Vol. 131: 79–85, 2018
https://doi.org/10.3354/dao03284

DISEASES OF AQUATIC ORGANISMS
Dis Aquat Org

Published October 16

NOTE

# Mass mortality hits gorgonian forests at Montecristo Island

**Eva Turicchia[1,2,3,4,*], Marco Abbiati[2,3,5,6], Michael Sweet[7], Massimo Ponti[1,2,3,4]**

[1]Dipartimento di Scienze Biologiche, Geologiche e Ambientali (BiGeA), University of Bologna, Via S. Alberto 163, 48123 Ravenna, Italy

[2]Centro Interdipartimentale di Ricerca per le Scienze Ambientali (CIRSA), Via S. Alberto 163, 48123 Ravenna, Italy

[3]Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa), Piazzale Flaminio 9, 00196 Roma, Italy

[4]Reef Check Italia onlus. c/o Dipartimento di Scienze della Vita e dell'Ambiente (DiSVA), Polytechnic University of Marche, Via Brecce Bianche, 60131 Ancona, Italy

[5]Dipartimento di Beni Culturali (DBC), University of Bologna, Via degli Ariani 1, 48121 Ravenna, Italy

[6]Istituto di Scienze Marine (ISMAR), Consiglio Nazionale delle Ricerche, 40126 Bologna, Italy

[7]Aquatic Research Facility, Environmental Sustainability Research Centre, University of Derby, Derby, DE22 2EY, UK

ABSTRACT: Mediterranean gorgonian forests are species-rich habitats, and like many other marine habitats they are threatened by anthropogenic disturbances and mass mortality events. These mortality events have often been linked to anomalies in the temperature profiles of the Mediterranean region. On 5 September 2017, colonies of the gorgonians *Eunicella singularis* and *Eunicella cavolini* exhibited rapid tissue loss, down to a depth of 30 m along the steep cliffs of Montecristo Island, Tuscan Archipelago National Park, Tyrrhenian Sea, Italy. Interestingly, Montecristo has previously been identified as a reference site for the ecological quality assessment of the western Mediterranean benthic assemblages on rocky bottoms. The observed mortality event occurred during a period of increased sea temperature. By utilising a combination of high-resolution oceanographic analysis, forecast models and citizen science initiatives, we propose that an early warning system for the concomitance of heat waves and mortality events can be put in place. A temperature-based coral disease surveillance tool could then be established for the entire Mediterranean Sea. Such a tool would allow for the timely study of mass mortality phenomena and the implementation of prompt mitigation and/or restoration initiatives. Finally, this specific mortality event, in a Marine Protected Area, offers a unique opportunity to monitor and assess the resilience of gorgonian populations and associated benthic assemblages in the absence of other, more directly, anthropogenic disturbances such as pollution and land runoff.

KEY WORDS: Coral disease · Global climate change · Mediterranean Sea · Heat wave · Marine protected areas · Marine animal forests



## INTRODUCTION

Montecristo Island is one of the least accessible and most protected areas in the Mediterranean Sea. The island is the core of the Tuscan Archipelago National Park (Italy), has been a State Natural Reserve since 1971, and is designated as a Special Protection Area (IT5160014; European Directive 79/409/EEC). The distance from the mainland and other populated islands (i.e. 41 km south of Elba Island, the nearest populated area), coupled with its impervious nature, has meant that historically only few people have inhabited

*Corresponding author: eva.turicchia2@unibo.it

this island. The island is also inaccessible to tourists and far away from major human disturbances, which have been shown to threaten the vast majority of the rest of the Mediterranean coast (e.g. coastal development, destructive fishing practices, and land based pollution; Micheli et al. 2013). For these reasons, Montecristo Island has been considered among the best preserved sites in this region, both on land and underwater. Its well-preserved benthic assemblages have therefore been used as a reference condition in the development of biotic indices for ecological quality assessment throughout the western Mediterranean Sea (see Cecchi et al. 2014 and references therein). To our knowledge, Montecristo has not been affected by severe benthic mass mortality events, which have been reported in many other locations within the Mediterranean over recent years (e.g. Cerrano et al. 2000, Calvo et al. 2011, Rivetti et al. 2014). The only exception was a localised and restricted mortality event, which affected the purple gorgonian *Paramuricea clavata* (Risso, 1826). This mortality event was reported in the late 1980s by the film director and underwater photographer Gerry Guldenschuh (in Bavestrello et al. 1994). Here we report the early stage of a mass mortality event affecting 2 other gorgonian species, *Eunicella singularis* (Esper, 1791) and *Eunicella cavolini* (Koch, 1887) off Montecristo Island. We further assessed if the anomalous water temperature that occurred at the end of summer 2017 could be one of the causes of the mass mortality.

## MATERIALS AND METHODS

Two scuba diving surveys were conducted by 6 scientific divers on 5 September 2017 at Montecristo Island (Tyrrhenian Sea; Fig. 1): one on the northwestern side of the island, Punta del Diavolo (42° 21.10′ N, 10° 17.97′ E), and the other on the southeastern side, Punta Forata (42° 19.11′ N, 10° 19.60′ E). Surveys were initially conducted in order to collate data on the abundance and depth distribution of

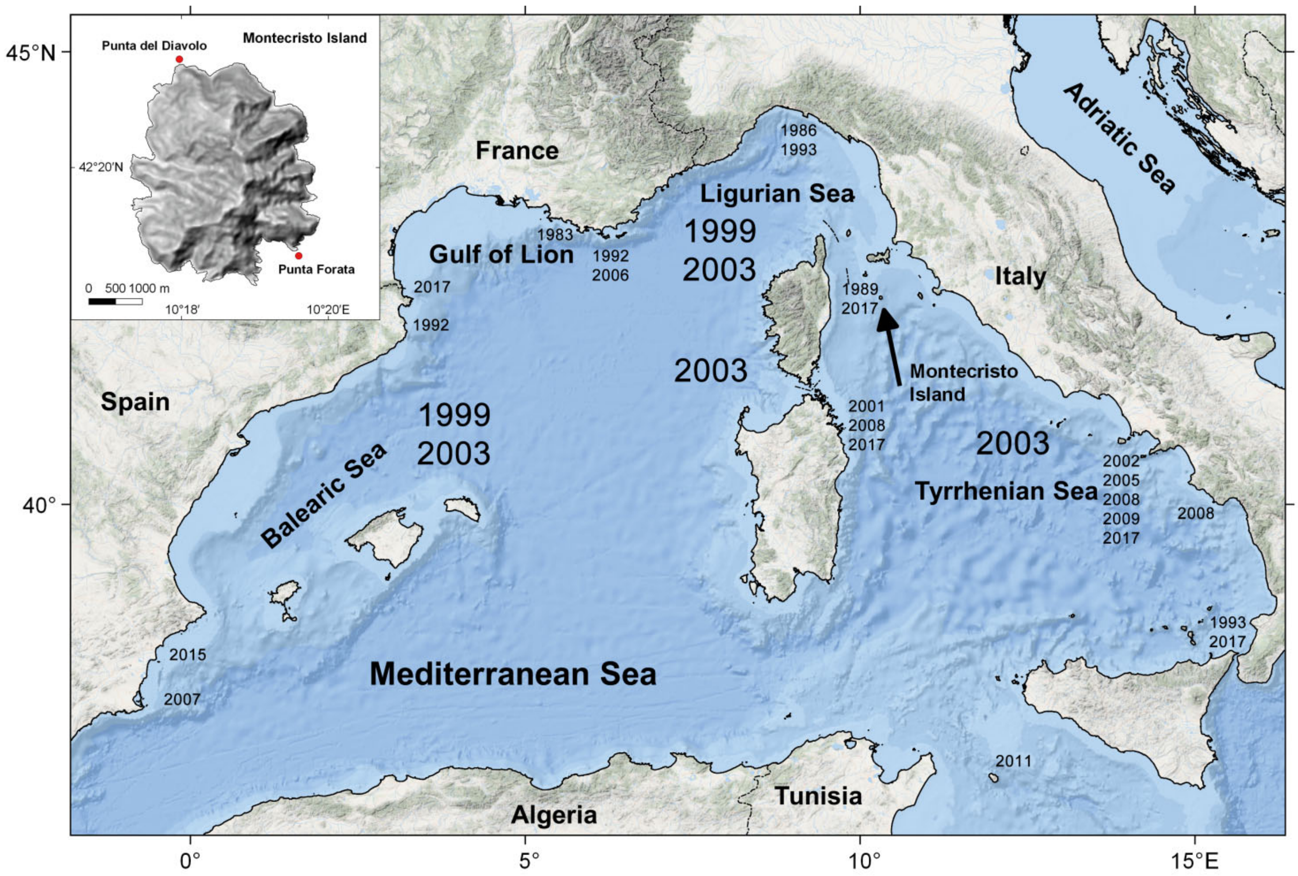


Fig. 1. Location of study sites, Punta del Diavolo and Punta Forata, at Montecristo Island, in the Tyrrhenian Sea. Numbers indicate the location and year of mass mortality events that have affected gorgonians in the western Mediterranean Sea as reported in Table S1 in Supplement 2. The larger the font of the number the wider the regional event. Open-source base maps: MapSurfer ASTER GDEM-SRTM Hillshade and ESRI Ocean; Mercator projection, WGS84 datum

selected ecological indicator species (including gorgonians). This was undertaken by conducting visual observations along random paths down to a depth of 40 m, in accordance with the Reef Check monitoring protocol for the Mediterranean Sea (Cerrano et al. 2017). Photos and videos were recorded by 2 Canon PowerShot cameras (models: G15 with a Patima case, and a G7 X with a Fantasea case), both equipped with Inon strobes. *In situ* depth and temperature were simultaneously recorded by 2 dive computers at 4 s intervals (models: Scubapro/Uwatec Aladin 2G and Tec 3G), with clocks synchronised to the cameras. At each site, mean temperature (± SE) at 1 m depth intervals was obtained by combining the data of the 2 dive computers.

In order to analyse the temporal trend of water temperature and any observed anomalies, daily mean water column temperature in the sampling area was downloaded from the European Union Copernicus Marine Environment Monitoring Service (CMEMS). The daily mean temperatures for 2017 were obtained from the Mediterranean Sea Physical Analysis and Forecasting product, which is based on a hydrodynamic model with a horizontal grid resolution of 1/24° (ca. 4.6 km in latitude) and 141 unevenly spaced depth levels (Clementi et al. 2017). By comparison, the daily climatological temperatures between 1987–2015 were computed from the Mediterranean Sea Physical Reanalysis product (MEDREA), based on a hydrodynamic model with a horizontal grid resolution of 1/16° (ca. 6.9 km in latitude) and 72 unevenly spaced depth levels also available on CMEMS (Simoncelli et al. 2014). The coastline of Montecristo Island falls into 4 calculation cells of the first hydrodynamic model and in 2 cells of the second. Since data from these cells were almost identical, in both cases the data from the first upper-left cell was utilised. It should be noted that the accuracy of these models varies both in space and depth. The root-mean-square error (RMSE) throughout the water column is on average 0.3°C, with a peak of 0.8°C at 30 m depth (Simoncelli et al. 2014, Clementi et al. 2017). Furthermore, a higher error ratio is likely to occur nearest to the coast. All data was analysed and plotted using the geographical information system QGIS and the computational software R (R Core Team 2018), with the package OceanView (Soetaert 2016).

## RESULTS AND DISCUSSION

Along the investigated submerged cliffs at Montecristo Island, the white gorgonian *Eunicella singularis* formed dense populations that shaped 'marine animal forests' (see Ponti et al. 2018). Colonies of *E. singularis* were found from 10 m to more than 40 m depth with higher densities (up to 10 ind. m$^{-2}$) between 15 and 25 m. In contrast, the yellow sea whip *E. cavolini* was much less dense than *E. singularis*, but colonies were found across a similar depth range (from 15 m to more than 40 m). Relatively higher densities of this species were found between 25 and 35 m (up to 5 ind. m$^{-2}$). Colonies of *Paramuricea clavata* were also observed but only in areas deeper than 25 m.

On 5 September 2017, colonies of *E. singularis* and *E. cavolini* exhibited signs of 'rapid tissue loss' at Punta Forata and Punta del Diavolo. The coenenchyme of affected colonies exhibited either partial or total detachment from the skeleton (Fig. 2). No encrusting epibionts were observed on any of the denuded skeletons assessed, suggesting the lesion progression was rapid in a similar manner to the tissue loss often seen in scleractinian corals on tropical reefs (e.g. Work et al. 2012). Interestingly, in a few colonies the coenenchyme appeared to remain attached when initially observed. However the tissue was easily dislodged by minor water movement (e.g. by a diver's hand moving in front of the coral; see Video S1 in Supplement 1 at www.int-res.com/articles/suppl/d131p079_supp/). This may be indicative of an early stage of the disease. Colonies which were affected by this rapid tissue loss were more commonly found above the thermocline, which reached to depths of 30 m at the sites surveyed. At Punta Forata, diseased colonies of both *E. singularis* and *E. cavolini* were observed down to 17 and 21 m depth respectively. These corresponded to water temperatures of 23 and 22°C, respectively (Fig. 3A). At Punta del Diavolo affected colonies were observed down to 25 m for *E. cavolini*, and 30 m for *E. singularis*, and these correlated with temperatures of 21 and 19°C, respectively (Fig. 3B).

The vertical profiles of daily mean water temperature (collected from 1 March to 30 November 2017 at Montecristo Island), showed an anomalous thermocline formation (Fig. 4) when compared to the climatology for the same period between 1987 to 2015 (MEDREA). In March 2017, water temperatures were almost 1°C warmer than the climatological reference period from the surface down to 60 m depth. In April, this anomaly increased to 2.5°C at 10 m depth and by the end of June, in shallow waters, rose to 3°C above the average. From July, the warming moved to greater depths until reaching the temperature anomaly of 4°C at depths of 25–30 m at the beginning of September.

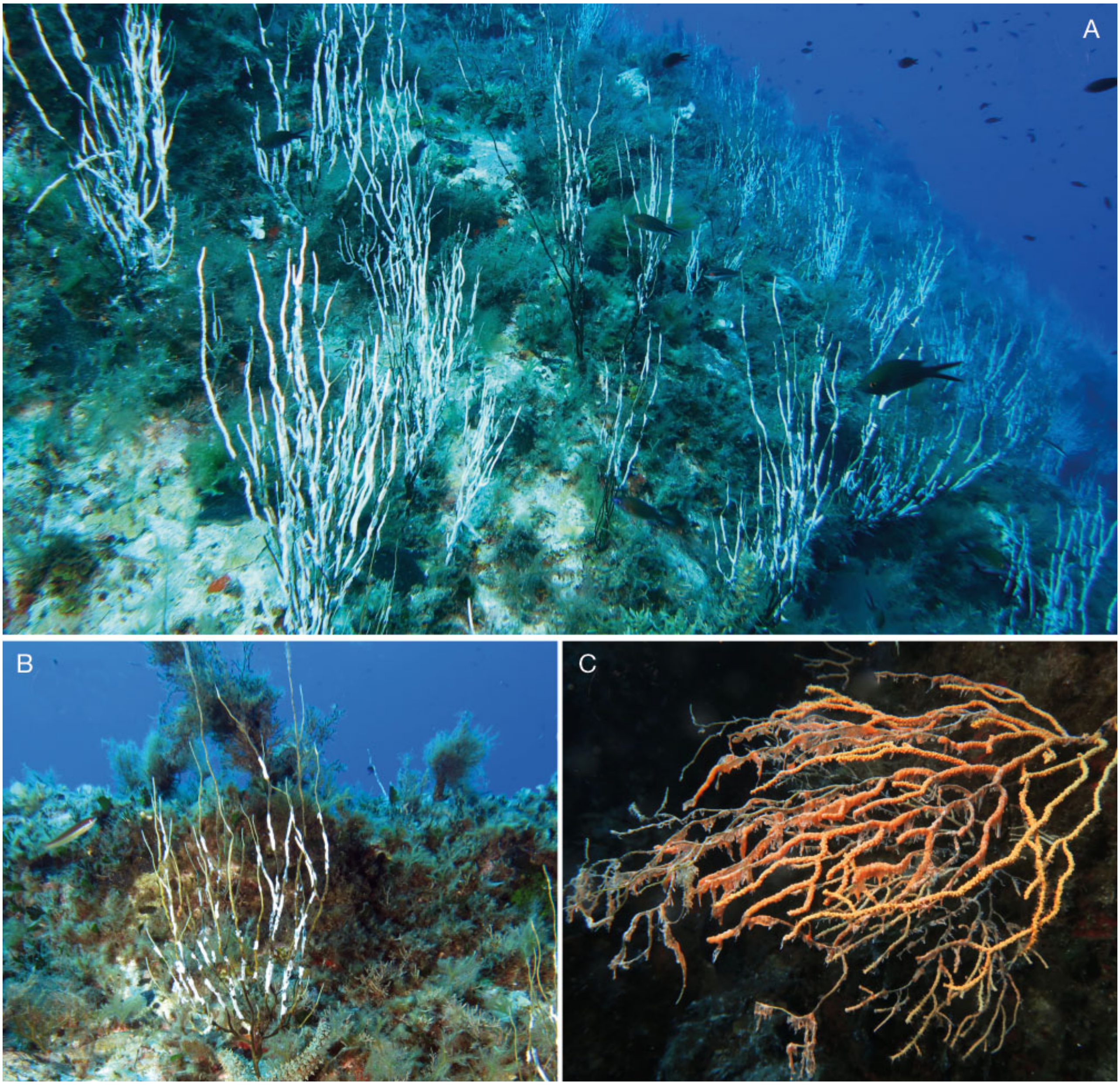


Fig. 2. Examples of colonies of (A,B) *Eunicella singularis* and (C) *E. cavolini* at Montecristo Island suffering from 'rapid tissue loss'

Mass mortality events of gorgonians are not undocumented. Indeed, such events have been recorded throughout the western Mediterranean Sea over recent decades, as reported in Fig. 1 (see Table S1 in Supplement 2 for an updated review). The first documented case of mass mortality in gorgonians occurred in the north-western Mediterranean Sea (the Gulf of Lion and the Ligurian Sea) in the 1980s. Overall, colonies of *P. clavata* and *E. singularis* were the most commonly affected species. However, *Eunicella* die-offs were never reported at Montecristo Island, even during the most extensive mass mortality events which occurred in the region in 1999 and 2003 (Cerrano et al. 2000, Garrabou et al. 2009).

Thermal stress plays an important role in the onset of gorgonian mass mortality events (e.g. Cerrano et al. 2000, Coma et al. 2009, Garrabou et al. 2009, Vezzulli et al. 2010, Calvo et al. 2011, Rivetti et al. 2014, Rubio-Portillo et al. 2016). Longer-lasting, hotter summer periods result in positive seawater temperature anomalies, strong water column stratification and a decrease in the available oxygen for benthic

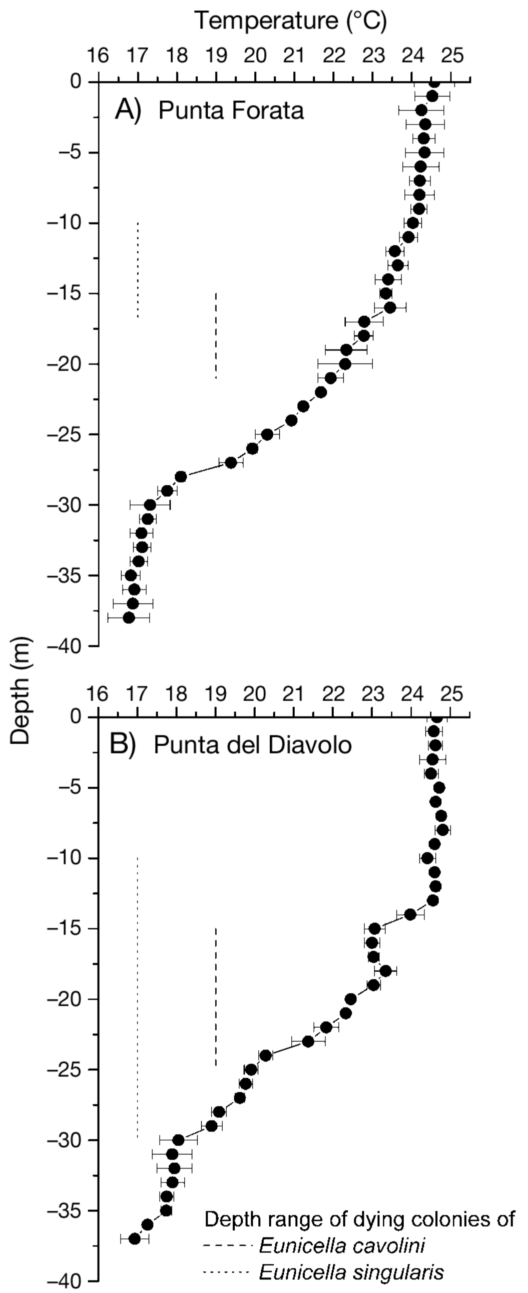


Fig. 3. Vertical water temperature (±SE) profiles and depth range associated with diseased colonies of *E. cavolini* and *E. singularis* at (A) Punta Forata and (B) Punta del Diavolo on the 5 September 2017. *In situ* mean water temperatures were obtained from 2 dive computers at 1 m depth intervals

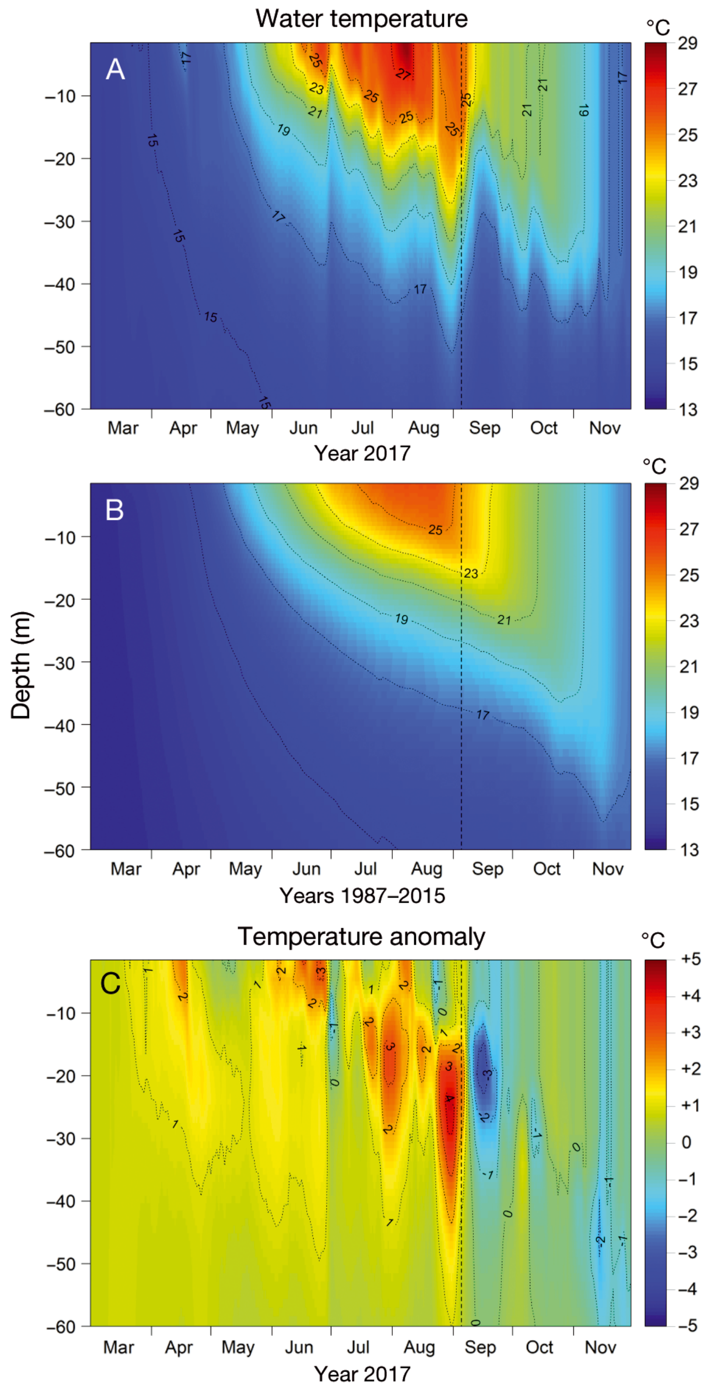


Fig. 4. Vertical profiles of water temperature at Montecristo Island from 1 March 30 November: (A) daily averages from 2017 CMEMS analysis; (B) daily climatological values (1987–2015) from CMEMS reanalysis; (C) daily thermal anomalies in 2017. The dashed line indicates the survey date

organisms. These stressors have a direct effect on the health of many benthic organisms, including gorgonians (Cerrano et al. 2000, Cerrano & Bavestrello 2008, Garrabou et al. 2009). For example, during these periods gorgonians exhibit reduced energetic reserves, likely because of investment in reproduction and low food availability (Coma et al. 2009). Furthermore, due to physiological stress, the gorgonians may lose the capacity to regulate their microbiome through the production of antimicrobial and quorum-sensing interfering compounds (see van de Water et al. 2018 and references therein). For example, alteration of the microbiome to a pathobiome state results in the onset of disease in various marine organisms (Sweet & Bulling 2017). Indeed, gorgonians harbour relative stable core microbial communities (La Rivière et al. 2015, van de Water et al. 2017), which likely play important roles in the health and fitness of these organisms. However, the true function of these core microbes remains to be fully understood (see La Rivière et al. 2015 and references therein).

While the purpose of this study was not to ascertain the causal agent of this die-off, other studies have assessed possible causal agents of previous events. For example, increases in microbes of the genus *Vibrio* (a commonly referenced marine pathogenic genus) have been found in diseased *P. clavata* and *E. singularis* when compared to healthy individuals from the same locations (Vezzulli et al. 2010, Rubio-Portillo et al. 2016). In another case, a heterogeneous consortium of filamentous cyanobacteria (including representatives from the genera *Synechococcus, Arthrospira* and other unculturable species belonging to the order Oscillatoriales) were more prevalent in diseased colonies of *E. singularis* and *E. cavolini* (Carella et al. 2014) when compared to healthy individuals. Regardless of the causal agent or agents, the trend in epidemics and pandemics in both marine and terrestrial systems is worrying, and any outbreak — especially mass die-offs — warrants further study.

Gorgonian marine forests are species-rich habitats and therefore ecologically important (Ponti et al. 2014, 2016, 2018). The increase in frequency, intensity and depth of thermal anomalies in these habitats is therefore alarming (Coma et al. 2009, Calvo et al. 2011, Rivetti et al. 2014). However, it is often argued that the resulting decline in reef health (cold water, temperate or tropical) stems from a combined effect of climate change and other, more local, stressors. In order to attempt to untangle such a complex network of stress effects, it is essential that reliable baselines are available for any given ecosystem (Harvell et al. 2002), especially for sites where other anthropogenic stressors (non-climate related) are reduced or non-existent, i.e. locations such as Montecristo Island.

Such baseline studies, together with the advent of CMEMS and the availability of real-time analysis, forecasting and reanalysis products for the whole Mediterranean Sea, may enable the development of an efficient temperature-based disease surveillance tool (Maynard et al. 2016). Access to high spatial resolution oceanographic data, as well as a 10 day forecasting capability, means an early warning system for the most sensitive of locations can be put in place, especially where marine forests exist, such as the one studied here. Such a tool should likely include other variables which may change in response to climate change; for example, oxygen levels, salinity, turbidity and availability of plankton biomass. The involvement of citizen scientists could also be utilised to develop such a management tool (Cerrano et al. 2017, Di Camillo et al. 2018).

In conclusion, we highlight a new mass mortality die-off of gorgonian forests in the Mediterranean Sea, and indicate that thermal anomalies are likely key triggers in the onset of the disease in this instance. We also illustrate that with a better understanding of the environmental conditions and other stressors (which may lead to future disease outbreaks), an ecosystem-based management plan can be adopted which attempts to prevent or mitigate the ecological damage caused by the loss of these marine forests.

*Acknowledgements*. We thank Daniela Pica, Ubaldo Pantaleo, Chiara Luciani and Pier Giacomo De Cecco who attended the underwater expedition supported by the University of Bologna and Reef Check Italia Onlus, and authorised by Tuscan Archipelago National Park (Permission #345/2017). This study is part of E.T.'s PhD and was conducted using EU Copernicus Marine Service Information.

## LITERATURE CITED

Bavestrello G, Bertone S, Cattaneo-Vietti R, Cerrano C, Gaino E, Zanzi D (1994) Mass mortality of *Paramuricea clavata* (Anthozoa, Cnidaria) on Portofino Promontory cliffs, Ligurian Sea, Mediterranean Sea. Mar Life 4: 15–19

Calvo E, Simó R, Coma R, Ribes M and others (2011) Effects of climate change on Mediterranean marine ecosystems: the case of the Catalan Sea. Clim Res 50:1–29

Carella F, Aceto S, Saggiomo M, Mangoni O, De Vico G (2014) Gorgonian disease outbreak in the Gulf of Naples: pathology reveals cyanobacterial infection linked to elevated sea temperatures. Dis Aquat Org 111:69–80

Cecchi E, Gennaro P, Piazzi L, Ricevuto E, Serena F (2014) Development of a new biotic index for ecological status assessment of Italian coastal waters based on coralligenous macroalgal assemblages. Eur J Phycol 49:298–312

Cerrano C, Bavestrello G (2008) Medium-term effects of die-off of rocky benthos in the Ligurian Sea. What can we learn from gorgonians? Chem Ecol 24:73–82

Cerrano C, Bavestrello G, Bianchi CN, Cattaneo-Vietti R and others (2000) A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-western Mediterranean), summer 1999. Ecol Lett 3:284–293

Cerrano C, Milanese M, Ponti M (2017) Diving for science — science for diving: Volunteer scuba divers support science and conservation in the Mediterranean Sea. Aquat Conserv 27:303–323

Clementi E, Pistoia J, Delrosso D, Mattia G and others (2017) Mediterranean Sea analysis and forecast (CMEMS MED-Currents V3.2 2015-2017). Copernicus Monitoring Environment Marine Service (CMEMS) https://dx.doi.org/10.25423/CMCC/MEDSEA_ANALYSIS_FORECAST_PHY_006_013
Coma R, Ribes M, Serrano E, Jiménez E, Salat J, Pascual J (2009) Global warming-enhanced stratification and mass mortality events in the Mediterranean. Proc Natl Acad Sci USA 106:6176−6181
Di Camillo CG, Ponti M, Bavestrello G, Krzelj M, Cerrano C (2018) Building a baseline for habitat-forming corals by a multi-source approach, including Web Ecological Knowledge. Biodivers Conserv 27:1257−1276
Garrabou J, Coma R, Bensoussan N, Bally M and others (2009) Mass mortality in northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. Glob Change Biol 15:1090−1103
Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD (2002) Climate warming and disease risks for terrestrial and marine biota. Science 296:2158−2162
La Rivière M, Garrabou J, Bally M (2015) Evidence for host specificity among dominant bacterial symbionts in temperate gorgonian corals. Coral Reefs 34:1087−1098
Maynard J, van Hooidonk R, Harvell CD, Eakin CM and others (2016) Improving marine disease surveillance through sea temperature monitoring, outlooks and projections. Philos Trans R Soc B 371:20150208
Micheli F, Halpern BS, Walbridge S, Ciriaco S and others (2013) Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: assessing current pressures and opportunities. PLOS ONE 8:e79889
Ponti M, Perlini RA, Ventra V, Grech D, Abbiati M, Cerrano C (2014) Ecological shifts in Mediterranean coralligenous assemblages related to gorgonian forest loss. PLOS ONE 9:e102782
Ponti M, Grech D, Mori M, Perlini RA, Ventra V, Panzalis PA, Cerrano C (2016) The role of gorgonians on the diversity of vagile benthic fauna in Mediterranean rocky habitats. Mar Biol 163:1−14
Ponti M, Turicchia E, Ferro F, Cerrano C, Abbiati M (2018) The understorey of gorgonian forests in mesophotic temperate reefs. Aquat Conserv
R Core Team (2018) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. www.R-project.org
Rivetti I, Fraschetti S, Lionello P, Zambianchi E, Boero F (2014) Global warming and mass mortalities of benthic invertebrates in the Mediterranean Sea. PLOS ONE 9:e115655
Rubio-Portillo E, Izquierdo-Muñoz A, Gago JF, Rosselló-Mora R, Antón J, Ramos-Esplá AA (2016) Effects of the 2015 heat wave on benthic invertebrates in the Tabarca marine protected area (southeast Spain). Mar Environ Res 122:135−142
Simoncelli S, Fratianni C, Pinardi N, Grandi A, Drudi M, Oddo P, Dobricic S (2014) Mediterranean Sea physical reanalysis (MEDREA 1987-2015) (Version 1). Copernicus Monitoring Environment Marine Service (CMEMS) https://dx.doi.org/10.25423/medsea_reanalysis_phys_006_004
Soetaert K (2016) Oceanview: visualisation of oceanographic data and model output. R package version 1.0.4. https://cran.microsoft.com/web/packages/OceanView/index.html
Sweet MJ, Bulling MT (2017) On the importance of the microbiome and pathobiome in coral health and disease. Front Mar Sci 4:9
van de Water JAJM, Melkonian R, Voolstra CR, Junca H, Beraud E, Allemand D, Ferrier-Pagès C (2017) Comparative assessment of Mediterranean gorgonian-associated microbial communities reveals conserved core and locally variant bacteria. Microb Ecol 73:466−478
van de Water JAJM, Allemand D, Ferrier-Pagès C (2018) Host−microbe interactions in octocoral holobionts — recent advances and perspectives. Microbiome 6:64
Vezzulli L, Previati M, Pruzzo C, Marchese A, Bourne DG, Cerrano C (2010) *Vibrio* infections triggering mass mortality events in a warming Mediterranean Sea. Environ Microbiol 12:2007−2019
Work TM, Russell R, Aeby GS (2012) Tissue loss (white syndrome) in the coral *Montipora capitata* is a dynamic disease with multiple host responses and potential causes. Proc R Soc B 279:4334−4341

*Editorial responsibility: Stephen Feist, Weymouth, UK*

*Submitted: January 29, 2018; Accepted: August 22, 2018*
*Proofs received from author(s): September 25, 2018*