



ORIGINAL ARTICLE

***Paramuricea clavata* (Anthozoa, Octocorallia) loss in the Marine Protected Area of Tavolara (Sardinia, Italy) due to a mass mortality event**

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Abstract

Recent studies highlight an increase in the frequency and intensity of marine mass mortalities of several species over the past 30–40 years, mainly in tropical and temperate areas. In the Mediterranean Sea these episodes particularly affect benthic suspension feeders, such as sponges and cnidarians. The main objective of this work was to document the loss of one of the main Mediterranean seascapes, *Paramuricea clavata* forests at the Marine Protected Area of Tavolara Punta Coda Cavallo, Sardinia (Italy), during the summer of 2008. Data regarding colony height, density, level of damage, and microbiological community were collected at two sites. Such parameters help us understand how mass mortality mechanisms act on this ecosystem engineer. We identified a change in size class distribution following a mass mortality that leaves mainly small colonies with a decrease in habitat complexity. Several tests on water chemistry demonstrate that the mortality event was not caused by local contamination. Moreover, microbiological tests on potential pathogenic agents suggest that bacteria belonging to the genus *Vibrio* are present as an opportunistic and not an etiological cause of *P. clavata* mortality events. Possible restoration approaches are discussed.

Introduction

Marine communities appear to be facing one of the worst periods in their recent history. The direct negative effects of several human activities (e.g. oil spills, coastal habitat modification, overfishing) are now amplified by climate change, which is compromising both the resistance and the resilience of many marine organisms. During the last decades, the Northwestern Mediterranean Sea has been hit by a series of mass mortality events, which impact benthic suspensivore organisms, such as sponges, cnidarians, bivalves, bryozoans and tunicates, and associated assemblages (Cerrano & Bavestrello 2009). These mortal-

ity events coincide with thermal anomalies generally caused by unusual water warming during prolonged periods of water column stability (CIESM, 2008).

Affected species often show modifications in their physiology (Previati *et al.* 2010), distributions, and sometimes phenology (Bavestrello *et al.* 2006), which can have unpredictable consequences on species' interactions (Hughes 2000). Often the affected species are ecosystem engineers and their rarefaction and/or disappearance has profound consequences on the habitat architecture, such as reducing spatial complexity and decreasing biodiversity richness (Matias *et al.* 2010). In the Mediterranean Sea, several causes of these mortality events have been

identified, typically associated with environmental factors (Cerrano *et al.* 2000, 2005; Pérez *et al.* 2000; Calvisi *et al.* 2003; Linares *et al.* 2005, 2008b; Cigliano & Gambi 2007; Previati *et al.* 2010) but a number of pathogens have also been implicated (Martin *et al.* 2002; Gay *et al.* 2004; Bally & Garrabou 2007; Vezzulli *et al.*, 2010). Among the affected areas in the Mediterranean, perhaps the Ligurian Sea can be considered the most severely affected (Garrabou *et al.* 2009). However, in the late summer of 2008, one of these particular thermal anomalies was registered in the Marine Protected Area of Tavolara Punta Coda Cavallo (Central Western Tyrrhenian Sea) and had a dramatic effect on sea-fan (Octocorallia: Gorgonacea) populations, particularly on two rocky shoals adjacent to Tavolara Island, where presence of large numbers of the gorgonian *Paramuricea clavata* characterizes one of the most famous dive spots in the area.

Paramuricea clavata is known to be sensitive to high temperatures (Cigliano & Gambi 2007; Coma *et al.* 2009; Fava *et al.* 2010; Previati *et al.* 2010) and can show an immediate response to these events. Crucially, this species is considered an ecosystem engineer and facilitator species (Bruno & Bertness 2001; Scinto *et al.* 2009) within coralligenous assemblages. The aims of this work were: (i) to describe the mass mortality event that affected populations of *P. clavata* and (ii) to determine whether a range of environmental parameters are correlated with *P. clavata* mass mortality. Possible pathways for restoration and management of this species are also discussed.

Material and Methods

Study area

Tavolara Island (40°54', 19' N; 9°42', 28' E) is formed from limestone-dolomite rock. Together with the granitic Molaro, Molarotto and other minor islets, Tavolara forms a small archipelago with an epibenthic community that has been well described by Navone & Trainito (2008) and Navone *et al.* (1992). In the study area, the effects of the mass mortality event on the pre-coralligenous and coralligenous assemblages of two nearby sites (termed Papa 1 and Papa 2) were quantified. Papa 1 ranges in depth from 15 to 39 m, and Papa 2 from 24 to 43 m. The current direction flows in a NE–SW direction, from Papa 2 towards Papa 1. At both sites there is a dense forest of *Paramuricea clavata* and also *Eunicella cavolinii* (Calvisi *et al.* 2003; Bianchi *et al.* 2007). SCUBA diving surveys were undertaken during October 2008, December 2008 and June 2009, which corresponded to the period when mortality was first noted for *P. clavata* and 3 and 9 months subsequently.

Population structure and mortality dynamics: field surveys

To study population dynamics, a minimum of six quadrats (50 × 50 cm) were randomly sampled from 40 to 20 m depth every 5 m from the bottom to the top of each shoal, following standard methodology set out by similar studies (Cerrano *et al.* 2005; Coma *et al.* 2006; Linares *et al.* 2008a) and in relation to the geomorphology of the sites (Papa 1 from –35 to –20 m; Papa 2 from –40 to –25 m). Within each quadrat the number of colonies (converted to colony density), colony heights, colony health (defined as the percentage of colony with damaged coenenchyme: 0% was considered healthy, <25, <50, <75, <99 and 100%), and the number of fishing lines and/or nets wrapped around the colonies were recorded. Furthermore, for each colony the epibiosis level was recorded (according to methods provided by Bavestrello *et al.* 1997) and the epibiotic organisms were identified. On the basis of organisms that had settled on the scleraxis we defined different temporal phases: (i) denuded (when the scleraxis is visible, with tissue on scleraxis), (ii) new (covered with filamentous green and/or red algae, and/or hydrozoans), (iii) medium (possessing a thick coat of algae, and/or sponges) and (iv) old (mainly colonized by calcareous organisms such as bryozoans). To test the differences in population composition, within sites and among times, ANOVA tests were performed after verifying that data were normally distributed and there was equality of variances.

We assumed that the pre-mortality population structure was very close to that observed in October (*i.e.* during/just after mortality) for three reasons: (i) most colonies had only just died, with naked scleraxis and with necrotic coenenchyme portions still present on the colonies, (ii) no fragments or whole colonies were found (implying that colonies had not detached from the base) and (iii) colonies were always measured – including the denuded and epibionted parts of the colonies. The post-mortality structure of colonies was considered to be typical of that observed from December 2008.

Environmental features – laboratory analyses

To evaluate whether chemical features of seawater and/or bacterial infections could be involved in the mortality, both seawater samples and portions of colonies were collected.

Seawater temperature and water chemistry

Temperature was measured during survey dives using two types of underwater computers: (i) UWATEC (± 0.5 °C), with a system that records and memorizes automatically

water temperature during the dives every 4 s, creating a profile, and (ii) underwater computers with a punctual temperature measurement (variation of ± 1 °C) that divers recorded manually every 5 m during the dive ascent. Water temperature data were taken in both sites. Average values of water temperature were accomplished with both manually recoded and automatic UWATEC data, separated by depth ranges: SST (sea surface temperature) or 0, 5, 10, 15, 20, 25, 30, 35 and 40 m depth.

To determine dissolved oxygen concentrations (DOC) during the mortality event, separate seawater samples were carefully collected, avoiding air bubbles, and immediately fixed following Carpenter's (1965) protocol. Inorganic nutrient concentrations were determined according to Hansen & Grasshoff (1983). Marine water was pre-filtered with cellulose acetate filters (0.45 μm pore diameter) and maintained at -20 °C until laboratory analysis. Nitrates, nitrites, ammonia and phosphates were analyzed with SYSTEA (nutrient analyzer) and silica concentrations were quantified using a Jasco V-500 spectrophotometer.

Microbiological analysis

Top colony pieces (n = 45 in total) of about 5 cm of healthy and damaged *P. clavata* colonies were taken (20 healthy and 25 damaged, all samples from different colonies). Samples were maintained in cold seawater (4 °C) until laboratory manipulation, then washed in sterile seawater to remove other bacteria or fauna that were not strictly related to *P. clavata* damage and incubated in an enriched APW (alkaline peptone water) culture broth. After 10 h, samples were plated onto thiosulfate citrate

bile salt sucrose (TCBS) agar to isolate the main morphotypes of bacteria belonging to the genus *Vibrio*. Other pieces of tissue were frozen (at -20 °C) until total genomic DNA could be extracted. After DNA extraction, bacterial samples were identified on the basis of their 16S rRNA gene sequences (see Vezzulli *et al.*, 2010 for full details of methods). To identify isolates, PCR amplification of a 798-bp region was performed using the universal primers BR1 (5'-AGAGTTTGATCCTGGCT-3') and BR2 (5'-GGACTACCAGGGTATCTAAT-3'), amplifying positions 8–806 of the *Escherichia coli* numbering of the 16S rRNA gene that include hyper-variable regions. 16S rRNA gene sequence similarity was determined with SEQ-MATCH (version 2) analysis of Ribosomal Database Project (RDP-II, Release 9) of the Center for Microbial Ecology, Michigan State University (<http://rdp.cme.msu.edu/seqmatch>). To assess the pathogenic potential of isolated strains towards *P. clavata* colonies, infection experiments were performed in aquaria at different temperatures and environmental conditions simulating those observed in the environment during the occurrence of mortality events (see Vezzulli *et al.*, 2010 for full details of experiments).

Results

Population structure and mortality dynamics: field surveys

In total, 476 colonies were observed in 158 quadrats. Records of colony densities, height and size class distribution show how the two sites (shoals) have a different population structure, and this appears to have elicited a different response to the mortality event.

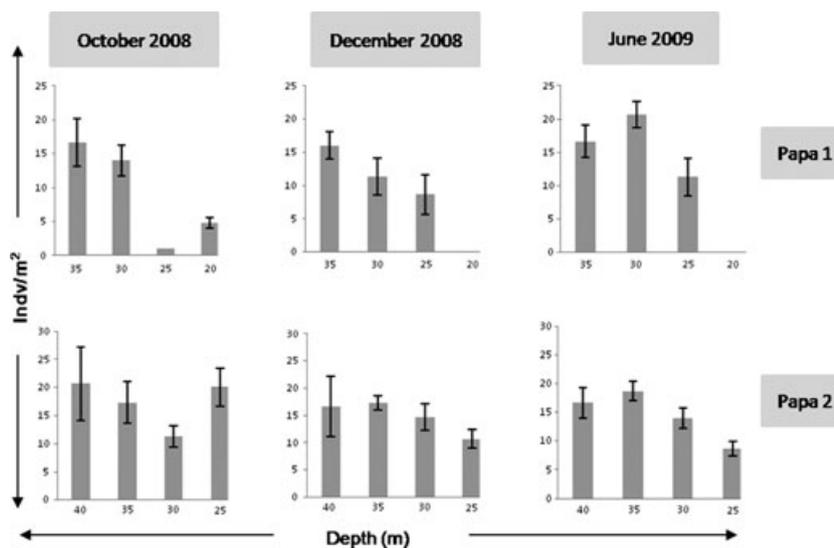


Fig. 1. Density averages for Papa 1 and Papa 2 at different depths in time with \pm SE.

Papa 1. In this site the mean density (\pm SE) was 9.12 ± 2.18 colonies per m^2 . Significant differences in densities were detected among depths ($P < 0.05$, Fig. 1), predominantly due to the low number of colonies in the upper limits of this species' distribution. The mean height of *Paramuricea clavata* (\pm SE) was 21.03 ± 4.24 cm during the mortality event and 27.72 ± 3.12 cm during the last survey, with no significant differences detected both in mean height of the colonies on the investigated temporal scale ($P > 0.05$, see also Fig. 2) and between the different depths ($P > 0.05$). Damaged colonies of *P. clavata* were found at all depths, but at 35 m depth the percentage of damage was mainly constant and generally lower than at the other (mostly shallower) depths (Fig. 3). Between 30 and 20 m depth, mortality occurred at a high percentage of colonies, and was especially prevalent in the larger sized classes. At 25 m depth, all size classes of colonies were 100% damaged, both in October 2008 and in December 2008. In the last survey, in June 2009, more

healthy colonies (compared with previous surveys) were found and the average size of the population had shifted towards smaller sized classes (*i.e.* 0–30 cm) (see Figs 1, 2 and 4).

Papa 2. In this site mean density (\pm SE) of *P. clavata* was 17.33 ± 2.13 colonies per m^2 . No differences in density were detected both among depths and the investigated periods ($P > 0.05$) (Fig. 1). Mean colony height (\pm SE) during the mortality event was 29.72 ± 6.86 cm and 28.54 ± 2.01 cm during the last survey. The smallest colonies were found at 25 m depth (Fig. 2), while colony height elsewhere was significantly greater ($P < 0.001$), although there was no obvious correlation between colony height and the depth of the substrate they occupied. Damaged colonies were found at all depths during the entire period of study. At 40 m depth the percentage of damaged colonies was generally low and varied between about 20 and 40%. By contrast, at 35 and 25 m depths the frequency of mortality was higher between October

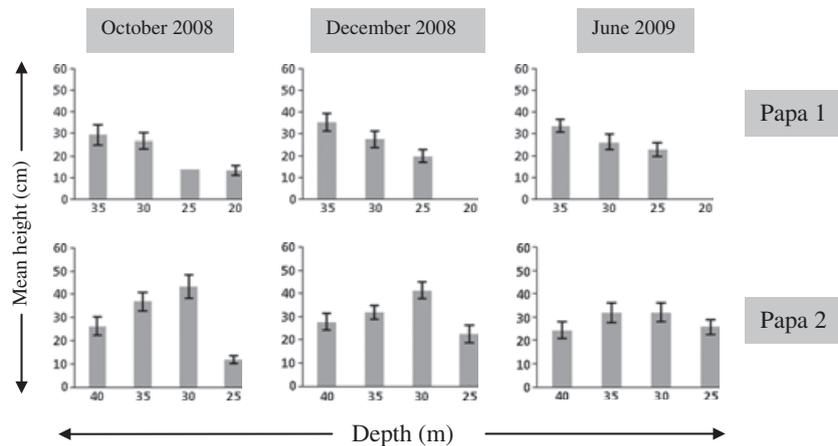


Fig. 2. Height averages for Papa 1 and Papa 2 at different depths in time with \pm SE.

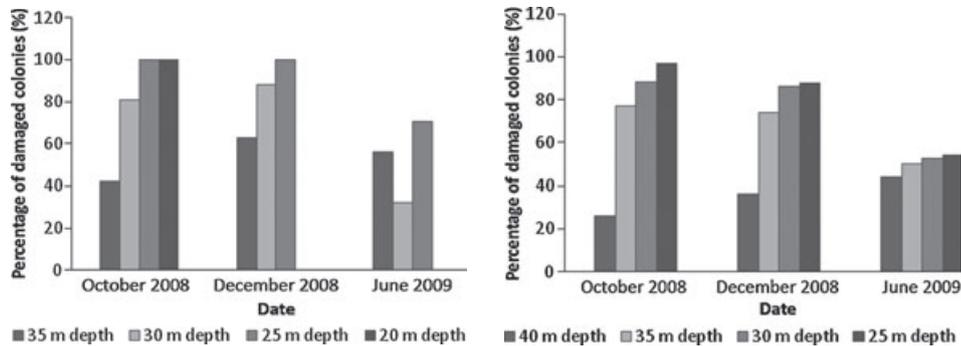


Fig. 3. Percentage of damaged colonies in time at all depths for the two study areas: Papa 1 (left) and Papa 2 (right). At deeper depths there are fewer damaged colonies, whereas at the superficial parts of the shoals, damage is greater and has affected more colonies. There is a general reduction in the last studied period, probably due to natural recovery and the loss of the larger and more damaged colonies.

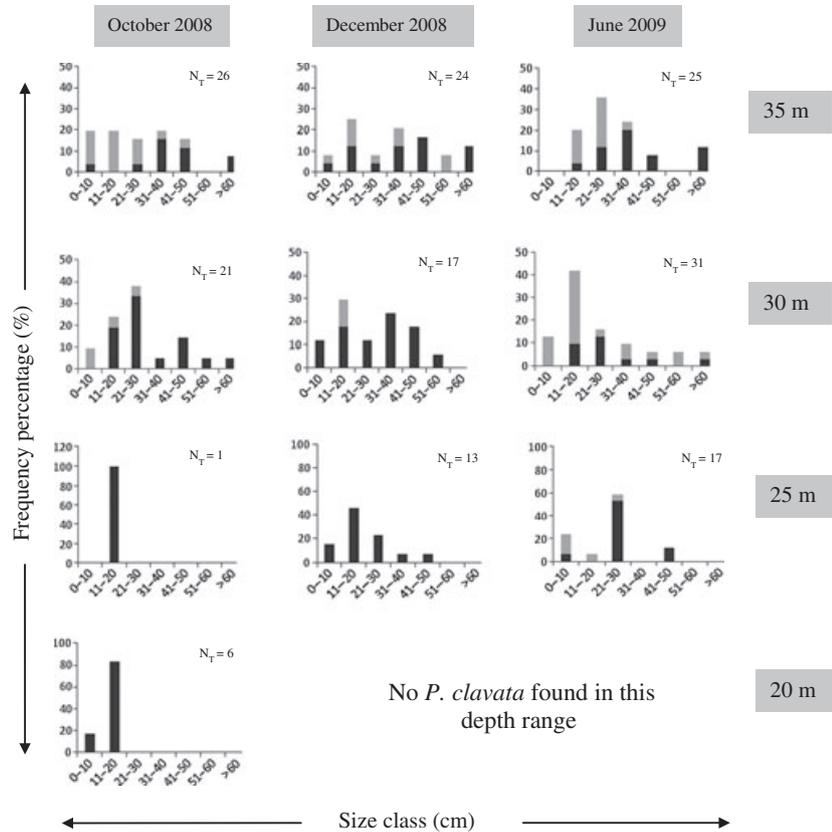


Fig. 4. Size class percentage frequency. Frequencies in damaged percentage per size class (black) and healthy percentage per size class (light grey). Papa 1. Frequencies are the percentage of damaged/healthy colonies found in a determinate size class.

and December, especially for the 21–30 cm size class individuals. In June, the size class distribution shifted towards the smaller size classes (*i.e.* there were more colonies in the range 0–30 cm) (Figs 1, 2 and 5). Overall, the mean percentage of damage of colonies indicates that damage is generally greater in the shallower parts of the shoals, in some cases up to 100% throughout the whole size class of individuals (Fig. 3).

At both sites, epibiosis on the denuded parts of the colonies followed a pattern of four temporally successive steps: (i) denuded branches, here recorded in October, (ii) newly settled organisms such as filamentous algae and hydroids, (iii) a medium stage of epizootic colonization with algae and small sponges, which was noted in December, and finally (iv) an old stage with colonization by algae, sponges, bryozoans and other calcareous organisms, which was found during the last surveys in June (Table 1).

Environmental features: laboratory analyses

Seawater temperature measurements confirmed the high temperature (22 ± 1 °C in September and 21 ± 0.5 °C in

October) along the water column and the absence (in the investigated depth range of between 20 and 43 m) of thermocline in October, confirming a prolonged water stability over it (Fig. 6). Temperature is depth-dependent; at all depths considered, water temperature was at least a degree higher during the months of September and October 2008 than in the previous year. Data for December 2007 were not available.

Although the dissolved oxygen concentrations were always high in both the sampling sites (close to healthy and damaged colonies), water results have highlighted higher levels of nitrite, nitrate and ammonia during the mortality event, especially around the damaged colonies where tissue degradation was taking part (Table 2). In contrast, phosphate concentrations were higher next to the healthy colonies. These concentrations led to P-limitation conditions (higher N/P ratio where N is the sum of nitrite, nitrate and ammonia concentrations) next to the compromised colonies, especially during October.

Microbiological tests revealed that *Vibrio* bacteria were consistently more abundant in diseased organisms with up to a twofold higher concentration compared with those found on the healthy corals (Fig. 7). The 16S rRNA

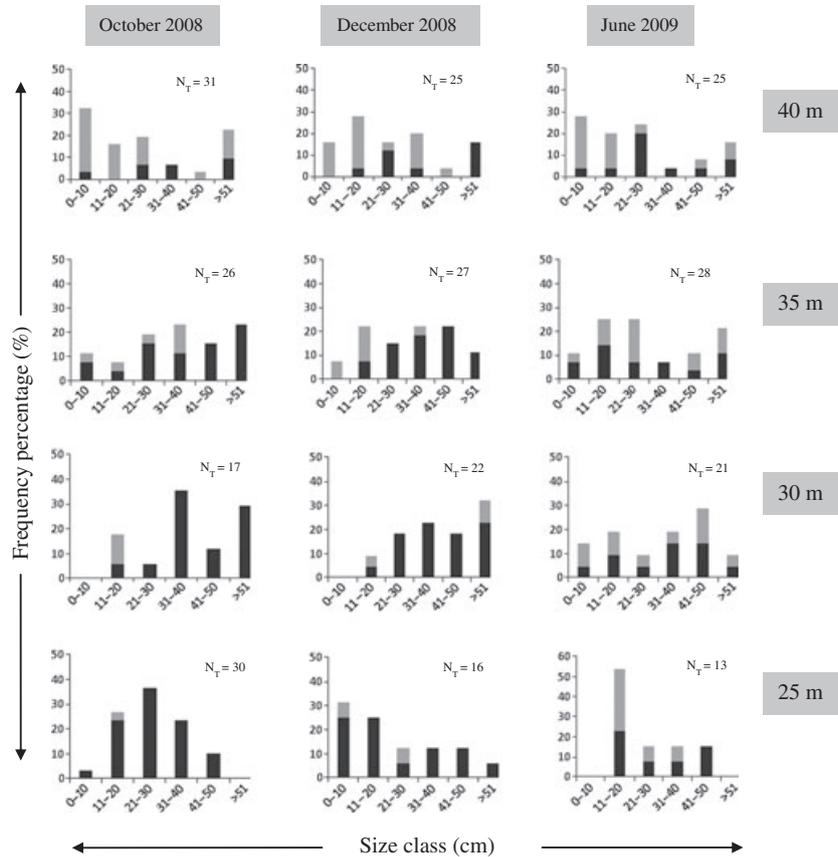


Fig. 5. Size class percentage frequency. Frequencies of damaged percentage per size class (black) and healthy percentage per size class (light grey). Papa 2. Frequencies are percentage of damaged/healthy colonies found in a determinate size class.

Table 1. Number of colonies affected and the type of epibiosis recorded on the colonies of the studied sites during and after the mass mortality event.

epibiosis type	October 2008	December 2008	June 2009
Papa 1			
denuded	60	26	0
new	25	52	40
medium	10	15	55
old	5	6	5
Papa 2			
denuded	70	43	1
new	11	27	36
medium	11	22	53
old	8	9	10

gene sequencing of 61 *Vibrio* isolates associated to diseased and healthy *Paramuricea clavata* colonies showed a close homology of the majority of the strains with *Vibrio harveyi* (n = 24), *Vibrio splendidus* (n = 22) and *Vibrio coralliilyticus* (n = 15), the latter only being identified in diseased organisms.

Discussion

The main aims of MPAs, as identified in the IUCN Guidelines for Establishing Marine Protected Areas (Kelleher & Kenchington 1992), are (i) to maintain essential ecological and life-support systems, (ii) to ensure the sustainable utilization of species and ecosystems and (iii) to preserve biotic diversity. Monitoring, defined as continuous observation of conditions over time, is a crucial tool for the conservation of marine biological diversity and provides managers with important data from which they can make informed decisions about patterns and processes that affect biodiversity, and thus the functioning (or not) of an MPA. Here, we present our monitoring data to describe some of the factors associated with a mass mortality of the gorgonian *Paramuricea clavata* at the MPA at Tavolara Island, Italy.

The mortality event described here affected a population of octocoral that is well known and utilized by the diving tourism industry in a ‘Specially Protected Area of Mediterranean Importance’ (SPAMI). Our results represent an important baseline for future monitoring

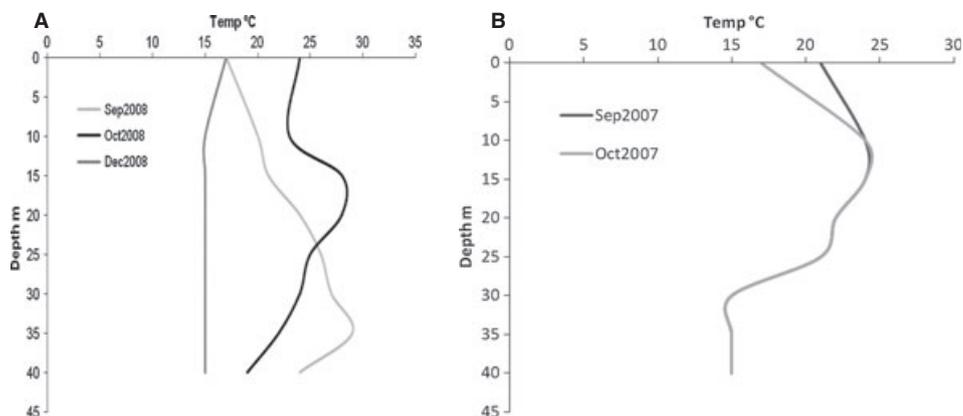


Fig. 6. Temperature profile from 2008 of the months of interest in the investigated area, recorded by SCUBA operators and SST (sea surface temperature) from <http://www.poseidon.ogs.it>. Data from December 2007 were not available.

Table 2. Environmental features recorded for the sea-water collected next the decaying (damaged) and the control (healthy) colonies.

		Dissolved oxygen		Silicate		Nitrite+nitrate		Ammonia		Phosphate		N/P ratio
		ml l ⁻¹	SD	μM	SD	μM	SD	μM	SD	μM	SD	
October	Healthy	7.49	0.13	1.15	0.05	2.40	0.18	1.63	0.08	0.18	0.01	22.9
	Damaged	7.23	0.14	1.54	0.21	3.11	0.41	2.10	0.42	0.15	0.01	35.4
December	Healthy	nd	nd	2.42	0.28	0.92	0.10	0.96	0.19	0.12	0.01	15.2
	Damaged	7.77	nd	2.12	0.36	0.96	0.06	1.23	0.37	0.10	0.02	22.0

N, nitrogen; nd, not detected; P, phosphate; SD, standard deviation.

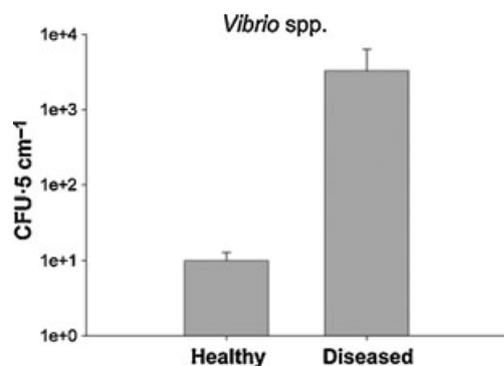


Fig. 7. Concentration of *Vibrio* found in the colonies (healthy and damaged) of Papa 1 and Papa 2. CFU = unity of bacteria colony formation with \pm SE. This graph considers all the *Vibrio* species found on the *Paramuricea* colonies: of these *V. harveyi* and *V. splendidus* were the main components on the healthy colonies and *V. corallilyticus* was also present on the damaged or diseased colonies.

programs on this long-lived, sessile species with slow population dynamics (Mistri & Ceccherelli 1994). Even though the mean colony density of the studied areas was lower than in other Mediterranean areas (Cerrano & Bavestrello 2008; Cupido *et al.* 2009; Garrabou *et al.* 2009), the seascape before the mortality episode was dominated by large colonies.

Broadly speaking, Papa 1 is less dense and has smaller colonies than Papa 2. Mean colony height did not differ over a relatively short period of 1–3 months after the mortality episode, but there was a clear shift towards small size classes by 9 months after the mortality event. This trend was reported also in other monitoring studies on gorgonian mortality (Cerrano *et al.* 2005; Cupido *et al.* 2008, 2009; Linares *et al.* 2008a,b,c). This phenomenon is mainly due to the loss of the colonies from the larger size classes and also the fragmentation and/or damage to branches. Moreover, the presence of recruits caused a shift towards smaller colonies, leading to a general loss of habitat complexity. Furthermore, there was evidence that most of the colony branches with epibionts that were counted in December 2008 had either fallen off or were broken in June 2009.

From 35 m (for Papa 2) and 30 m depth (for Papa 1), up to the surface of the shoals, the larger colonies were more affected (*i.e.* had a higher percentage of damage) by the mortality event: deeper colonies were less affected in both sites. Colonies living at greater depths could hence constitute a reservoir for the production of planulae for future population recoveries (bottom-up and lateral supply).

In coralligenous assemblages, perhaps the most important habitats in the Mediterranean Sea (Ballesteros 2006),

gorgonians and particularly *P. clavata*, are considered key species, being important engineering and/or foundation species (*sensu* Dayton, 1972; Mistri & Ceccherelli 1994; Cupido *et al.* 2009). Mass mortality events have wide consequences for gorgonian populations (Linares & Doak 2010) and for the community that depends on them, as the loss of these species alters sedimentation, turbidity and water movement, which negatively affect the complex structure of the hard-bottom benthic communities and the local biodiversity richness (Scinto *et al.* 2009). In both September and October 2008, the position of the thermocline could not be detected down to 40 m depth during the mortality event and temperature was ~ 2 °C higher than during September 2007. The verified thermal anomalies and the constant warming of the Mediterranean may have important consequences for the natural biocenosis (Bianchi 2007; Coma *et al.* 2009) and may be the cause of the mass mortality events occurring in the last few years (Pérez *et al.* 2000; Pérez 2008; Coma *et al.* 2009).

In October, seawater analyses indicated altered values of ammonia, nitrite and nitrate close to damaged colonies, which were higher than usual and likely due to tissue degradation. These anomalies were not recorded in December, after the mortality episode had finished. Changes in phosphate values could have been related to the summer increase of urban sewage outflow due to high tourist density. An alteration of the nutrient concentrations was highlighted by the change of the N/P ratio values (Table 2), which may potentially favor unusual phytoplanktonic and/or bacterial species. The P-limited situation could have added an energetic constraint on the weak *P. clavata* population. These general conditions (high seawater temperature, altered N/P ratio) could have facilitated the increase of bacteria on damaged colonies. We uncovered three main groups of *Vibrio*, of which *Vibrio coralliilyticus* has been implicated as an important cause of mortality for Mediterranean *P. clavata* (Martin *et al.* 2002; Bally & Garrabou 2007) and Caribbean corals (Cervino *et al.* 2004). *Vibrio* bacteria are normally found in seawater and are thermodependent: at high temperatures (22–24 °C) *Vibrio* grows rapidly. *Vibrio coralliilyticus* showed the highest virulence toward *P. clavata* colonies and satisfied Koch postulates for pathogenicity. This bacterium appears to act as an opportunistic agent, infecting weak, thermally stressed colonies and compromising colony recovery (Vezzulli *et al.*, 2010).

Until now there have been no standardized actions to mitigate the impact of mass mortalities of *P. clavata*. Intervention strategies remain to be validated and it is important, especially where diving activity is frequent, to avoid population fragmentation that would lead to a progressive reduction in population density (Linares & Doak 2010) and a general loss of biodiversity (Cerrano &

Bavestrello 2009). For this reason, monitoring is the only effective approach to plan adequate programs of intervention. Hypotheses to limit damages and/or improve recovery damaged colonies include: (i) development of an 'early warning system' to measure water stratification and predict mass mortalities and (ii) utilization of pruning and transplant technique protocols. For example, controlled miniaturization of larger colonies could lead to more resistant and resilient specimens that will also furnish a number of fragments for transplants to highly damaged areas to be used for restoration. Certainly, manipulation and transplant experiments need to be designed and tested before this strategy can be used routinely (see for example the pilot study of Linares *et al.* 2008c). Sites within MPAs have greater possibilities for recovery and adequate management, as the anthropogenic impacts are reduced and controlled; but as shown in this and other studies, MPA protection certainly does not prevent mass mortalities related to environmental causes.

Conclusions

Short-term effects of mortality events include habitat simplification and reducing the economic value due to a decrease of touristic appreciation (Trainito 2007; Navone & Trainito 2008). Evaluation of long-term consequences needs adequate monitoring programs. On the basis of previous mortality episodes described in different areas (Liguro-Provençal Basin and Tyrrhenian Sea), long-term effects may vary in relation to the presence of healthy 'pocket reservoir' populations living below the water stability area delimiting the thermal anomalies. Their presence may represent an important larval supply to facilitate the recovery of shallow populations. High water temperature and prolonged summer conditions are among the most relevant causes of these mass mortality events (including the one reported here), reducing natural defences of colonies. In these compromised conditions, colonies are more vulnerable to infections and energetic constraints.

Acknowledgements

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