* (Linnaeus, 1758) in the Gulf of Gabes. *Heliyon* 3:e00195. <https://doi.org/10.1016/j.heliyon.2016.e00195>
- Ferrier-Pagès C, Peirano A, Abbate M, Cocito S, Negri A, Rottier C, Riera P, Rodolfo-Metalpa R, Reynaud S (2011) Summer autotrophy and winter heterotrophy in the temperate symbiotic coral *Cladocora caespitosa*. *Limnol Oceanogr* 56:1429–1438. <https://doi.org/10.4319/lo.2011.56.4.1429>
- Giani M, Sartoni G, Nuccio C, Ferrari CR, Najdek M, Berto D, Sist P, Urbani R (2016) Organic aggregates formed by benthopleustophyte brown alga *Acinetospora crinita* (Acinetosporaceae, Ectocarpales). *J Phycol* 52:550–563. <https://doi.org/10.1111/jpy.12413>
- Giuliani S, Virno Lamberti C, Sonni C, Pellegrini D (2005) Mucilage impact on gorgonians in the Tyrrhenian Sea. *Sci Total Environ* 353:340–349. <https://doi.org/10.1016/j.scitotenv.2005.09.023>
- Hoogenboom M, Rodolfo-Metalpa R, Ferrier-Pages C (2010) Co-variation between autotrophy and heterotrophy in the Mediterranean coral *Cladocora caespitosa*. *J Exp Biol* 213:2399–2409. <https://doi.org/10.1242/jeb.040147>
- Innamorati M, Nuccio C, Massi L, Mori G, Melley A (2001) Mucilages and climatic changes in the Tyrrhenian Sea. *Aquat Conserv Mar Freshw Ecosys* 11:289–298. <https://doi.org/10.1002/aqc.448>
- Jiménez AP, Hadjioannou L, Petrou A, Nikolaidis A, Evriviadou M, Lange MA (2014) Mortality of the scleractinian coral *Cladocora caespitosa* during a warming event in the Levantine Sea (Cyprus). *Reg Environ Change J* 16:1963–1973. <https://doi.org/10.1007/s10113-014-0729-2>
- Kersting DK, Linares C (2012) *Cladocora caespitosa* bioconstructions in the Columbretes Islands Marine Reserve (Spain, NW Mediterranean): distribution, size structure and growth. *Mar Ecol Evolut Persp* 33:427–436. <https://doi.org/10.1111/j.1439-0485.2011.00508.x>
- Kersting DK, Linares C (2019) Living evidence of a fossil survival strategy raises hope for warming-affected corals. *Sci Adv*. <https://doi.org/10.1126/sciadv.aax2950>
- Kersting DK, Bensoussan N, Linares C (2013) Long-term responses of the endemic reef-builder *Cladocora caespitosa* to Mediterranean warming. *PLoS ONE* 8:e70820. <https://doi.org/10.1371/journal.pone.0070820>
- Kersting DK, Ballesteros E, De Caralt S, Linares C (2014a) Invasive macrophytes in a marine reserve (Columbretes Islands, NW Mediterranean): spread dynamics and interactions with the endemic scleractinian coral *Cladocora caespitosa*. *Biol Invasions* 16:1599–1610. <https://doi.org/10.1007/s10530-013-0594-9>
- Kersting DK, Teixidó N, Linares C (2014b) Recruitment and mortality of the temperate coral *Cladocora caespitosa*: implications for the recovery of endangered populations. *Coral Reefs* 33:403–407. <https://doi.org/10.1007/s00338-014-1144-3>
- Kersting DK, Cebrian E, Casado C, Teixidó N, Garrabou J, Linares C (2015) Experimental evidence of the synergistic effects of warming and invasive algae on a temperate reef builder coral. *Sci Rep* 5:18635. <https://doi.org/10.1038/srep18635>
- Kersting DK, Cebrian E, Verdura J, Ballesteros E (2017) A new *Cladocora caespitosa* population with unique ecological traits. *Mediterr Mar Sci* 18:38–42. <https://doi.org/10.12681/mms.1955>
- Koukouras A, Kühlmann D, Voultsiadou E, Vafidis D, Dounas C, Chintiroglou C, Koutsoubas D (1998) The macrofaunal assemblage associated with the scleractinian coral *Cladocora caespitosa* (L.) in the Aegean Sea. *Ann Inst Oceanogr* 74:97–114
- Kružić P, Benković L (2008) Bioconstructional features of the coral *Cladocora caespitosa* (Anthozoa, Scleractinia) in the Adriatic Sea (Croatia). *Mar Ecol* 29:125–139. <https://doi.org/10.1111/j.1439-0485.2008.00220.x>
- Kružić P, Požar-Domac A (2007) Impact of tuna farming on the banks of the coral *Cladocora caespitosa* in the Adriatic Sea. *Coral Reefs* 26:665. <https://doi.org/10.1007/s00338-007-0237-7>
- Kružić P, Sršen P, Benković L (2012) The impact of sea water temperature on coral growth parameters of the colonial coral *Cladocora caespitosa* (Anthozoa, Scleractinia) in the Eastern Adriatic Sea. *Facies* 58:477–491. <https://doi.org/10.1007/s10347-012-0306-4>
- Kružić P, Lipje L, Mavrič B, Rodić P (2014) Impact of bleaching on the coral *Cladocora caespitosa* in the eastern Adriatic Sea. *Mar Ecol Prog Ser* 509:193–202. <https://doi.org/10.3354/meps10962>
- Lorenti M, Buia MC, Di Martino V, Modigh M (2005) Occurrence of mucous aggregates and their impact on *Posidonia oceanica*

- beds. *Sci Total Environ* 353:369–379. <https://doi.org/10.1016/j.scitotenv.2005.09.025>
- Morri C, Peirano A, Bianchi CN, Sassarini M (1994) Present-day bioconstructions of the hard coral *Cladocora caespitosa* (L.) (Anthozoa, Scleractinia) in the Eastern Ligurian Sea (NW Mediterranean). *Biol Mar Medit* 1:371–372
- Peirano A, Morri C, Mastronuzzi G, Bianchi CN (1998) The coral *Cladocora caespitosa* (Anthozoa, Scleractinia) as a bioherm builder in the Mediterranean Sea. *Memorie Descrittive Carta Geologica D'italia* 52:59–74
- Peirano A, Morri C, Bianchi CN, Rodolfo-Metalpa R (2001) Biomass, carbonate standing stock and production of the Mediterranean coral *Cladocora caespitosa* (L.). *Facies* 44:75–80. <https://doi.org/10.1007/BF02668168>
- Piazzoli L, Atzori F, Cadoni N, Cinti MF, Frau F, Ceccherelli G (2018) Benthic mucilage blooms threaten coralligenous reefs. *Mar Environ Res* 140:145–151. <https://doi.org/10.1016/j.marenvres.2018.06.011>
- Pitacco V, Orlando-Bonaca M, Mavric B, Lipej L (2014) Macrofauna associated with a bank of *Cladocora caespitosa* (Anthozoa, Scleractinia) in the gulf of Trieste (N Atlantic). *Ann Ser His Nat* 24:1–14
- Rodolfo-Metalpa R, Bianchi CN, Peirano A, Morri C (2005) Tissue necrosis and mortality of the temperate coral *Cladocora caespitosa*. *It J Zool* 72:271–276. <https://doi.org/10.1080/11250000509356685>
- Rodolfo-Metalpa R, Peirano A, Houlbr eque F, Abbate M, Ferrier-Pages C (2008) Effects of temperature, light and heterotrophy on the growth rate and building of the temperate coral *Cladocora caespitosa*. *Coral Reefs* 27:17–25. <https://doi.org/10.1007/s00338-007-0283-1>
- Sartoni G, Sonni C (1991) *Tribonema marinum* J. Feldmann e *Acinetospora crinita* (Carmichael) Sauvageau nelle formazioni mucilaginoso bentoniche osservate sulle coste toscane nell'estate 1991. *Inf Bot Ital* 23:23–30
- Sartoni G, Boddi S, Hass J (1995) *Chrysonephos lewisii* (Sarcinochrysidales, Chrysophyceae), a new record for the Mediterranean algal flora. *Bot Mar* 38:121–125
- Sartoni G, Urbani R, Sist P, Berto D, Nuccio C, Giani M (2008) Benthic mucilaginous aggregates in the Mediterranean Sea: origin, chemical composition and polysaccharide characterization. *Mar Chem* 111:184–198. <https://doi.org/10.1016/j.marchem.2008.05.005>
- Schiaparelli S, Castellano M, Povero P, Sartoni G, Cattaneo-Vietti R (2007) A benthic mucilage event in North-Western Mediterranean Sea and its possible relationships with the summer 2003 European heatwave: short term effects on littoral rocky assemblages. *Mar Ecol* 28:1–13. <https://doi.org/10.1111/j.1439-0485.2007.00155.x>
- Vertino A, Stolarski J, Bosellini FR, Taviani M (2014) Mediterranean corals through time: from Miocene to Present. In: Goffredo S, Dubinsky Z (eds) *The Mediterranean Sea: its history and present challenges*. Springer, Dordrecht, pp 257–274
- Zuljevic A, Nikolic V (2008) The highly invasive alga *Caulerpa racemosa* var. *cylindracea* poses a new threat to the banks of the coral *Cladocora caespitosa* in the Adriatic Sea. *Coral Reefs*. <https://doi.org/10.1007/s00338-008-0358-7>

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