Received: 22 February 2023 | Revised: 5 February 2024 | Accepted: 8 February 2024

DOI: 10.1002/aqc.4120

SHORT COMMUNICATION

WILEY

A rapid assessment method to monitor the health status of habitat-forming species in coastal benthic ecosystems

Laura Figuerola-Ferrando [1,2] | Joaquim Garrabou [3] | Cristina Linares [1,2]

[1]Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Universitat de Barcelona (UB), Barcelona, Spain

[2]Institut de Recerca de la Biodiversitat (IRBio), Universitat de Barcelona (UB), Barcelona, Spain

[3]Institut de Ciències del Mar (CSIC), Barcelona, Spain

Correspondence
Laura Figuerola-Ferrando, Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Universitat de Barcelona (UB), Barcelona, Spain.
Email: lfiguerola@ub.edu

Funding information
European Union's Horizon 2020 research and innovation programme; Ministerio de Ciencia, Innovación y Universidades; Parc Natural del Montgrí, Illes Medes i Baix Ter; Departament de Territori i Sostenibilitat, Generalitat de Catalunya; Interreg MED Program project; European Union's Horizon 2020 research and innovation programme

Abstract

1. Marine habitat-forming (MHF) species in the Mediterranean are among the most threatened coastal species by human activities. In recent decades, different stressors (e.g., warming-induced marine heatwaves and algal blooms) have caused mass mortality events in these key species. Overall, a common method to assess their health status at the Mediterranean Sea scale is lacking.
2. To fill this gap, the aim of this work is to present and validate a cost-effective method, the Mortality Rapid Assessment Method, that is able to assess the health status of key MHF species, even through Citizen Science.
3. The Mortality Rapid Assessment Method is based on determining the impact of mortality on MHF species derived from the metric percentage of affected colonies or individuals. To validate the ability of the proposed method to assess the health status, it was compared to a more commonly used but time-consuming and expert-required metric based on the injured surface percentage of the colonies or individuals. For the validation, one of the most extensive (>47,500 colonies) demographic datasets of the octocoral *Paramuricea clavata* was used to conduct a comprehensive metric comparison.
4. The results showed a highly significant correlation between metrics from both methods ($\rho = 0.86$), confirming that the percentage of affected colonies provides a reliable assessment of the health status of gorgonian populations over broad spatial and temporal scales.
5. Bearing in mind that this metric can be applied to different MHF species, such as sponges, bryozoans and calcareous algae, and by non-scientific personnel (managers and trained volunteers), its implementation can contribute to inform and enhance the effectiveness of the conservation and management plans for key MHF species at the scale of the Mediterranean Sea.

KEYWORDS

climate change, epibiosis, gorgonian, impact category, marine heatwaves, Mediterranean, mortality, necrosis, *Paramuricea clavata*

1 | INTRODUCTION

Coastal benthic ecosystems are highly diverse and productive marine environments (Seitz et al., 2014) characterized by their outstanding contribution of goods and services (Barbier et al., 2011). Nonetheless, they are significantly under threat, facing multiple stressors and cumulative impacts from human activities (Bevilacqua et al., 2020). Notably, the Mediterranean Sea, with about 20–30% of endemism (Bianchi & Morri, 2000; Coll et al., 2010), is one of the most exposed regions to anthropogenic pressures (Cramer et al., 2018; Halpern et al., 2008).

In the Mediterranean Sea, the coralligenous assemblages are among the most threatened habitats. These assemblages are endemic calcareous formations of biogenic origin in the Mediterranean produced by the accumulation of encrusting algae growing in dim light conditions, which have high ecological importance and exceptional biodiversity as they harbour approximately 10% of Mediterranean species (Ballesteros, 2006). These assemblages and the key species shaping them, marine habitat-forming (MHF) species, are subject to different synergistic stressors related to anthropogenic pressures (Di Camillo et al., 2023); mainly overharvesting, pollution, invasive species, and more recently, warming-driven mass mortality events (MMEs; Ballesteros, 2006; Bevilacqua et al., 2021; Cebrian et al., 2021, Garrabou et al., 2022b). These MMEs are associated with marine heatwaves (MHWs), which are extreme events characterized by abrupt and prolonged periods of high sea surface temperature at a particular location (Oliver et al., 2018; Scannell et al., 2016). In recent decades, MHWs have been increasing in frequency, intensity, and duration in the Mediterranean Sea, resulting in an increase in severe MMEs, especially from the surface down to 30 m depth, over large spatial scales (Darmaraki et al., 2019; Garrabou et al., 2022b). In addition, since MMEs affect a broad diversity of phyla at different spatial scales and wide depth ranges (e.g., Garrabou et al., 2009, 2022b), it is crucial to develop cost-effective methods to assess the impacts of MMEs and the health status of affected populations addressing relevant scales of observation.

Despite the ecological importance of MHF species (e.g., Ballesteros, 2006), only the response of some species and populations to global change has been addressed (e.g., Garrabou et al., 2009, 2021; Linares et al., 2005; Verdura et al., 2019). MHF species provide structural complexity that increases biodiversity and supports the associated key ecosystem services (de Ville d'Avray et al., 2019). Furthermore, these species, especially octocorals and sponges, are characterized by slow population dynamics and long lifespans, which results in a high vulnerability to natural and anthropogenic stressors (Garrabou & Harmelin, 2002; Linares et al., 2007; Montero-Serra et al., 2018a, 2019; Teixidó et al., 2011). These features highlight the urgency of establishing cost-effective methods to scale up empirical observations and accurately evaluate the impacts of climate change and other stressors on these species. This information is essential to inform and support the implementation of effective conservation and management plans.

In this context, the aim of this work is to validate the Mortality Rapid Assessment Method based on the quantification of the percentage of affected colonies or individuals, a cost-effective metric to provide a large-scale and long-term assessment of the health status of key MHF species in a rapid and easy manner. To do so, the proposed metric was compared with a more commonly used but time-consuming metric based on the quantification of the percentage of the injured surface of each of the colonies or individuals. The metric comparison is tested and validated using an extensive and representative demographic dataset of the red gorgonian (*Paramuricea clavata*), one of the most affected species by MMEs. In fact, this dataset was selected since encompassed 24 years of data and populations displaying contrasted MMEs impacts, allowing to test the ability of the Mortality Rapid Assessment Method to inform on populations health status (e.g., Garrabou et al., 2022b; Linares et al., 2008). Although the metric percentage of affected colonies or individuals, on which is based the Mortality Rapid Assessment Method, was designed and applied in gorgonian species, its applicability can be extended to other organisms (e.g., sponges, bryozoans, and calcareous algae; see Table 1) inhabiting coastal benthic ecosystems.

2 | METHODS

2.1 | Metrics to assess the health status

The percentage of injured surface (used in the traditional method to assess the health status) consists of quantifying the percentage of death tissue of each colony of the same local population by *in situ* visual scuba diving sampling. The degree of damage is assessed on a five-unit interval scale based on the total surface area of the colony or individual. It has been shown to be an effective and robust metric in determining the severity of mass mortality in several taxa (Table 1). However, it is time-consuming and expert-required, since determining the injured extend in most of MHF species is often challenging.

In contrast, the percentage of affected colonies or individuals (used in the Mortality Rapid Assessment Method) is based on the quantification of the percentage of injured colonies or individuals in the local populations (see below in the section "*Demographic dataset*" the definition of local population) by *in situ* visual scuba diving sampling.

Based on previous studies, a colony or individual was considered to be affected by mortality when it showed injuries or cover by epibionts (i.e., epibionts on the already death tissue of the colony or individual) over ≥10% of its surface (Garrabou et al., 2009, 2019; Linares et al., 2008). The affected colonies are separated into three categories that inform the timing of mortality impact: (i) recent mortality or necrosis (denuded colony axis and/or colony overgrowth by pioneer species), (ii) old mortality or epibiosis (colony overgrowth by non-pioneer species such as bryozoans, sponges, and calcareous algae), and (iii) colonies affected by both recent necrosis and epibiosis, integrating recent and past disturbance events (Figure 2; Linares et al., 2005). Thus, in both metrics, the assessment

TABLE 1 Metrics to assess the conservation status of MHF species.

Metric	Estimated sampling time (time to sample 100 colonies or individuals)	Expertise (type of personnel)	Species	References using the metric (examples)
Mean percentage of injured surface	40′ /50′	Scientific personnel	Bryozoa *Myriapora truncata* *Pentapora fascialis* Cnidaria *Corallium rubrum* *Eunicella cavolini* *Eunicella singularis* *Paramuricea clavata*	Cerrano et al., 2000; Coma et al., 2004; Linares et al., 2005; Cupido et al., 2008; Sini et al., 2015; Crisci et al., 2017; Hereu et al., 2017, 2018a,b,c, 2019, 2020a,b; Piazzi et al., 2019; Gómez-Gras et al., 2021; Zentner et al., 2023
Percentage of affected colonies	10′ /20'	Scientific and non-scientific personnel (e.g., MPA managers and trained volunteers)	Bryozoa *Adeonella calveti* *Amathia verticillata* *Calpensia nobilis* *Myriapora truncata* *Pentapora fascialis* *Reteporella grimaldii* *Schizobrachiella sanguinea* Cnidaria *Astroides calycularis* *Balanophyllia europaea*[a] *Caryophyllia inornata*[a] *Cladocora caespitosa* *C. rubrum* *Eunicella cavolini* *Eunicella singularis* *Eunicella verrucosa* *Leptogorgia sarmentosa* *Leptopsammia pruvoti*[a] *Madracis pharensis* *Oculina patagónica* *P. clavata* *Parazoanthus axinellae* Porifera *Agelas oroides*[a] *Aplysina aerophoba*[a] *Cacospongia mollior*[a] *Chondrosia reniformis*[a] *Crambe crambe*[a]	Garrabou et al., 2009, 2022a,b; Crisci et al., 2011; Sini et al., 2015; Kružić et al., 2016; Rubio-Portillo et al., 2016; Hereu et al., 2018c, 2020a; Piazzi et al., 2019; Betti et al., 2020a; Zentner et al., 2023; Figuerola-Ferrando et al., 2023 www.observadoresdelmar.es

(Continues)

TABLE 1 (Continued)

Metric	Estimated sampling time (time to sample 100 colonies or individuals)	Expertise (type of personnel)	Species	References using the metric (examples)
			Hippospongia comunis[a]	
			Ircinia variabilis[a]	
			Sarcotragus foetidus[a]	
			Sarcotragus faciculatus[a]	
			Spongia lamella[a]	
			Spongia officinalis[a]	
			Rhodophyta	
			Lithophyllum incrustans[a]	
			Lithophyllum stictaeforme[a]	
			Mesophyllum alternans[a]	
			Peyssonellia sp[a]	

Note: The estimated sampling time is based on expert knowledge and refers to the time that a SCUBA diver takes to sample 100 colonies or individuals by visual sampling in each metric. Expertise (skilled personnel able to apply the metrics in the sampling) and examples of references using each metric are also shown.

[a]Individual species that not form a colony.

can be conducted for recent mortality, old mortality, or both (see below in the section "*Metrics comparison*").

The Mortality Rapid Assessment Method has been used as an easily implemented metric to assess the general health status of populations from different MHF species (Table 1). Moreover, it has been performed not only by scientists but also by non-scientific personnel such as managers of marine protected areas and trained volunteers through marine citizen science initiatives (see Figuerola-Ferrando et al., 2023; Table 1). To facilitate its application in conservation and management, the percentage of affected colonies or individuals can be translated into a MMEs severity category to easily determine the health status of each population (Garrabou et al., 2022b; Linares et al., 2008) and inform managers or other stakeholders. Four severity classes were defined according to the percentage of affected colonies/individuals: non-impact populations (<10% of affected colonies/individuals), low-impact populations (≥10 and <30% of affected colonies/individuals), moderate-impact populations (≥30 and <60% of affected colonies/individuals), and severely impact populations (≥60% of affected colonies/individuals).

2.2 | Demographic dataset

Information from both metrics, (i) percentage of injured surface and (ii) percentage of affected colonies, was collected by experts during different sampling campaigns. This dataset includes a total of 47,523 *P. clavata* colonies dwelling in seven north-western Mediterranean locations and 59 sites encompassing large latitudinal (from 38 to 43°N) and longitudinal (from 0 to 9°E) ranges sampled between 1998 and 2021 (Figure 1, Table 2). These locations (i.e., general monitoring areas) are characterized by contrasting temperature regimes (Bensoussan et al., 2010), and during the studied period, the different sites (i.e., specific sampling areas within locations) underwent contrasting local MMEs, potentially leading to distinct levels of injury among the inhabiting populations (Garrabou et al., 2022b).

Following Garrabou et al. (2019), a local population was considered as a group of colonies, individuals, or cover of the same species (ranging from tens to thousands depending on the species) dwelling in a specific geographic location defined by spatial coordinates and depth range until they are no longer present. Based on genetic studies, local populations are separated by no more than 20 metres, without genetic connectivity between them (Mokhtar-Jamaï et al., 2011). Note that at the same geographic location, several records for the same species from different years and depth ranges can be obtained, as depth-related gradients (e.g., temperature, disturbance intensity, light, or food availability; see Montero-Serra et al., 2018b) drive a vertical disconnection, generating different local populations.

2.3 | Metrics comparison

To validate the effectiveness of the percentage of affected colonies approach, the values of both metrics from each local population of the

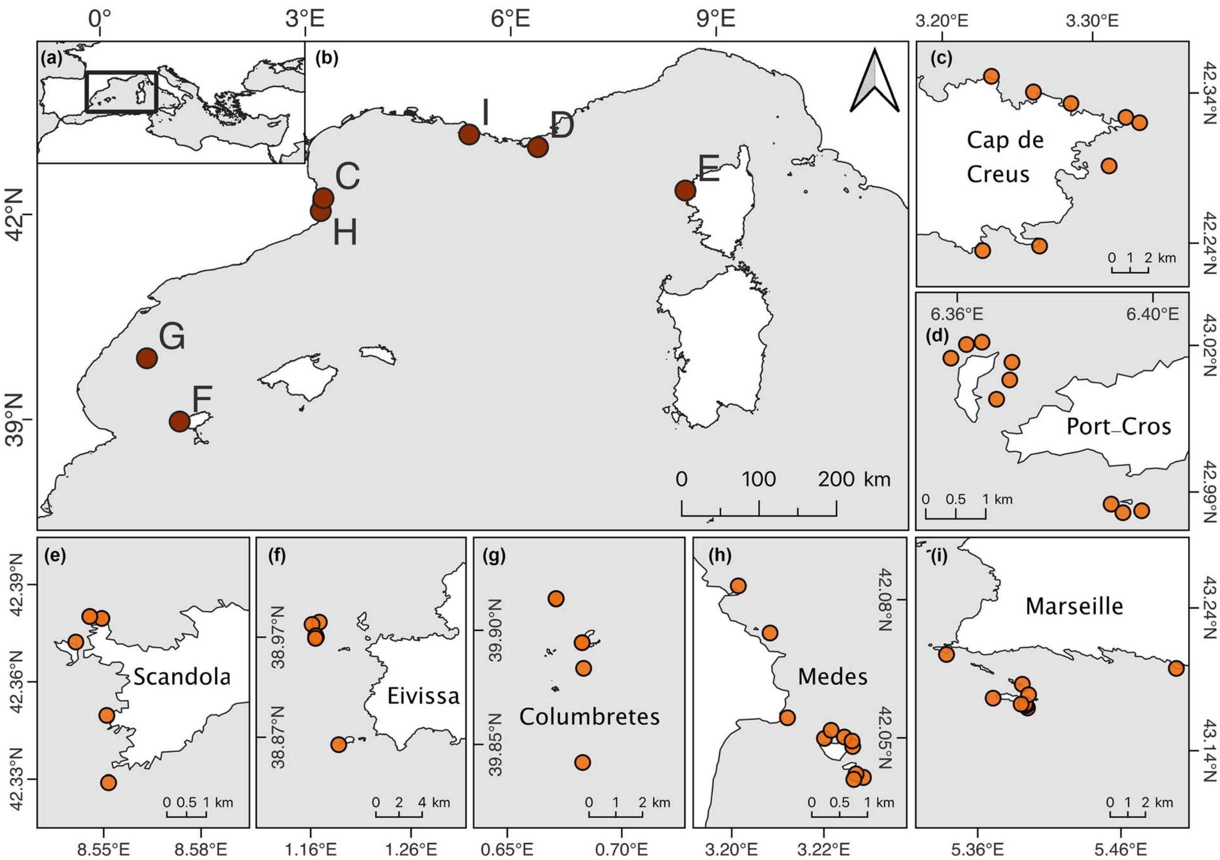

FIGURE 1 General location of the study area in the Mediterranean Sea (a). Study locations in the northwestern Mediterranean (b). Specific sample sites in each location of Cap de Creus (c), Port-Cros (d), Scandola (e), Eivissa (f), Columbretes (g), Medes (h), and Marseille (i) in which both metrics are extracted. Geographic scale and local specific coordinates are indicated for the Western Mediterranean (B) and in each location (c – i) in decimal degrees. Note than sites may overlap on the map (see the number of sites per locations in Table 2).

demographic dataset, obtained by experts, were correlated using Spearman's rank correlation. First, the comparison was performed pooling together all mortality types, and second, only recent mortality data, in all locations together and separately. Note that in recent mortality correlations, locations displaying low sample sizes (mean number of mortalities per site and year <10) were removed from the analysis.

3 | RESULTS

Approximately one-third of the *P. clavata* colonies showed mortality (17,639), including recent injuries (3089 colonies; Table 2). The percentage of affected colonies was significantly positively correlated with the mean percentage of injured surface including old and recent mortality ($\rho = 0.86$, $p < 0.001$) and considering only recent mortality ($\rho = 0.95$, $p < 0.001$; Figure 3; Sup Table S1 and S2). The narrow range between the confidence intervals (0.83–0.89 in all mortality; 0.93–0.96 in recent mortality; Tables S1 and S2) revealed few uncertainties in the correlation prediction. However, the range of the mean percentage of injured surface values increased as the impact category worsened (i.e., moderate and severe categories) because of the low sample size and few or no populations reaching values between 75% and 100% of the mean injured surface, especially with regard to the recent mortality correlations (Figure 3). It is noteworthy that most of the recent mortality values (Figure 3b) are below 25% of the mean injured surface, only exceeded by a value of 46.2% corresponding to one of the most affected sites in the Medes Islands during the 2018 MHW (see www.t-mednet.org), which resulted in a severely impacted population (76.7% of the colonies affected; see Figure S2).

Additionally, Spearman's rank correlation coefficients showed strong correlations at all locations for both, all mortality (ranging from $\rho = 0.89$ to $\rho = 0.96$), and recent mortality datasets ($\rho = 0.96$ to $\rho = 0.98$; Supplementary Figure S2 and Table S2). Although the confidence intervals varied slightly by location, ranging from narrower (e.g., Medes: 0.93–0.97) to wider (e.g., Eivissa: 0.76–0.98; Table S1), the correlation remained consistently strong. The locations exhibiting the highest levels of affection were Columbretes (mean injured surface of 92%, and 96% of affected colonies), Scandola (mean injured surface of 86%, and 93% of affected colonies), and Cap de Creus (mean injured surface of 72%, and 100% of affected colonies; Figure S2A).

Among the studied *P. clavata* populations, the moderate impact category was the most prevalent category (45% of the affected

TABLE 2 Information of the sampling localities of the studied populations, including the number of sites per locality, depth range (in meters), sampling period (in years), total number of *Paramuricea clavata* monitored colonies, and total number of *P. clavata* affected colonies ("All": all mortality including recent and old mortality; and "Recent": only recent mortality data) in which information of both metrics are extracted.

Locality	Sites (n)	Depth range (m)	Sampling period (years)	Total monitored colonies	Total affected colonies (all/recent)
Cap de Creus (Cap de Creus Natural Park, Spain)	8	16–32	2017, 2019, 2021	3855	1843/574
Columbretes (Columbretes Islands Marine Reserve, Spain)	8	31–43	2001, 2004, 2008, 2009, 2011, 2021	1573	736/16
Eivissa (Nature reserves of Es Vedrà, Es Vedranell and the Illots de Ponent, Spain)	7	30–55	2010, 2016, 2021	2254	837/279
Medes (Natural Park of Montgrí, les Illes Medes i el Baix Ter, Spain)	11	14–22	2016–2021	9140	4363/1394
Marseille (Parc National des Calanques, France)	11	8–36	1998, 2000–2006, 2020	13,417	4477/759
Port – Cros (National Parc of Port-Cros, France)	9	20	1999–2003, 2005–2009	9579	2968
Scandola (Scandola Marine Protected Area, France)	5	21–25	2003–2011, 2017, 2020	7705	2415/67
TOTAL	**59**	**8–55**	**1998–2021**	**47,523**	**17,639/3089**

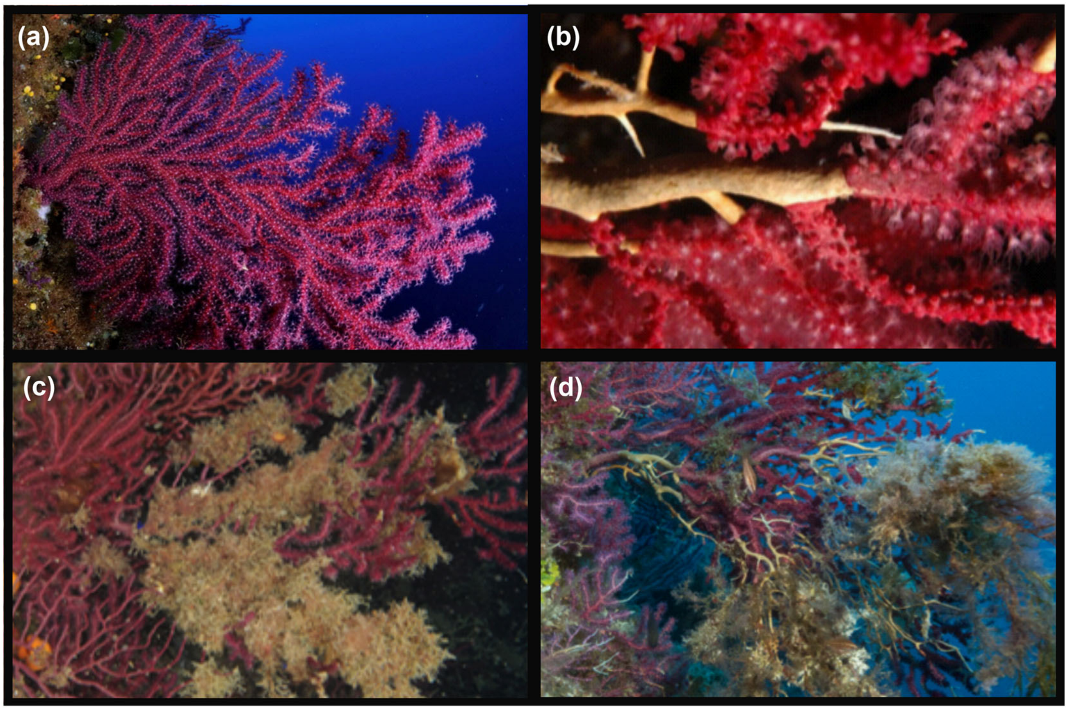

FIGURE 2 Red gorgonian (*Paramuricea clavata*) colonies in a good health status (a) and varying injuries: recent mortality (necrosis; b), old mortality (epibiosis; c), and recent and old mortality (necrosis and epibiosis; d). All images are from MedRecover research group.

populations), followed by the low impacted category (29% of the affected populations). In contrast, the severe and non-impacted categories were less frequently observed (19% and 7% of the affected populations, respectively). Regarding recent mortality, the non-impacted and low impacted categories included the majority of the studied populations (58% and 31%, respectively), leaving only a 10% of the populations with moderate impact, and 1% with severe impact categories (Figure 3).

4 | DISCUSSION

This study validated the Mortality Rapid Assessment Method as a reliable and cost-effective approach to assess the health status of the red gorgonian *P. clavata* populations that can be extended to other MHF species. Furthermore, the definition of four health status impact categories derived from the method offers valuable insights for the design and implementation of conservation and management plans.

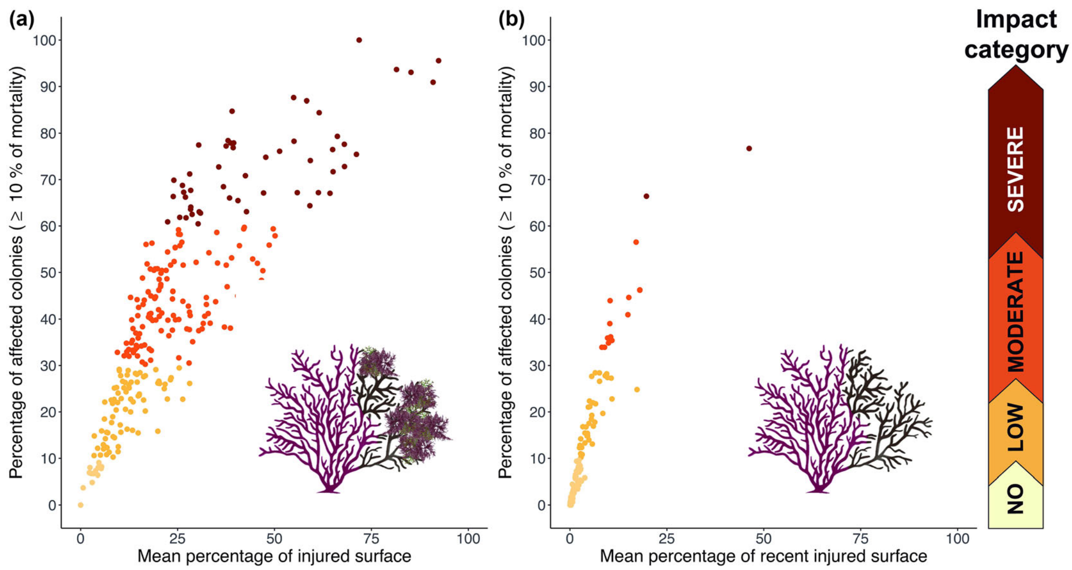

FIGURE 3 Correlation between the metric mean percentage of injured surface and the metric percentage of affected colonies, for all mortality (a; Spearman's rank correlation ρ = 0.86, $p < 0.001$) and recent mortality (b; Spearman's rank correlation ρ = 0.95, $p < 0.001$; see Table S1 and S2 for details). Points represent the mean mortality value of each location, site, and year. Impact category is represented by a colour scale, from light to dark according to the percentage of affected colonies; non-impact populations (<10% of affected colonies), low-impact populations (≥10 and <30% of affected colonies), moderate-impact populations (≥30 and <60% of affected colonies), and severely impact populations (≥60% of affected colonies).

4.1 | High correlation between metrics

A significant positive correlation between both metrics (i.e., the percentage of affected colonies, and the percentage of injured surface) was revealed when considering all mortality and recent mortality. In addition, the relationship between the two metrics is consistent and robust regardless of the location. Bearing in mind the history of MMEs (see www.t-mednet.org), the warmest locations that had suffered more, such as Columbretes, showed higher maximum values in the mean percentage of injured surface and larger confidence intervals compared to less affected locations. These small differences among locations—which do not impact the correlation between the metrics—only reinforce the variability within Mediterranean locations linked to recurrent MMEs with different intensities and periods of recovery, in addition to the impacts of other regional and local stressors such as storms, fishing gears, and diving frequency, among others.

4.2 | Assessing immediate and long-term impacts on MHF species

The proposed metric disaggregates immediate and past disturbance events that can occur at both local and regional scales. These disturbances include filamentous and mucilaginous algal blooms (Berdalet et al., 2017; Cerrano & Bavestrello, 2008; Piazzi et al., 2018), diving frequentation (Linares & Doak, 2010), storms (Teixidó et al., 2013), fishing gear (Betti et al., 2020b), and MHWs (Garrabou et al., 2022b), causing injuries in gorgonians and other species. When examining the recent mortality data in the studied *P. clavata* populations, the underlying disturbances led to minor effects on the total percentage of affected colonies. This resulted in populations mostly categorized as non-impacted or low-impacted by recent mortality. Thus, the remaining impact primarily steamed from populations with recurrent disturbances. These results are in line with previous studies (Cerrano et al., 2005; Linares et al., 2005). However, the recent increase in MHWs frequency and intensity (Garrabou et al., 2022b), characterized as one of the main impacts on gorgonian populations, coupled with other global and local stressors (e.g., Zentner et al., 2023), could cause changes in these relationships, increasing the percentage of recent injuries to the affected gorgonian populations (Estaque et al., 2023).

4.3 | Potential application to other species and beyond

Assessing the conservation status of different species is particularly challenging, especially when integrating recent and past mortalities. Given that some MHF species are differentially affected by warming-related as well as to other disturbances (Bevilacqua et al., 2021; Cerrano et al., 2000; Garrabou et al., 2009; Garrabou et al., 2022b; Linares et al., 2007; Perez et al., 2000), the studied metric could be applied to other MHF species, especially sessile invertebrates from rocky coastal benthic ecosystems. In fact, to date, the metric percentage of affected colonies/individuals has been successfully implemented in other octocoral species (e.g., *Eunicella cavolini*, *E. singularis*, *Leptogorgia sarmentosa*, and *Corallium rubrum*), hexacorals (e.g., *Balanophyllia europaea*, *Cladocora caespitosa*, *Leptopsammia pruvoti*, *Madracis pharencis*, and *Oculina patagonica*), porifera (e.g., *Agelas oroides*, *Crambe crambe*, and *Sarcotragus fasciculatus*), and in the calcareous algae from the phylum Rhodophyta (e.g., *Lithophyllum stictaeforme* and *Mesohphyllum alternans*; see the completed list of species and references in Table 1). However, in some species, the assessment is reduced only to partial and total recent mortality without distinguishing between recent and old injuries. For example, in sponges, the dead "skeleton" is only apparent *in situ* for short periods of time (approximately 1 month depending on sea conditions) before being detached from the substratum (Cebrian et al., 2011; Smith, 1941; Wulff, 2006). Eventually, this limitation hinders our ability to accurately assess the impacts of past MMEs not only on sponges but also on other species for which the affected tissues do not remain for long periods after the disturbance, as observed in the case of gorgonians.

Taken together, these findings demonstrate that the percentage of affected colonies or individuals provides robust information for assessing the health status not only of red gorgonian populations but also of other MHF species from coralligenous assemblages and beyond. In addition, the applications of this metric made by non-scientific personnel (such as managers of marine protected areas and trained volunteers through marine citizen science, which undergo training and specific recommendations including a minimum of logged dives; e.g., 40 dives, see Figuerola-Ferrando et al., 2023; Garrabou et al., 2022a, for details), are reliable and can help to expand our scales of observation, complementing more complex and time-consuming methodologies implemented by research teams. These methodologies encompass various metrics, including colony/individual size, diameter, and injured surface, population size structure, and density. The integration of combined metrics will gain a more comprehensive understanding of the health status of coralligenous assemblages' populations and their MHF species (see Di Camillo et al., 2023) in light of the dramatic increase in the intensity and recurrence of MHWs and other disturbances.

4.4 | Insights for management and conservation

As important as unravelling a population's conservation status are the implications of this metric for conservation and management planning at global and local scales. In this context, coralligenous assemblages were considered a priority habitat in the European Marine Strategy Framework Directive (MSFD; 2008/56/EC) and the Integrated Monitoring Assessment Programme IMAP from the Barcelona Convention (UNEP/MAP, 2017)—both aiming to improve the Good Environmental Status (GES) of the seas. In recent decades, conservation planning in benthic ecosystems has increasingly embraced rapid assessment and effective monitoring tools from single to multiple species, communities, or habitats (e.g., Alquezar & Boyd, 2007; Parravicini et al., 2010). This underscores the potential effectiveness of the Mortality Rapid Assessment Method (i.e., applying the percentage of affected colonies or individual's metric and translating the information into an impact category) in contributing to the GES quantification of habitats by covering broad spatial, temporal, and taxonomic scales. Notably, the impact category assessment given by the percentage of affected colonies/individuals acts as a baseline for an overview of the responses of MHF species to global warming and other drivers of habitat degradation, supporting adaptive management in coastal areas, specifically local-scale management in marine protected areas (MPAs). For example, identifying areas or species with worsened population health status. In this context, the impact category assessment can support the regulation to reduce the impact of other local stressors to enhance the long-term viability of populations, such as high diver frequentation in MPAs, where there is synergic positive interaction between local and marine heatwave impacts (Zentner et al., 2023).

AUTHOR CONTRIBUTIONS

Cristina Linares and Joaquim Garrabou conceptualized the main idea of the manuscript; investigated; and provided funding acquisition for the study. Laura Figuerola-Ferrando conceptualized the study; performed formal analysis; investigated; prepared visualizations; wrote—original draft of the manuscript; and wrote—review and editing, along with the contributions from all coauthors.

ACKNOWLEDGMENTS

We acknowledge the support of all the people that helped us with the field surveys in the different locations during all the years. We also acknowledge Núria Margarit for the illustrations in the Figure 3. This research has been partially funded and supported by CORFUN project TED2021-131622B-I00 funded by Ministerio de Ciencia, Innovación y Universidades (MCIN/AEI/10.13039/501100011033) and European Union "NextGenerationEU"/PRTR, the HEATMED project RTI2018-095346-BI00 funded by MCIU/AEI/FEDER, the "Parc Natural del Montgrí, Illes Medes i Baix Ter" and the "Departament de Territori i Sostenibilitat, Generalitat de Catalunya" project (PTOP-2017-130 and PTOP-2021-3), Interreg MED Program project (MPA-Engage - Ref: 5216|5MED18_3.2_M23_007) and the European Union's Horizon 2020 research and innovation programme (grant SEP-210597628—FutureMARES). JG acknowledge the funding of the Spanish government through the 'Severo Ochoa Centre of Excellence' accreditation (CEX2019-000928-S). CL gratefully acknowledges the financial support by ICREA under the ICREA Academia program. LF was supported by FI SDUR grant (2020 FISDU 00482) from the "Generalitat de Catalunya." The authors are part of the Marine Conservation research group - MedRecover (2021 SGR 01073) from the "Generalitat de Catalunya."

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Laura Figuerola-Ferrando https://orcid.org/0000-0003-3323-544X
Joaquim Garrabou https://orcid.org/0000-0001-9900-7277
Cristina Linares https://orcid.org/0000-0003-3855-2743

REFERENCES

Alquezar, R. & Boyd, W. (2007). Development of rapid, cost effective coral survey techniques: tools for management and conservation planning. *Journal of Coastal Conservation*, 11(2), 105–119. https://doi.org/10.1007/s11852-008-0011-1

Ballesteros, E. (2006). Mediterranean coralligenous assemblages: a synthesis of present knowledge. *Oceanography and Marine Biology*, 44, 123–195. https://doi.org/10.1201/9781420006391-7

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. & Silliman, B.R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169–193. https://doi.org/10.1890/10-1510.1

Bensoussan, N., Romano, J.C., Harmelin, J.G. & Garrabou, J. (2010). High resolution characterization of Northwest Mediterranean coastal waters thermal regimes: to better understand responses of benthic communities to climate change. *Estuarine, Coastal and Shelf Science*, 87(3), 431–441. https://doi.org/10.1016/j.ecss.2010.01.008

Berdalet, E., Tester, P.A., Chinain, M., Fraga, S., Lemée, R., Litaker, W. et al. (2017). Harmful algal blooms in benthic systems: recent progress and future research. *Oceanography*, 30(1), 36–45. https://doi.org/10.5670/oceanog.2017.108

Betti, F., Bavestrello, G., Bo, M., Enrichetti, F. & Cattaneo-Vietti, R. (2020a). Effects of the 2018 exceptional storm on the Paramuricea clavata (Anthozoa, Octocorallia) population of the Portofino promontory (Mediterranean Sea). *Regional Studies in Marine Science*, 34, 101037. https://doi.org/10.1016/j.rsma.2019.101037

Betti, F., Bavestrello, G., Bo, M., Ravanetti, G., Enrichetti, F., Coppari, M. et al. (2020b). Evidences of fishing impact on the coastal gorgonian forests inside the Portofino MPA (NW Mediterranean Sea). *Ocean and Coastal Management*, 187, 105105. https://doi.org/10.1016/j.ocecoaman.2020.105105

Bevilacqua, S., Airoldi, L., Ballesteros, E., Benedetti-Cecchi, L., Boero, F., Bulleri, F. et al. (2021). Mediterranean rocky reefs in the Anthropocene: present status and future concerns. *Advances in Marine Biology*, 89, 1–51. https://doi.org/10.1016/bs.amb.2021.08.001

Bevilacqua, S., Katsanevakis, S., Micheli, F., Sala, E., Rilov, G., Sarà, G. et al. (2020). The status of coastal benthic ecosystems in the Mediterranean Sea: evidence from ecological indicators, 7, 475. *Frontiers in Marine Science*, 7. https://doi.org/10.3389/fmars.2020.00475

Bianchi, C.N. & Morri, C. (2000). Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. *Marine Pollution Bulletin*, 40(5), 367–376. https://doi.org/10.1016/S0025-326X(00)00027-8

Cebrian, E., Linares, C. & Garrabou, J. (2021). Warming may increase the vulnerability of calcareous algae to bioinvasions. *Marine Pollution Bulletin*, 173, 113099. https://doi.org/10.1016/j.marpolbul.2021.113099

Cebrian, E., Uriz, M.J., Garrabou, J. & Ballesteros, E. (2011). Sponge mass mortalities in a warming Mediterranean Sea: are cyanobacteria-harboring species worse off? *PLoS ONE*, 6(6), e20211. https://doi.org/10.1371/journal.pone.0020211

Cerrano, C., Arillo, A., Azzini, F., Calcinai, B., Castellano, L., Muti, C. et al. (2005). Gorgonian population recovery after a mass mortality event. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 15(2), 147–157. https://doi.org/10.1002/aqc.661

Cerrano, C. & Bavestrello, G. (2008). Medium-term effects of die-off of rocky benthos in the Ligurian Sea. What can we learn from gorgonians? *Chemistry and Ecology*, 24(SUPPL. 1). https://doi.org/10.1080/02757540801979648

Cerrano, C., Bavestrello, G., Bianchi, C.N., Cattaneo-Vietti, R., Bava, S., Morganti, C. et al. (2000). A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-Western Mediterranean), summer 1999. *Ecology Letters*, 3(4), 284–293. https://doi.org/10.1046/j.1461-0248.2000.00152.x

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F.B.R., Aguzzi, J. et al. (2010). The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS ONE*, 5(8), e11842. https://doi.org/10.1371/journal.pone.0011842

Coma, R., Pola, E., Ribes, M. & Zabala, M. (2004). Long-term assessment of temperate octocoral mortality patterns, protected vs. unprotected areas. *Ecological Applications*, 14(5), 1466–1478. https://doi.org/10.1890/03-5176

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.P., Iglesias, A. et al. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, 8(11), 972–980. https://doi.org/10.1038/s41558-018-0299-2

Crisci, C., Bensoussan, N., Romano, J.C. & Garrabou, J. (2011). Temperature anomalies and mortality events in marine communities: insights on factors behind differential mortality impacts in the NW Mediterranean. *PLoS ONE*, 6(9), e23814. https://doi.org/10.1371/journal.pone.0023814

Crisci, C., Ledoux, J.B., Mokhtar-Jamaï, K., Bally, M., Bensoussan, N., Aurelle, D. et al. (2017). Regional and local environmental conditions do not shape the response to warming of a marine habitat-forming species. *Scientific Reports*, 7(1), 1–13. https://doi.org/10.1038/s41598-017-05220-4

Cupido, R., Cocito, S., Sgorbini, S., Bordone, A. & Santangelo, G. (2008). Response of a gorgonian (*Paramuricea clavata*) population to mortality events: recovery or loss? *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18(6). https://doi.org/10.1002/aqc.904

Darmaraki, S., Somot, S., Sevault, F., Nabat, P., Cabos Narvaez, W.D., Cavicchia, L. et al. (2019). Future evolution of marine heatwaves in the Mediterranean Sea. *Climate Dynamics*, 53(3–4), 1371–1392. https://doi.org/10.1007/s00382-019-04661-z

de Ville d'Avray, L.T., Ami, D., Chenuil, A., David, R. & Féral, J.P. (2019). Application of the ecosystem service concept at a small-scale: the cases of coralligenous habitats in the North-Western Mediterranean Sea. *Marine Pollution Bulletin*, 138, 160–170. https://doi.org/10.1016/j.marpolbul.2018.10.057

Di Camillo, C.G., Ponti, M., Storari, A., Scarpa, C., Roveta, C., Pulido Mantas, T. et al. (2023). Review of the indexes to assess the ecological quality of coralligenous reefs: towards a unified approach. Frontiers in marine. *Science*, 10, 1252969. doi, https://doi.org/10.3389/fmars.2023.1252969

Estaque, T., Richaume, J., Bianchimani, O., Schull, Q., Mérigot, B., Bensoussan, N. et al. (2023). Marine heatwaves on the rise: one of the strongest ever observed mass mortality event in temperate gorgonians. *Global Change Biology*, 29(22), 6159–6162. https://doi.org/10.1111/gcb.16931

Figuerola-Ferrando, L., Linares, C., Zentner, Y., López-Sendino, P. & Garrabou, J. (2023). Marine citizen science and the conservation of Mediterranean corals: the relevance of training, expert validation, and robust sampling protocols. *Environmental Management*. https://doi.org/10.1007/s00267-023-01913-x

Garrabou, J., Bensoussan, N., Di Franco, A., Boada, J., Cebrian, E., Santamaria, J. et al. (2022a). *Monitoring climate-related responses in Mediterranean marine protected areas and beyond: eleven standard protocols*, Barcelona, Spain: Institute of Marine Sciences, Spanish Research Council ICM-CSIC, p. 74. https://doi.org/10.20350/digitalCSIC/14672

Garrabou, J., Coma, R., Bensoussan, N., Bally, M., Chevaldonné, P., Cigliano, M. et al. (2009). Mass mortality in northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. *Global Change Biology*, 15(5), 1090–1103. https://doi.org/10.1111/j.1365-2486.2008.01823.x

Garrabou, J., Gómez-Gras, D., Ledoux, J.B., Linares, C., Bensoussan, N., López-Sendino, P. et al. (2019). Collaborative database to track mass mortality events in the Mediterranean Sea. *Frontiers in Marine Science*, 6, 707. https://doi.org/10.3389/fmars.2019.00707

Garrabou, J., Gómez-Gras, D., Medrano, A., Cerrano, C., Ponti, M., Schlegel, R. et al. (2022b). Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. *Global Change Biology*, 28(19), 5708–5725. https://doi.org/10.1111/gcb.16301

Garrabou, J. & Harmelin, J.G. (2002). A 20-year study on life-history traits of a harvested long-lived temperate coral in the NW Mediterranean: insights into conservation and management needs. *Journal of Animal Ecology*, 71(6), 966–978. https://doi.org/10.1046/j.1365-2656.2002.00661.x

Garrabou, J., Ledoux, J.-B., Bensoussan, N., Gómez-Gras, D. & Linares, C. (2021). Sliding Toward the of Mediterranean Coastal Marine Rocky Ecosystems. In: *Ecosystem collapse and climate change*. Cham: Springer, pp. 291–324.

Gómez-Gras, D., Linares, C., Dornelas, M., Madin, J.S., Brambilla, V., Ledoux, J.B. et al. (2021). Climate change transforms the functional identity of Mediterranean coralligenous assemblages. *Ecology Letters*, 24(5), 1038–1051. https://doi.org/10.1111/ele.13718

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C. et al. (2008). A global map of human impact on marine ecosystems. *Science*, 319(5865). https://doi.org/10.1126/science.1149345

Hereu, B., Aspillaga, E., Boada, J., Capdevila, P., Medrano, A., Pagès, M. et al. (2018c). *Seguiment del medi marí al parc natural de cap de Creus i al parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2018*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals i Medi Natural. pp. 232.

Hereu, B., Aspillaga, E., Capdevila, P., Linares, C., Medrano, A., Montero, I. et al. (2017). *Seguiment anual de Briozous, Gorgònia vermella i coves a la Reserva natural Parcial Marina de les Medes del parc natural del Montgrí, les illes Medes i el Baix Ter. Any 2017*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals

Hereu, B., Aspillaga, E., Capdevila, P., Linares, C., Medrano, A., Pagès, M. et al. (2018a). *Seguiment anual de briozous, gorgònia vermella i coves a la Reserva natural Parcial Marina de les Medes del parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2018*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals. pp. 76.

Hereu, B., Aspillaga, E., Capdevila, P., Rovira, G., Garrabou, J., López-Sanz, A. et al. (2018b). *Seguiment del medi marí al parc natural de cap de Creus i al parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2017*, Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals i Medi Natural. pp. 198.

Hereu, B., Aspillaga, E., Casals, D., Ortega, J., Pérez, M., Mascaró, O. et al. (2020a). *Seguiment del medi marí al parc natural de cap de Creus i al parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2020*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals i Medi Natural. pp. 242.

Hereu, B., Casals, D., Linares, C., Margarit, N., Ortega, J. & Rovira, G. (2019). *Seguiment anual de briozous, gorgònia vermella i coves a la Reserva natural Parcial Marina de les Medes del parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2019*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals. pp. 80.

Hereu, B., Casals, D., Ortega, J., Rovira, G. & Linares, C. (2020b). *Seguiment del medi marí al parc natural de cap de Creus i al parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2019*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals i Medi Natural. pp. 168.

Hereu, B., Rovira, G., Casals, D., Ortega, J., Margarit, N., Medrano, A. et al. (2020c). *Seguiment anual de briozous, gorgònia vermella i coves a la Reserva natural Parcial Marina de les Medes del parc natural del Montgrí, les Illes Medes i el Baix Ter. Memòria 2020*. Generalitat de Catalunya: Departament de Territori i Sostenibilitat. Direcció General de Polítiques Ambientals i Medi Natural. pp. 96.

Kružić, P., Rodić, P., Popijač, A. & Sertić, M. (2016). Impacts of temperature anomalies on mortality of benthic organisms in the Adriatic Sea. *Marine Ecology*, 37(6), 1190–1209. https://doi.org/10.1111/maec.12293

Linares, C., Coma, R., Diaz, D., Zabala, M., Hereu, B. & Dantart, L. (2005). Immediate and delayed effects of a mass mortality event on gorgonian population dynamics and benthic community structure in the NW Mediterranean Sea. *Marine Ecology Progress Series*, 305, 127–137. https://doi.org/10.3354/meps305127

Linares, C., Coma, R., Garrabou, J., Díaz, D. & Zabala, M. (2008). Size distribution, density and disturbance in two Mediterranean gorgonians: *Paramuricea clavata* and *Eunicella singularis*. *Journal of Applied Ecology*, 45(2), 688–699. https://doi.org/10.1111/j.1365-2664.2007.01419.x

Linares, C. & Doak, D.F. (2010). Forecasting the combined effects of disparate disturbances on the persistence of long-lived gorgonians: a case study of *Paramuricea clavata*. *Marine Ecology Progress Series*, 402, 59–68. https://doi.org/10.3354/meps08437

Linares, C., Doak, D.F., Coma, R., Díaz, D. & Zabala, M. (2007). Life history and viability of a long-lived marine invertebrate: the octocoral *Paramuricea clavata*. *Ecology*, 88(4), 918–928. https://doi.org/10.1890/05-1931

Mokhtar-Jamaï, K., Pascual, M., Ledoux, J.B., Coma, R., Féral, J.P., Garrabou, J. et al. (2011). From global to local genetic structuring in the red gorgonian *Paramuricea clavata*: the interplay between oceanographic conditions and limited larval dispersal. *Molecular Ecology*, 20(16), 3291–3305. doi, https://doi.org/10.1111/j.1365-294X.2011.05176.x

Montero-Serra, I., Garrabou, J., Doak, D.F., Figuerola, L., Hereu, B., Ledoux, J.B. et al. (2018a). Accounting for life-history strategies and timescales in marine restoration. *Conservation Letters*, 11(1), e12341. https://doi.org/10.1111/conl.12341

Montero-Serra, I., Garrabou, J., Doak, D.F., Ledoux, J.B. & Linares, C. (2019). Marine protected areas enhance structural complexity but do not buffer the consequences of ocean warming for an overexploited precious coral. *Journal of Applied Ecology*, 56(5), 1063–1074. https://doi.org/10.1111/1365-2664.13321

Montero-Serra, I., Linares, C., Doak, D.F., Ledoux, J.B. & Garrabou, J. (2018b). Strong linkages between depth, longevity and demographic stability across marine sessile species. *Proceedings of the Royal Society B: Biological Sciences*, 285(1873), 20172688. https://doi.org/10.1098/rspb.2017.2688

Oliver, E.C.J., Donat, M.G., Burrows, M.T., Moore, P.J., Smale, D.A., Alexander, L.V. et al. (2018). Longer and more frequent marine heatwaves over the past century. *Nature Communications*, 9(1), 1–12. https://doi.org/10.1038/s41467-018-03732-9

Parravicini, V., Micheli, F., Montefalcone, M., Villa, E., Morri, C. & Bianchi, C.N. (2010). Rapid assessment of epibenthic communities: a comparison between two visual sampling techniques. *Journal of Experimental Marine Biology and Ecology*, 395(1–2), 21–29. https://doi.org/10.1016/j.jembe.2010.08.005

Perez, T., Garrabou, J., Sartoretto, S., Harmelin, J.G., Francour, P. & Vacelet, J. (2000). Mass mortality of marine invertebrates: an unprecedented event in the northwestern Mediterranean. *Comptes Rendus de l'Académie des Sciences. Série III*, 323(10), 853–865. https://doi.org/10.1016/S0764-4469(00)01237-3

Piazzi, L., Atzori, F., Cadoni, N., Cinti, M.F., Frau, F. & Ceccherelli, G. (2018). Benthic mucilage blooms threaten coralligenous reefs. *Marine*

Environmental Research, 140, 145–151. https://doi.org/10.1016/j.marenvres.2018.06.011

Piazzi, L., Gennaro, P., Montefalcone, M., Bianchi, C.N., Cecchi, E., Morri, C. et al. (2019). STAR: an integrated and standardized procedure to evaluate the ecological status of coralligenous reefs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 29(2), 189–201. https://doi.org/10.1002/aqc.2983

Rubio-Portillo, E., Izquierdo-Muñoz, A., Gago, J.F., Rosselló-Mora, R., Antón, J. & Ramos-Esplá, A.A. (2016). Effects of the 2015 heat wave on benthic invertebrates in the Tabarca marine protected area (Southeast Spain). *Marine Environmental Research*, 122, 135–142. https://doi.org/10.1016/j.marenvres.2016.10.004

Scannell, H.A., Pershing, A.J., Alexander, M.A., Thomas, A.C. & Mills, K.E. (2016). Frequency of marine heatwaves in the North Atlantic and North Pacific since 1950. *Geophysical Research Letters*, 43(5), 2069–2076. https://doi.org/10.1002/2015GL067308

Seitz, R.D., Wennhage, H., Bergström, U., Lipcius, R.N. & Ysebaert, T. (2014). Ecological value of coastal habitats for commercially and ecologically important species. *ICES Journal of Marine Science*, 71(3), 648–665. https://doi.org/10.1093/icesjms/fst152

Sini, M., Kipson, S., Linares, C., Koutsoubas, D. & Garrabou, J. (2015). The yellow gorgonian *Eunicella cavolini*: demography and disturbance levels across the Mediterranean Sea. *PLoS ONE*, 10(5), e0126253. https://doi.org/10.1371/journal.pone.0126253

Smith, F.G.W. (1941). Sponge disease in British Honduras, and its transmission by water currents. *Ecology*, 22(4), 415–421. https://doi.org/10.2307/1930719

Teixidó, N., Casas, E., Cebrian, E., Linares, C. & Garrabou, J. (2013). Impacts on coralligenous outcrop biodiversity of a dramatic coastal storm. *PLoS ONE*, 8(1), e53742. https://doi.org/10.1371/journal.pone.0053742

Teixidó, N., Garrabou, J. & Harmelin, J.G. (2011). Low dynamics, high longevity and persistence of sessile structural species dwelling on Mediterranean coralligenous outcrops. *PLoS ONE*, 6(8), e23744. https://doi.org/10.1371/journal.pone.0023744

UNEP/MAP. (2017). *Integrated monitoring and assessment program of the Mediterranean Sea and coast and related assessment criteria UN environment/MAP Athens*, Greece: UNEP.

Verdura, J., Linares, C., Ballesteros, E., Coma, R., Uriz, M.J., Bensoussan, N. et al. (2019). Biodiversity loss in a Mediterranean ecosystem due to an extreme warming event unveils the role of an engineering gorgonian species. *Scientific Reports*, 9(1), 1–11. https://doi.org/10.1038/s41598-019-41929-0

Wulff, J.L. (2006). Rapid diversity and abundance decline in a Caribbean coral reef sponge community. *Biological Conservation*, 127(2), 167–176. https://doi.org/10.1016/j.biocon.2005.08.007

Zentner, Y., Rovira, G., Margarit, N., Ortega, J., Casals, D., Medrano, A. et al. (2023). Marine protected areas in a changing ocean: adaptive management can mitigate the synergistic effects of local and climate change impacts. *Biological Conservation*, 282, 110048. https://doi.org/10.1016/j.biocon.2023.110048

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Figuerola-Ferrando, L., Garrabou, J. & Linares, C. (2024). A rapid assessment method to monitor the health status of habitat-forming species in coastal benthic ecosystems. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 34(3), e4120. https://doi.org/10.1002/aqc.4120