Mortality of marine organisms (coralligenous habitats) associated to seawater temperature anomalies (Summer/Autumn 2012) in the Levantine Sea (Cyprus)

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Abstract:

Purpose:

To describe a mortality event of coralligenous marine organisms and establish/evaluate the extent of bleaching, necrosis and recovery of *Cladocora caespitosa* colonies, along the coast of Cyprus during a prolonged period of higher-than-average sea temperature anomalies (Summer/Autumn 2012).

Methods: With the use of Scuba-diving and image-analysis software, we monitored the extent of mortality of 29 colonies of *C. caespitosa* by measuring and comparing the area-percentage of healthy tissue, affected tissue (bleached, necrotic) and older mortality events (encrusted skeleton).

Results: Coral mortality was documented for seven coralligenous taxa. Particularly for *C. caespitosa,* in September 2012, on average 12.2% of the colonies surface area was affected. In October 2012, *C. caespitosa* showed on average 11.3% of the colony surface area affected, owing the difference to colonies that showed total mortality. At the same time, 10% (3 of 29) of the colonies showed recovery (6-8%) in the pigmentation of bleached polyps.

Conclusions: Coralligenous habitats in the Levantine Sea are affected greatly by warming events, to the extent where a very small percentage of polyps/colonies show resilience/recovery under thermal stress. Bleaching of *C. caespitosa,* even though limited to a few colonies, was documented for the first time in the Levantine Sea, and possibly for the Mediterranean.

Key words: Levantine Sea, Climate Change, ecological impacts, coralligenous, bleaching, Cyprus, *Cladocora caespitosa*.

Introduction

Sea Surface Temperatures (SSTs) have been shown to increase globally (by 0.3^0C to 1.0^0C) over the last millennium [1] with increases in the Mediterranean and the Levantine Sea being particularly intense [2]. These anomalies, attributed largely to anthropogenically induced climate change and global warming [3,4] have been extensively documented in the Mediterranean [5,6] and have been shown to affect greatly the coralligenous communities in the marine environment [7-10].

The Levantine Sea, the easternmost and most oligotrophic part of the Mediterranean [13,14] is a marine laboratory where ecological processes develop in demanding environmental conditions due to human activities and most probably climate change. Due to damming of most of its freshwater sources, the Levant was once considered a barren seascape. Due to higher salinity and temperature levels, it is considered to hold less biodiversity than it's Western counterparts, but even so it still holds a considerable amount of wealth of biological species, native and exotic [15], interacting with the environment through highly dynamic ecological pathways.

Multispecies mass-mortality events, resulting from abnormally warm SST events, have been described in a number of occasions since the 1960's [8,10,12]. For example, Kersting, *et al.* in their recent paper (2013) used data collected over an 11-year period, and in which they recorded mortality of the coral *Cladocora caespitosa* during nine summers [7]. They found significant association between necrosis and temperature increase [7]. *C. caespitosa,* one of the two endemic zooxanthellae scleractinian corals in the Mediterranean, and the only one able to form banks [16] has been broadly studied in relation to it's sensitivity to warming events and tolerance levels [7-9]. Despite the fact that other factors, such as pathogens [18], salinity levels [19] and corallivores [20] might also play important roles in the mortalities of scleractinian species, the strong association of water temperature rise and necrosis in *C. caespitosa* is indisputable.

The mortality episode of the summer of 2012 was a result of a prolonged period of higher-than-average SST anomalies. This warming event was also documented by data loggers, installed at 25m depth in the South coast of Cyprus, but nevertheless coralligenous habitats were observed to be mostly affected in shallow (0-15m) coastal areas.

In tropical corals, it is not unusual that anomalous warming events and other factors, such as low salinity, cold-water incursions, doldrum conditions, exposure to air during low tides result in the expulsion of the intracellular endosymbiotic zooxanthellae [21,22,31] causing bleaching. In the Mediterranean, however, bleaching has only been documented in *Oculina patagonica* when elevated temperatures have been found to cause coral-bleaching pathogens to become more virulent [23,32].

Study site and data collection

Coralligenous communities of varying diversity are found all around Cyprus' shallow coastal waters [24]. The Southeastern part of Cyprus, where we focused the investigation on the mortality of coralligenous habitats (Fig. 1), has a relatively high diversity of marine organisms, including a higher abundance of *C. caespitosa* colonies compared to other areas in Cyprus. The area is highly populated, especially in the summer months, a time when high numbers of tourists visit the island. Needless to say, a large number of hotels occupy the area, with the expected inflow of nutrients in the Sea eminently reaching high levels. In addition, inflow of nutrients in the area is exacerbated by agricultural and aquaculture practices, the extent of which, though easily observed, have not yet been extensively quantified.

Figure 1: Study site (red dot) in the South-Eastern-most point of Cyprus, Levantine Sea. (Image Landsat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO)

Methods

Seawater temperatures at different depths were provided by diving personal computers. Long-term SST anomalies from the Reynolds NCEP optimal interpolation analysis [33] were obtained from a 1° x 1° grid centered on 34.5 ºN, 34.5 ºE. Summer months are considered: July, August, September and October.

During the 13th of September, observations on the condition of scleractinian corals were made from 2-10m depth, inspecting exposed as well as covered areas (e.g. ledges, crevices). Concentration on C. caespitosa colonies, 29 colonies were tagged and measured (max. length, width, height) and photos taken (Canon G12). ImageJ software (Image Processing and Analysis in Java) [25] was used to calculate the area-percentage cover of healthy tissue, affected tissue (bleached, necrotic) and encrusted skeleton (from older mortality events) for each colony. During visits, prior to the warming event to the same area, we recorded the concentration of corallivorous taxa (Paguroidea and *Coralliophyla spp.*) on the colonies. In order to estimate the pressure exerted, by means of corallivory, on the already stressed colonies of *C. caespitosa,* and to identify the response of these predators to limitations in prey we repeated the observations on the 12th of October 2012. Throughout the warming event we visited different habitats, in various depths around the island of Cyprus, and observed mortalities of coralligenous organisms inside crevices and ledges, where direct sunlight did not reach.

Results

SST and SWT

The 2012 summer months' mean SST anomalies, reached the highest from the last 30-years record (Fig. 2a). The data used to create the time series showing an increasing trend, with 2012 and 2010 being the warmest in the last 10-year period (Fig. 2b), were given to us by recreational divers. The highest temperatures collected with the use of handheld diving computers were recorded during the months of August to October, based on the average from all localities (Fig. 2c). The Southeastern part of the island, however, experienced the highest temperature recorded in July (29°C). At the same time, mass-mortalities in coralligenous organisms were noticed by commercial and recreational divers all around the island of Cyprus.

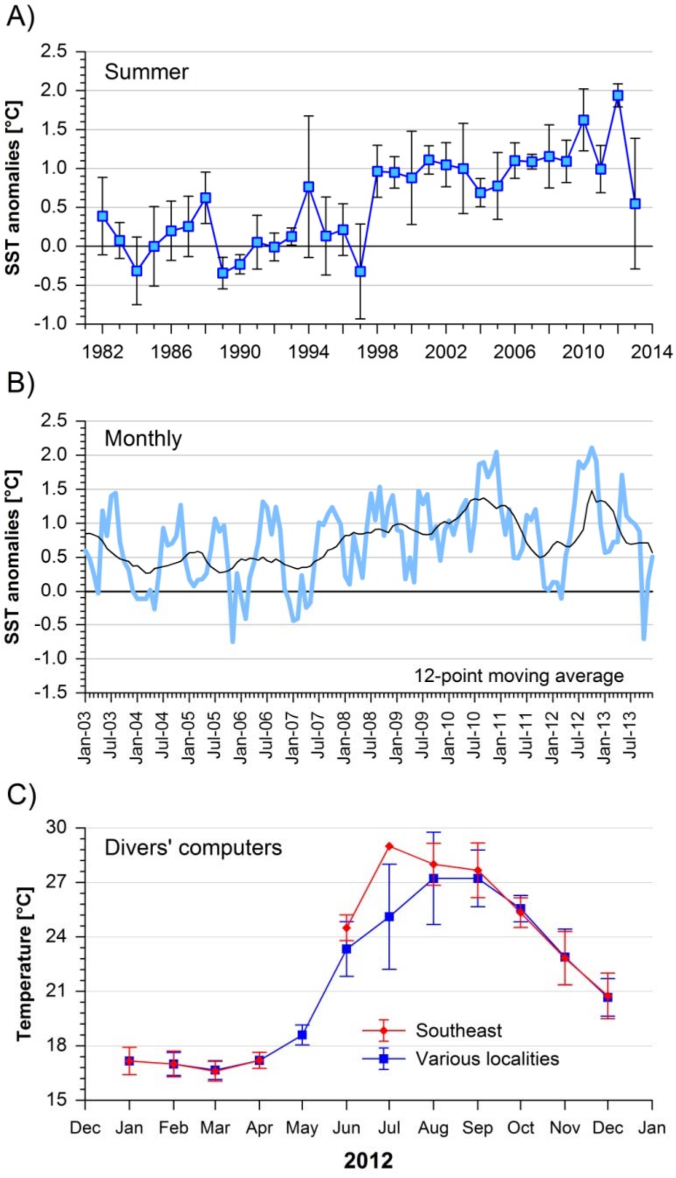

Figure 2 a) Summer (JASO) mean (±SD) SST anomalies off Southeast Cyprus, 1982-2013. b) Monthly SST anomalies off Southeastern Cyprus, 2003-2013 including 12-point moving average, c) Seawater temperature readings (5-10m depth) for 2012, from hand-held dive computers.

Six scleractinian species (*C. caespitosa, Madracis pharensis, Phyllangia mouchezii, Balanophyllia europaea, Caryophillia inornata* and *Polycyathus muellerae*) and one coralline algae (*Mesophyllum* sp.) were observed to undergo partial or total necrosis, during the same period (August-September 2012).

A wide range of colony sizes (ranges of H: 6-26cm, L: 15-62cm, W: 11-35cm) was measured, thus covering a broad range of ages of the species.

A year later, a visit to the same area revealed a very slow response by the colonies, with only a few recruits documented. At the same time the parts of the colonies that were affected by total necrosis had been completely colonized by algae (mostly filamentous and calcareous), sponges, and to a lesser extend by bryozoans and serpulid polychaetes.

Cladocora colonies

During the first survey (13th September 2012) we recorded 93% of the tagged colonies (27 29) of *C. caespitosa* exhibiting various degrees of affected areas (Table 1, Fig. 6). Affected areas, which that had undergone recent necrosis, were also observed in 93% of the colonies. All of the colonies had polyps that had experienced old mortality events, evident by the encrusted areas of the skeleton (Fig. 6).

During the second survey (12th October 2012), we revisited the tagged colonies. Seventy five percent of the colonies continued to increase in percentage of necrosis by 1-10%, whereas the rest remained at the same levels. Despite the continuation of necrosis in some of the polyps, we observed 10% of the colonies, were bleaching was detected previously, to recover (Fig. 3). Polyps in colonies No. 10, 13 and 16, which had previously lost pigmentation, were seen to have regained their pigments by 6-8%. Furthermore, 55% of the colonies continued loosing pigmentation by 1-21%, whereas 35% showed neither loss nor gain in pigmentation.

Corallivores

Decapod crustaceans of the superfamily Paguroidea (hermit crabs) and gastropod mollusks of the genus *Coralliophila* spp. were the observed in the course of our extended fieldwork observations, In total, 169 individuals were observed, out of which 150 (89%) belonged to Paguroidea and 19 (11%) to *Coralliophila* spp. The amount of corallivores recorded prior to the warming event was 58, whereas the number observed during, and after, was 111.

The maximum number of corallivores found on a single colony was 10 (recorded once), but most commonly, colonies were engaged by one or two corallivores. Fig. 4 shows that after the warming event, the amount of colonies with at least one corallivore, more than tripled (from 18 to 66). Six colonies were recorded before the warming event with two corallivores on them, whereas 13 colonies were observed with the same number of corallivores after the event.

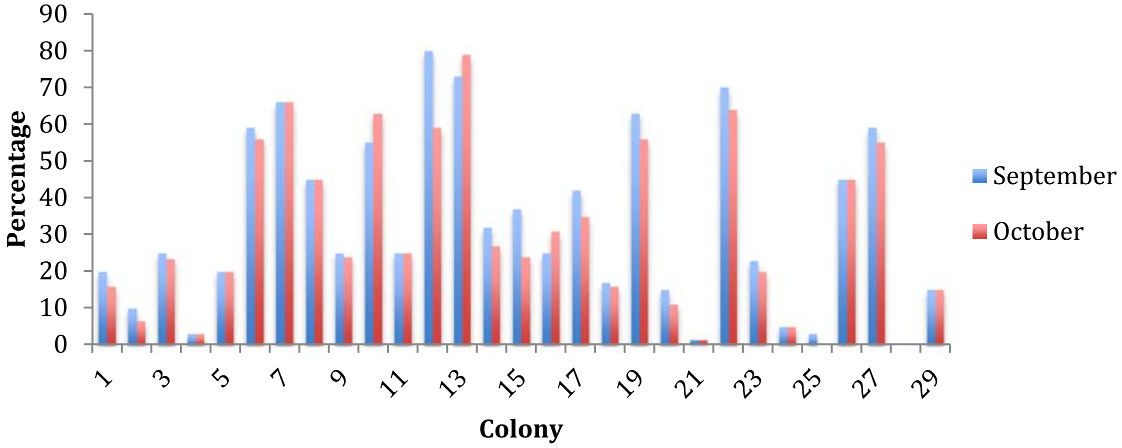

Figure 3. Changes in the percentages of pigmentation in the tagged *Cladocora caespitosa* colonies in September 13th and October 12th 2012.

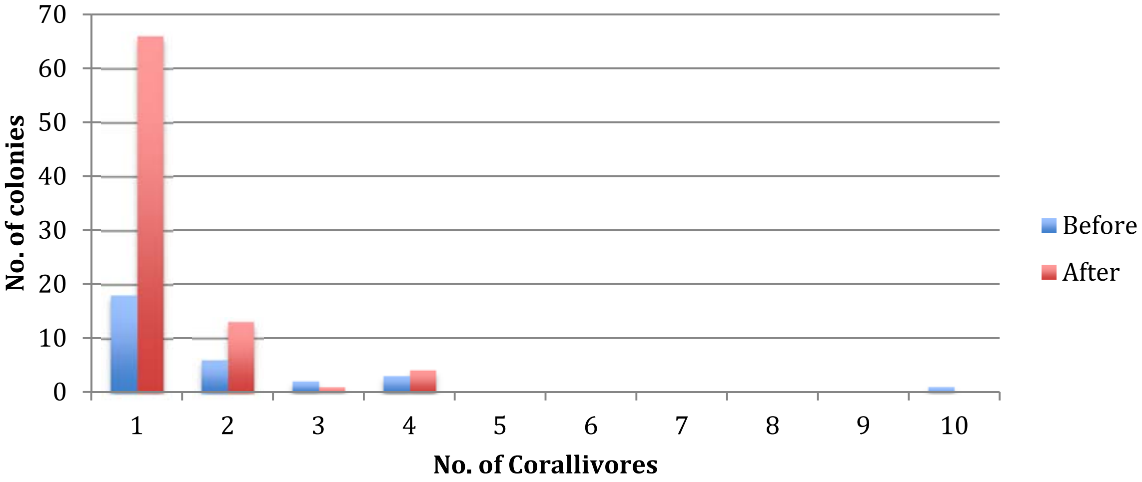

Figure 4. Amount of *Cladocora caespitosa* colonies with varying number of corallivores before (September 2010, June 2011, July 2012) and after (September and October 2012) the warming event of 2012.

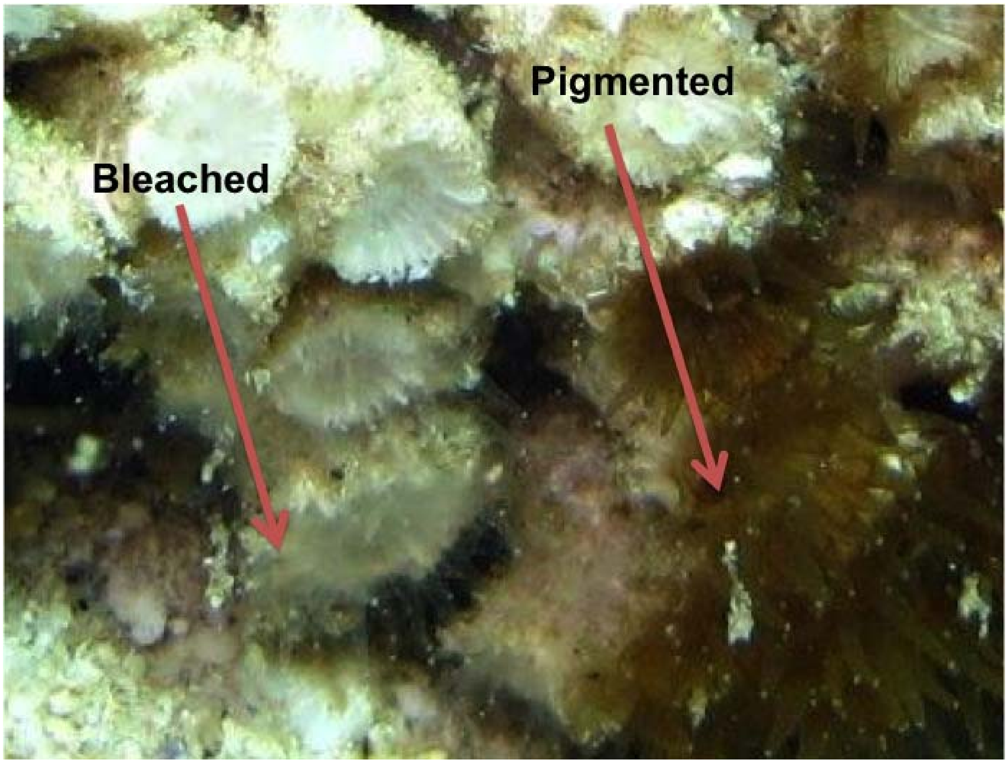

Figure 5. Pigmented and bleached *Cladocora caespitosa* polyps (13th September 2012, Liopetri, 6m depth, Cyprus)

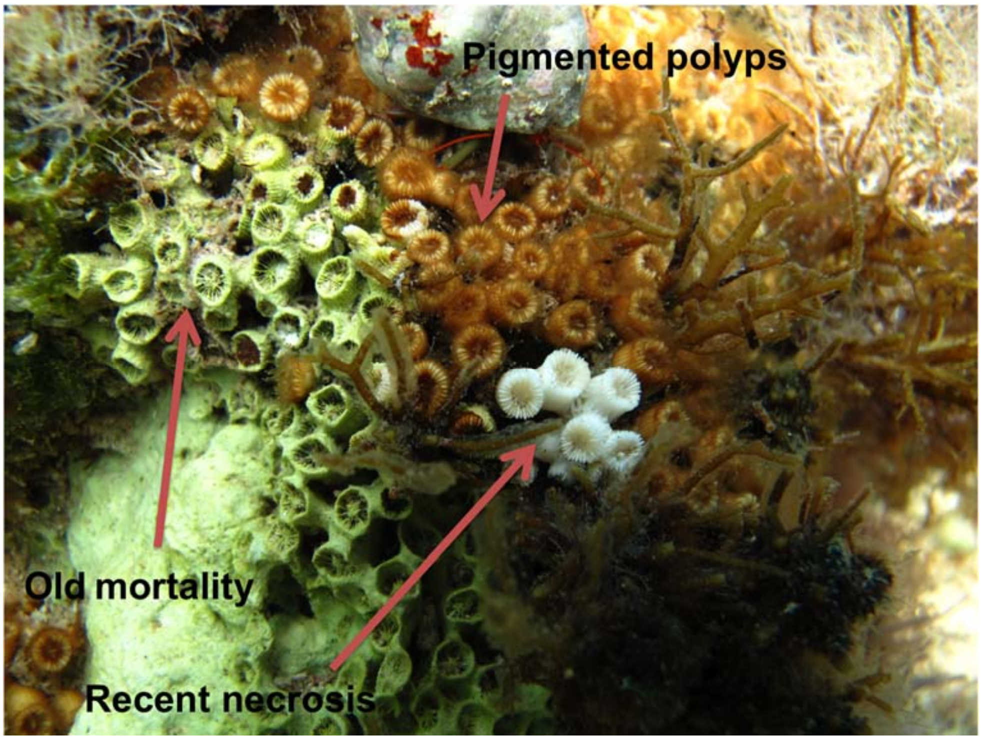

Figure 6. *Cladocora caespitosa* colony with pigmented polyps, recent and old necrotic corallites. (13th September 2012, 6m depth, Liopetri, Cyprus)

	September 2012				October 2012			
♯ of colony	% Pigmented	% Bleached	% Necrosis	% Old mortality	% Pigmented	% Bleached	% Necrosis	% Old mortality
1	20	5	2.5	72.5	16	7.5	4	72.5
2	10	0	1	89	6.5	2	2.5	89
3	25	3	22	50	23.5	2.5	24	50
4	3	18	4	75	3	15	7	75
5	20	15	1	64	20	13.5	2.5	64
6	59	3	1	37	56	5	2	37
7	66	5	1	28	66	5	1	28
8	45	10	0	45	45	8	2	45
9	25	55	15	5	24	50	21	5
10	**55**	15	10	20	**63**	7	10	20
11	25	15	55	5	25	12	58	5
12	80	5	5	10	59	19	12	10
13	**73**	15	5	7	**79**	9	5	7
14	32	25	15	28	27	20	25	28
15	37	10	3	50	24	16	10	50
16	**25**	25	7	43	**31**	15	11	43
17	42	14	4	40	35	19	6	40
18	17	10	3	70	16	11	3	70
19	63	5	2	30	56	7	7	30
20	15	17	3	65	11	13	11	65
21	1.5	2.5	1	95	1.5	2.5	1	95
22	70	0	0	30	64	0	6	30
23	23	8	4	65	20	11	4	65
24	5	0	0	95	5	0	0	95
25	3	3	75	19	0	3	78	19
26	45	17	7	31	45	14	10	31
27	59	13	6	22	55	11	12	22
28	0	4	85	11	0	0	89	11
29	15	35	5	45	15	29	11	45
Mean	**33.1**	**12.2**	**11.8**	**43.0**	**30.7**	**11.3**	**15.0**	**43.0**
SD	**24.0**	**11.8**	**21.7**	**27.0**	**23.2**	**10.2**	**22.1**	**27.0**
Max	**80**	**55**	**85**	**95**	**79**	**50**	**89**	**95**
Min	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**

Table 1. Percentages of pigmented (e.g. healthy tissue), bleached, necrotic and old mortality (past events), in the colonies studied, for September and December 2012.

Discussion and conclusions

The results of our study show that, the SST anomalies recorded in the summer of 2012 unquestionably had a substantial effect on the shallow water coralligenous communities of Cyprus by affecting one of the most important members of the community, scleractinian corals. The height of the warming event was during July – August 2012, as recorded by satellite data and divers' computers. These were the highest SST anomalies recorded in Cyprus since the initiation of satellite measurements (November 1981). The second highest warming was recorded in summer 2010. This rising trend of higher anomalies (warmer than average) in the Levantine Sea, has been reported by others [11, Herut *et al.* submitted.]. The trend, that clearly started since the late 1990s, along with evidence of ecological disturbance, should act as an alarming call for the future and serve as a warning on the extent of regional environmental change.

Our evidence comes from direct observations of mortalities of at least seven coralligenous taxa (six scleractinian corals and one algae) found around the coast of Cyprus. These observations were made up to a maximum depth of 10m, including sheltered areas, such as crevices and ledges, where direct sunlight and hence, UV irradiation, does not reach. Even though mass-mortality events can be triggered by various other environmental, biological and physical factors, such as decrease in salinity [19], lack of nutrients and/or the presence of pathogens/corallivores [18, 20], it is our belief that the elevated temperature, higher than the corresponding monthly mean, that took place during that period, was the direct reason. The fact that organisms affected were also found in areas were direct sunlight does not reach, re-enforces the assumption that the moralities were not a consequence of increased exposition to UV radiation.

From monitoring of tagged *Cladocora* colonies we estimated the extent of the effect that warming events of this scale could have on coralligenous communities. Even though the highest temperatures were recorded in July, the highest SST anomalies had started since May 2012. By September, a large number of the colonies (>90%) were affected by having substantial percentage of the colony in total necrotic stage (mean: 11.8%, Table 1). This trend continued for at least one more month, when the mean percentage of necrotic areas reached 15%. The same colonies have been affected in the past, as shown by the fact that old mortalities summed up to a total mean of 43% (all colonies). Their skeletons were encrusted, in varying degrees, by algae (filamentous and calcareous), sponges, bryozoans and serpulid polychaetes.

The resulting necrosis from the 2012 warming event was a somehow anticipated outcome. However, an unexpected find was the fact that some of the colonies, showed bleached areas. Bleaching, by the expulsion of symbiotic zooxanthellae in corals of the Mediterranean has only been recorded, up to now, in the species *Oculina patagonica*. Despite the fact that *C. caespitosa* colonies have been documented, on a multitude of events, to succumb to warming events [7-9,17] by experiencing total or partial necrosis, bleaching has not been documented. Furthermore, three of the colonies with bleached areas showed signs of recovery, by re-gaining their pigmentation. These last observations have led us to believe that the status of *C. caespitosa,* and their endosymbionts in the Levantine Sea (Cyprus in particular), require revising.

The fact that different environmental conditions exist between the Levantine and the rest of the Mediterranean must have a considerable effect on the species. Our hypothesis is that, the different response of *C. caespitosa* is either a result of acclimation of the physiology of the corals, and/or their zooxanthellae, adapting to different environmental parameters, or due to different clades of zooxanthellae occupying the polyps.

Zooxanthellae from the tropics have been observed to have varying tolerances to elevated temperatures [27]. Research in the Mediterranean has shown that only two clades are found in Cnidarians, with only one (Clade A) in scleractinians [28]. The Levantine Sea enjoys a large number of alien species invading from the Red Sea (Lessepsian migration), altering the biodiversity and affecting indigenous organisms. Over the course of the last 144 years, since the Suez Canal was constructed, hundreds of species of different taxa crossed and settled in the Mediterranean, with the Levantine Sea serving as their first hub [26]. Hence, in light of tangible evidence of Lessepsian invaders, it would not come as a surprise if Lessepsian zooxanthellates were to be discovered.

Corallivores feeding on *C. caespitosa* in our study site included a significant number of Paguroidea crabs and to a lesser extent, the gastropod *Coralliophyla*. The amount of these corallivores appears to have increased during the last stages of the warming event (October

2012), based on our observations of higher numbers recorded in our study-area. This must have been as a result of the scarcity of foraging grounds. Nevertheless, the fact that we observed more corallivores, does not necessarily mean that they had actually increased in numbers, but rather that they had congregated on the remaining food source. This fact probably put much more pressure on the already-stressed surviving polyps.

One year after the warming event, the coral communities still show the impact of the 2012 mortality with only few new recruits having been documented, indicating the slow recovery capabilities of these habitats. In general, an effect of this size by this kind of warming events, on any type of habitat, will reasonably have a negative result on the whole of the ecological community. This was also shown in the behavioral response of corallivorous taxa in the study-area.

The intensity, frequency and impacts of such mortality events on the marine communities of Cyprus, and the Levantine basin in general, need to be studied based on an interdisciplinary approach. Further research involving the reproduction of the effect of thermal stress on *C. caespitosa* in controlled aquarium experiments, in order to verify experimentally the contribution of increasing temperatures, for short and prolonged periods, on the mortality events and the extend of bleaching as a mediatory state to necrosis. Additionally, a comparative study of *C. caespitosa* in vitro, using specimens from a broad geographical range of the Mediterranean would identify physiological differences that might exist between different populations.

Supplementary ecological studies on the reproduction, recruitment and growth rates of coralligenous organisms in the Levantine Sea should be carried out, in order to identify potential problems that might appear in the light of climatic changes and global warming. Besides, knowledge on these slow-growing organisms can also supply further insights on the realism of climatic changes [29, 30].

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