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BACKGROUND

Anthropogenic climate change, and global warming in particular, has strong and increasing impacts on marine ecosystems (Poloczanska et al., 2013; Halpern et al., 2015; Smale et al., 2019). The Mediterranean Sea is considered a marine biodiversity hotspot contributing to more than 7% of world's marine biodiversity including a high percentage of endemic species (Coll et al., 2010). The Mediterranean region is a climate change hotspot, where the respective impacts of warming are very pronounced and relatively well documented (Cramer et al., 2018). One of the major impacts of sea surface temperature rise in the marine coastal ecosystems is the occurrence of mass mortality events (MMEs). The first evidences of this phenomenon dated from the first half of '80 years affecting the Western Mediterranean and the Aegean Sea (Harmelin, 1984; Bavestrello and Boero, 1986; Gaino and Pronzato, 1989; Voultsiadou et al., 2011). The most impressive phenomenon happened in 1999 when an unprecedented large scale MME impacted populations of more than 30 species from different phyla along the French and Italian coasts (Cerrano et al., 2000; Perez et al., 2000). Following this event, several other large scale MMEs have been reported, along with numerous other minor ones, which are usually more restricted in geographic extend and/or number of affected species (Garrahou et al., 2009; Rivetti et al., 2014; Marbà et al., 2015; Rubio-Portillo et al., 2016, authors' personal observations). These events have generally been associated with strong and recurrent marine heat waves (Crisci et al., 2011; Kersting et al., 2013; Turicchia et al., 2018; Bensoussan et al., 2019) which are becoming more frequent globally (Smale et al., 2019).

Both field observations and future projections using Regional Coupled Models (Adloff et al., 2015; Darmaraki et al., 2019) show the increase in Mediterranean sea surface temperature, with more frequent occurrence of extreme ocean warming events. As a result, new MMEs are expected during the coming years. To date, despite the efforts, neither updated nor comprehensive information can support scientific analysis of mortality events at a Mediterranean regional scale. Such information is vital to guide management and conservation strategies that can then inform adaptive management schemes that aim to face the impacts of climate change.

MAIN GOALS

The Mass Mortality Events database (hereafter MME-T-MEDNet) is a collaborative initiative involving more than 30 research institutions from 10 Mediterranean countries including EU and non-EU countries. This initiative aims to facilitate the access to information (published in scientific journals and gray literature or still unpublished) related to Mediterranean MMEs.

The main objectives of the initiative are to:

- Assemble and standardize existing information on MMEs;
- Identify geographic gaps that need to be addressed through future monitoring and research efforts;
- Assessing species vulnerability to MMEs and identifying observation taxonomic gaps;

- Fostering the analysis of the relationship between MMEs and environmental conditions, with an emphasis on marine heat waves;
- Provide an unrestricted, open-source and easy access dataset;
- Ensure transparency and clarity regarding the origin of each dataset and adequate data citation.
- Providing information for the assessment of the impact of MMEs on the biodiversity and socio-economic activities.

METHODS

The data from the MME-T-MEDNet database is deposited at Digital CSIC, the institutional repository of the Spanish National Research Council, and can be accessed via <http://hdl.handle.net/10261/171445> (Garrahou et al., 2018). The database is also available in the T-MEDNet web platform which is devoted to tracking climate change effects in the Mediterranean Sea (<http://t-mednet.org/mass-mortality/mass-mortality-events>) where also explanations for data upload, edition, exploration and download are provided to enhance the collaborative effort in tracking MMEs in the basin.

The database was built from published records, predominantly from scientific journals and, to a smaller extent, from gray literature and technical reports. The database also benefited from previous reviews on MMEs (Rivetti et al., 2014; Marbà et al., 2015). To complete the database, we conducted a comprehensive literature search on ISI Web of Knowledge and Google Scholar using different search strategies combining the following different keywords: "mass mortality," "mortality outbreak," "necrosis," "die-off," "temperature anomaly," "warming," "climate change," "heat wave," "Mediterranean," the names of different Mediterranean basins (e.g., Adriatic, Tyrrhenian, Aegean, Ionian) and the scientific names of affected species (e.g., *Paramuricea clavata*, *Corallium rubrum*). The final date available in our literature search was June 2017. For papers dealing with MMEs, we checked the cited references. Our search focused on macro- and mega-benthic species, while neither pelagic species (marine mammals and fish) nor commercially exploited species in aquaculture (e.g., mussels) were included in the current version of the database.

Description of the Mass Mortality Database

Field observations of mass mortality events in a specific geographic location (site) are the core of the MME-T-MEDNet database. One database record corresponds to the observation of abnormal (high) values of partial and/or total mortality (usually through quantitative indicators) in one local population at one specific time (or period). Here, we consider a local population as a group of colonies or specimens/individuals of the same species (ranging from tens to thousands depending on the species) dwelling in a specific geographic location that is defined by coordinates and depth range.

For each mass mortality event, the following information (main options in parenthesis) is provided:

- Geographic position (latitude and longitude in decimal degrees, datum WGS84);
- Ecoregion (following Spalding et al., 2007), basin, country;

- Year and season of the MME;
- Depth range in meters of the MME (minimum, maximum);
- Protection level of the affected site at the time of the MME event (protected, unprotected);
- Taxa/species affected;
- Degree of impact (sampling effort and % affected individuals);
- Biotic and abiotic parameters driving the mortality (e.g., high temperature, pathogens);
- Reference (published - paper in a scientific journal, conference proceedings, technical reports, or unpublished data);
- Data availability (public, private).

To assign the protection level, we integrated the latest version of the MAPAMED database (www.mapamed.org) to the MMEs database. MAPAMED (Marine Protected Areas in the Mediterranean) is a GIS database that gathers information on marine protected areas of the Mediterranean, and more generally on sites of interest to the conservation of the marine environment.

When the geographic coordinates were not specified in the publication source, they were estimated whenever possible based on the auxiliary information provided in the publication. Some data could not be included in the database because the position estimates were inaccurate. We expect these data to be included in the MME-T-MEDNet database by the authors.

The full description of the used database fields and units used can be found both in the internet url:<http://hdl.handle.net/10261/171445> and in the database description <http://t-mednet.org/mass-mortality/mass-mortality-events>.

Data Search, Update, and Use

Different filters can be applied in the Data Explorer option from the menu bar (<http://t-mednet.info/mass-mortality/mass-mortality-events>): Species, Geographic areas (by zooming in and out), Years, Ecoregions, Depth range, Degree of impact, Protection level etc. The “Visualize all data” option button deactivates the filter allowing the visualization of all the available data. Visualization of private data is restricted to the owner of the dataset. Public data are available to download in an Excel file format. The list of references, from which the downloaded information was obtained, is also provided.

Regarding the update of the MME-T-MEDNet, the database was carefully designed to ensure full control of the contributors regarding the status of their data -private or public- as well as citation system or data edition among others. We expect private data to become public after the publication of the corresponding paper. For unpublished data, the contributors are the only ones responsible for the uploaded information to the database and warrant that they have sufficient rights to be able to make the content available under the database license.

The public dataset from the MME-T-MEDNet database will be available to contributors and registered users to use in their analyses. The citation system based on the specific License Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) (<https://creativecommons.org/licenses/by-nc-sa/4.0/>) guarantees the transparency regarding the origin of the data.

RESULTS

A total of 196 papers were analyzed, of which 64 contained relevant information for the MME-T-MEDNet database. Overall, we extracted information regarding 676 mass mortality events (one event corresponds to one species, one location and one period) observed between the years 1979 to 2017 throughout the Mediterranean Sea. These events encompassed 93 species from 9 major taxonomic groups. In order of importance: Cnidaria, Porifera, Bryozoa, Bivalvia, Chordata (Ascidiacea), Rhodophyta, Annelida, Chlorophyta, Echinodermata. The reported mass mortality events mainly concerned the Western Mediterranean ecoregion, with 55.5% of observations (i.e., Liguro-Provençal: 25.4%, Balearic: 16.6%, and Tyrrhenian: 13.5% sub-ecoregions); followed by the Adriatic Sea with 23.5%, the Aegean Sea (12.7%), and the Ionian Sea (0.4%) (**Figure 1**). It is noteworthy that most information concerns the coast of EU countries while there is almost a complete lack of reports from the southern—eastern Mediterranean coasts, from Morocco to Lebanon.

In terms of taxonomic groups, Cnidaria and Porifera accounted for 85% of the observations, with 47.4 and 37.6% of records, respectively. Mortality events for Porifera were recorded in a greater number of geographic areas compared to Cnidaria, including areas which have been historically harvested for commercial bath sponges (e.g., Aegean Sea and Tunisian Plateau/Gulf of Sidra). Other taxonomic groups such as Bryozoa, Bivalvia and Ascidiacea displayed a lower number of mortality events (**Figure 1**).

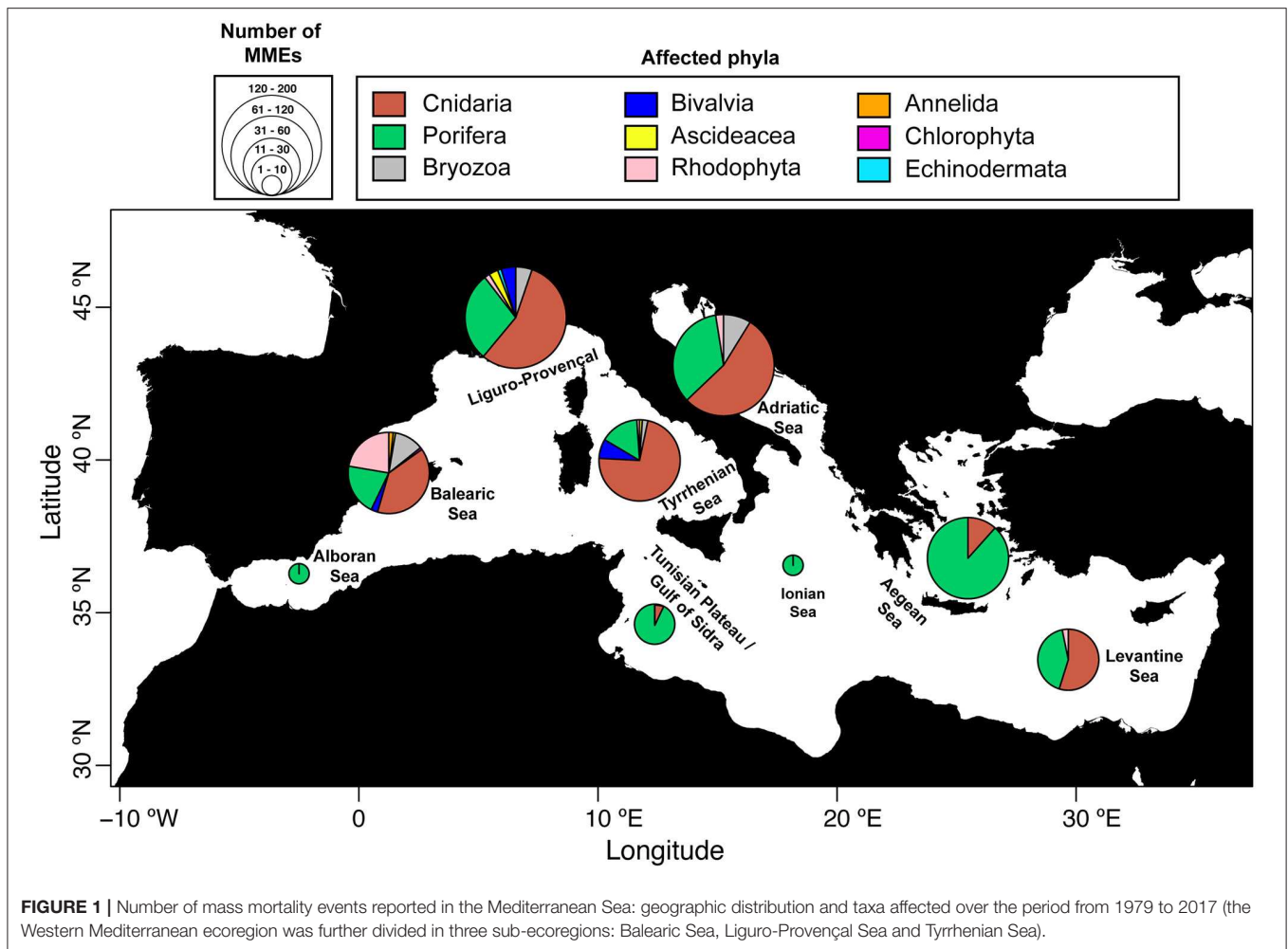
CONCLUSION

The MME-T-MEDNet collaborative effort provides a unique opportunity to map and track spatial and temporal trends of mass mortality events in the Mediterranean Sea. The database will support the analysis of relationship between thermal conditions and/or other environmental variables such as the number of marine heat wave days as well as processes possibly linked with thermal anomalies (e.g., occurrence of the proliferation of filamentous algal blooms and mucilage).

We expect researchers and managers in charge of biodiversity conservation (e.g., Marine Protected Areas, environmental agencies, etc.) to contribute with non-published observations on mass mortality events. We will also expand the collaboration through marine citizen science initiatives, in order to include datasets obtained through these initiatives after validation by the scientific community (e.g., www.observadoresdelmar.es, www.reefcheckmed.org, cs.cigesmed.eu/). This effort corresponds to the need to reinforce data and tools to support data sharing and coordinated monitoring across the Mediterranean Sea. The final goal is building a network of sentinel observatories for detecting changes across the basin.

Overall, the collaborative nature of the MME-T-MEDNet database will promote and support an updated and publicly-available dataset on MMEs across the Mediterranean Sea, especially in the non-EU regions for which the data is urgently needed.

The MME-T-MEDNet database is providing for the very first time a comprehensive dataset on reported MMEs of macro- and



mega-benthic species from Mediterranean coastal ecosystems. Most records reported in the database concern Cnidarian and Porifera species for which clear-cut signs of recent necrosis are simple to report from field observations (e.g., denuded skeletons in gorgonians and sponges, dead noble pen shell *Pinna nobilis*). However, records of mortality for other benthic species might be under-evaluated because the lack of taxonomic expertise and knowledge on necrosis signs such as in Bryozoan and Rodophyta species. Providing the resources (materials and capacity building trainings) to fill this gap of information is required to get an more complete picture of the MMEs impacts across the Mediterranean. In this sense, the T-MEDNet platform provides supplementary materials (images, documents and video tutorials) to support the implementation of standardized monitoring protocols on climate related effects in the Mediterranean Sea. Besides, the database architecture allows upgrading to include MMEs from other taxa not considered in the current version and which could be the interest of the participants joining the initiative (e.g., coastal fish species that are being reported as suffering recurrent mortalities and commercially exploited species by aquaculture).

Finally and most importantly, the web-based collaborative tools implemented in the MME-T-MEDNet database are offering a unique opportunity to have almost real-time information on the onset of MMEs at the Mediterranean scale. The information provided will be key to fuel basic research and management actions in order to support national and international conventions for the conservation of Mediterranean biodiversity.

REFERENCE TO DIGITAL REPOSITORY OF THE DATABASE

The MME-T-MEDNet databased was published in the CSIC Digital repository.

DOI: <http://dx.doi.org/10.20350/digitalCSIC/8575>.

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DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

JG conceived and designed the MME-T-MEDNet database. DG-G conducted the literature survey, and data analysis. JG wrote the first version of paper with the support of DG-G, J-BL, CL, and NB. All authors contributed in the preparation of the final version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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