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RESEARCH ARTICLE

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Identifying conservation priorities for gorgonian forests in Italian coastal waters with multiple methods including citizen science and social media content analysis

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Abstract

Aim: Gorgonian forests are among the most complex of subtidal habitats in the Mediterranean Sea, supporting high biodiversity and providing diverse ecosystem services. Despite their iconic status, the geographical distribution and condition of gorgonian species is poorly known. Using multiple online data sources, our primary aims were to compile, map and analyse observations of gorgonian forests in Italian coastal waters to assess the biological complexity of gorgonian forests, evaluate impacts and vulnerable species, and identify areas of special interest inside and outside of marine protected areas (MPAs) to help prioritize conservation strategies and actions.

Location: Italy. Mediterranean Sea.

Methods: Using a multi-source data integration approach, we collected and integrated data from scientific publications, the World Wide Web including social media platforms, citizen science projects and SCUBA diver questionnaires into a unified spatial framework. This method provided up-to-date information on the geographical distribution, abundance, and health of major habitat-forming gorgonian species in Italian coastal waters.

Results: Higher abundance and complexity of gorgonian species occurred outside MPAs. Areas of Special Interest (n = 167) were identified (80 inside and 87 outside MPAs). Three locations supported all seven focal species: Capo Caccia MPA, Portofino MPA and Catania (unprotected). The purple gorgonian (*Paramuricea clavata*), the most abundant and geographically widespread species with highest forest complexity, was affected by multiple stressors including thermal stress, disease and fishing.

Main conclusions: The multi-source approach was a rapid and cost-effective tool to gather, analyse and map disparate data on gorgonian forests spanning 27 years of underwater observations both inside and outside of MPAs. The unique perspective given by this approach demonstrates the suboptimal protection of several habitat-forming gorgonian species. The approach has great potential for wider application and offers a more inclusive participatory model for crowdsourcing and repurposing under-utilized observations while also increasing ocean literacy.

KEYWORDS
biogeography, citizen science, gorgonian forests, marine policy, web ecological knowledge

1 | INTRODUCTION

Densely branching assemblages of gorgonians, referred to here as gorgonian forests, are among the most ecologically and economically important biotopes of Mediterranean subtidal seascapes (Kipson et al., 2011; Ponti et al., 2016). By increasing the complexity of the environment, gorgonian forests support high biodiversity, deviate currents, modify sedimentation rates, sequester carbon, delay the spread of invasive algae (Casas-Güell et al., 2015; Cerrano et al., 2010) and provide a wide range of ecosystem services (Ballesteros, 2003; de Ville d'Avray et al., 2019). For instance, through complex biophysical structures, gorgonian forests provide a valuable shelter, feeding and nursery habitat for many commercially important benthic invertebrates and fish (Ballesteros, 2003; Cerrano et al., 2010; Ponti et al., 2016, 2018; Valisano et al., 2016). These architecturally complex marine animal forests are popular with recreational SCUBA divers generating socio-economic benefits and increasing the digital observational data on seascape conditions (Cerrano et al., 2017; Ponti et al., 2011; Rodrigues et al., 2016).

The ecological integrity of gorgonian forests and thus the flow of interlinked ecosystem services is increasingly threatened by exposure to multiple stressors including thermal stress linked to accelerated global warming (Cerrano et al., 2000; Coma et al., 2009; Huete-Stauffer et al., 2011; Verdura et al., 2019), the spread of non-indigenous species (NIS) (Cebrian et al., 2018; Galil, 2019), and local anthropogenic activities such as anchoring, fishing, land-based sources of pollution and recreational SCUBA diving (Bavestrello et al., 1997; Milazzo et al., 2002; Mistri & Ceccherelli, 1995). Mass mortality events among gorgonian forests have been increasing in frequency and intensity over the past two decades in the Mediterranean Sea (Linares & Doak, 2010; Santangelo et al., 2015), with thermal stress and subsequent water stratification and disease associated with climate change being the most likely cause (Coma et al., 2009; Vezzulli et al., 2013). The loss of gorgonians and associated crustose coralline algae results in a transition towards a lower complexity autotrophic regime dominated by filamentous algae (Ponti et al., 2014). In 2017, the International Union for the Conservation of Nature (IUCN) estimated that at least 25% of anthozoans were threatened in the Mediterranean Sea, when accounting for similar conservation status in the 50% of species that are still data deficient (Otero et al., 2017). Although regarded as a 'Priority Habitat Type' in the EU Habitats Directive (Council Directive 92/43, 1992), and with some species listed in the IUCN Red List of Threatened Species (appendix II), habitat-forming gorgonian species, except for *Corallium rubrum* and *Savalia savaglia* in the Mediterranean Sea, still lack any significant protection under national laws and legal tools (Otero et al., 2017). Marine protected areas (MPAs) have been considered a potentially powerful tool for the protection of gorgonian forests in the Mediterranean Sea, contingent on relevant geographical placement, sufficient resourcing, effective regulations, and high compliance (Coma et al., 2004).

With increasing impact from marine heatwaves (Darmaraki et al., 2019; Smale et al., 2019), the spread of NIS (Cebrian et al., 2018) and other cumulative human impacts including fishing both inside and outside of MPAs (Betti et al., 2020), there is an urgent need for reliable baseline information on the geographical distribution, health and impacts to major habitat-forming gorgonian species in the Mediterranean region (Otero et al., 2017). Current gorgonian species distributions are poorly known in the coastal waters of Italy and long-term and spatially extended monitoring datasets are rare, with most studies focussing on specific sites usually within MPAs (Cupido et al., 2009; Coma et al., 2009; Gambi et al., 2010; Crisci et al., 2011).

Over the past few years, marine citizen science has emerged as an effective and low-cost tool to enhance information gathering across broader spatial and temporal scales than most conventional scientific projects, and at the same time foster increased ocean literacy and shared responsibility for ocean health (Di Minin et al., 2015; Earp & Liconti, 2020; Thiel et al., 2014; Vieira et al., 2020). In addition, an increasing number of recreational SCUBA divers are posting digital underwater videos and photographs on social media and uploading to crowdsourced web-based applications, of which some also have reliable metadata revealing the observer location, depth and the time of observation. Enabled by the growth of both underwater imaging and image sharing digital platforms, the SCUBA diving collective has created a vast ecological data repository of underwater videos and photographs that are publicly available on the World Wide Web (WWW) (Di Camillo et al., 2018). Collection and synthesis of crowdsourced information in ecological informatics is a rapidly emerging approach sometimes referred to as Web Ecological Knowledge (WEK) (sensu Di Camillo et al., 2018) or iEcology (sensu Jarić et al., 2020), defined as the study of ecological patterns and processes using online data usually generated for other purposes and stored digitally (e.g. Internet search activity, social media interactions and uploaded data and media) (Jarić et al., 2020). This accessible online information enables the investigation of historical trends and filling data gaps across broad geographical regions, complementing existing scientific studies to support decision making in marine conservation (Toivonen et al., 2019).

In Italy, growing concern over the mortality of gorgonians at local dive sites is being expressed by the SCUBA diving community through frequent posts on social media that often remain unnoticed by the scientific community. To support effective conservation strategies through prioritization of sites for action, we created a new database of the geographical distribution, abundance, health and impacts to the main habitat-forming gorgonian species in Italian coastal waters. We applied a multi-source data mining approach that included WEK, in combination with data from citizen science, scientific publications, and questionnaires. Our objectives were to compile, map and analyse observations in Italian coastal waters to: (1) assess the complexity of gorgonian forests based on species composition and abundance; (2) assess the type and magnitude of impacts to gorgonian forests and species to identify vulnerability; (3) compare the complexity and magnitude of impact of gorgonian forests inside and outside of MPA boundaries and (4) identify areas of special interest both inside and outside of existing MPAs to help prioritize conservation strategies and actions.

2 | METHODS

2.1 | Multi-source data synthesis

Data on the distribution, abundance and condition of seven major habitat-forming species of gorgonians in Italian coastal waters were acquired, collated and evaluated using a multi-source data synthesis workflow (adapted from Di Camillo et al., 2018) including: (1) peer-reviewed and grey literature; (2) citizen science projects; (3) archived survey datasets available on the WWW including social media diver observations (photos and videos); and 4.) questionnaires completed after diving by SCUBA divers (Appendix S1). The primary habitat-forming gorgonian species (Alcyonacea) of interest here were as follows: *Eunicella cavolini* (Koch 1887), *Eunicella singularis* (Esper 1791), *Eunicella verrucosa* (Pallas 1766), *Paramuricea clavata* (Risso 1826), *C. rubrum* (Linnaeus 1758) and to a lesser extent *Leptogorgia sarmentosa* (Esper 1789). One hexacoral (Zoantharia) *Savalia savaglia* (Bertoloni 1819) was also included in data collection. Data on MPA locations and type were obtained from the World Database on Protected Areas (UNEP-WCMC & IUCN 2019).

2.1.1 | Literature review

Scientific data were gathered using a systematic literature review based on a specific list of search terms (English and Italian language) (Table 1) and entered into the Internet search engine Google Scholar. Data were extracted from a total of 50 scientific publications. For *C. rubrum*, a large amount of data was extracted from the comprehensive CorMedNet dataset (http://cormednet.medrecover.org/).

2.1.2 | Citizen science

Data from citizen science activities were provided by Reef Check Italia (RCI) (https://www.reefcheckmed.org/) and extracted from iNaturalist (https://www.inaturalist.org/). These data originated from SCUBA diver surveys (Appendix S2) and underwater photographs conducted by trained observers. All records were quality checked with expert knowledge for RCI (Cerrano et al., 2017), and validated by researchers in iNaturalist.

2.1.3 | SCUBA diver questionnaires

A questionnaire was created to further investigate the distribution, abundance and health of the focal species in Italian coastal waters (Appendix S2). Following ethical approval, the questionnaire was

TABLE 1 Search terms used in the systematic literature review methods implemented for the collection of science-derived data on distribution, abundance and state of gorgonian forests in Italian coastal waters. Both English and Italian language was used

Theme	Search term
Distribution	Gorgonian forest + distribution + Mediterranean AND/OR Italy Habitat-forming gorgonians + distribution + Mediterranean AND/OR Italy Species name + distribution + Mediterranean AND/OR Italy
Abundance	Gorgonian forest + abundance + Mediterranean AND/OR Italy Habitat-forming gorgonians + abundance + Mediterranean AND/OR Italy Species name + abundance + Mediterranean AND/OR Italy
Damage	Gorgonian forest + damage OR mortality+ Mediterranean AND/OR Italy Habitat-forming gorgonians + damage OR mortality + Mediterranean AND/OR Italy Species name + damage OR mortality + Mediterranean AND/OR Italy
Abandoned fishing lines	Gorgonian forest + fishing OR marine debris + Mediterranean AND/OR Italy Habitat-forming gorgonians +fishing OR marine debris + Mediterranean AND/OR Italy Species name + fishing OR marine debris+ Mediterranean AND/OR Italy

distributed to the diving community using leaflets with a Quick Response (QR) code linking directly to the questionnaire at the European Dive Show in Bologna (1–3 March 2019). The online questionnaire was also shared on social media and sent via email to 629 Italian diving centres and the staff of Italian MPAs.

2.1.4 | Web ecological knowledge

Information acquired from the WWW included amateur underwater videos and pictures obtained mainly from Facebook and YouTube (the latest information obtained was dated 17/05/2019). A standardized sequence of steps was applied to retrieve ecological information on the focal species (Figure 1). Terms were searched in both English and Italian language to include social media posts from non-English speakers. The Purple Octopus crowdsourcing tool (http://www.purpleoctopus.org/groupsourcing/index.php) was used to explore the messages and images posted on Facebook by combining the data with the selected species names. Names and locations of Italian dive sites (www.logbookimmersioni.it) were used as key terms to further retrieve ecological information on the focal species. Photographs and video taken in Italian coastal waters were observed by experts to identify species to select information only where one of the seven focal species were observed. Authors of material published on the WWW were contacted, where possible, by social media message or email for more details about the record, such as dive date, exact location, depth and temperature. Records lacking information on date and dive location were discarded. The abundance and extent of damage of the gorgonian forest was estimated visually and assigned to impact classes following a standardized method, and additional visual information was also recorded.

2.2 | Data processing and evaluation

The focal gorgonian species were chosen because they are found in Italian coastal waters, have known sensitivity to stressors, including thermal stress and harvesting in the case of *C. rubrum*, and are easily distinguished from one another by colour and shape which minimizes misidentification. For all data sources, the abundance of the gorgonian forest was recorded into abundance classes following RCI standardized methods. Abundances of *E. cavolini*, *E. singularis*, *E. verrucosa*, *S. savaglia*, *L. sarmentosa* and *P. calavata* were recorded according to the following classes: 1 = 1 individual, 2 = 2 individuals, 5 = 3–5 individuals, 10 = 5–10 individuals, 50 = 11–50 individuals and 100 = >51. For *C. rubrum*, the recorded classes were: 1 = an isolated specimen, 2 = some scattered specimens, 5 = several scattered specimens, 10 = one crowded area, 50 = some crowded areas and 100 = several crowded areas. The extent of damage of the colonies was logged in percentage classes: 0% damage for a healthy colony, 10%, 25%, 50%, 75%, 99% damage in order of gravity, and 100% for a dead colony (Appendix S2). Where available the water depth and the presence or absence of epibionts, mucilage assemblages, abandoned, lost or discarded fishing lines, and eggs/juveniles were recorded (Table 2). The presence or absence of fishing lines was used to calculate the average occurrence of fishing lines inside and outside of MPAs.

All records were quality checked through a data validation process based on literature cross-checking (e.g. consistency among reported species) and manual procedures (e.g. matching dive site names to geographic coordinates). The origin of all inconsistent data was further investigated to attempt its correction. All data failing the quality control after further inspection were permanently deleted from the database. The resulting data set comprises separate records for each single species found by each observer/scientific publication in a diving site. Diving sites ($n = 61$) were georeferenced using geographical coordinates (Datum WGS84) with a minimum accuracy of ±15″ (=±0.00417°) and both diving sites and MPAs were mapped (Appendix S3).

2.3 | Data analysis

2.3.1 | Creation of indices

Two multi-metric indices based on the quick Mesophotic Assemblages Ecological Status (q-MAES) index (Canovas-Molina et al., 2016) were created to assess: (1) the complexity of gorgonian forests; and (2) observed damage/impact to gorgonian forests. Two indices were applied as follows: (1) Gorgonian forest complexity index ($I_{\text{complexity}}$) using data on the number of focal gorgonian species present in each grid cell and the mode of abundance classes of the dominant species in the grid; and (2) Gorgonian forest impact index (I_{impact}) using data on the mode of damage of dominant species in each grid cell and the average occurrence of abandoned fishing lines.

Three scores were assigned to each metric depending on extent: Low (1), Medium (2), High (3) (Table 3). The final values of the indices were obtained by summing the metric scores according to the following formulas:

$$I_{\text{complexity}} = S_{\text{sp}} + S_{\text{ab}}; \quad I_{\text{impact}} = S_{\text{d}} + S_{\text{i}} \qquad (1)$$

where S_{sp} is the number of species; S_{ab} the score of abundance mode of dominant species; S_{d} the score of damage mode of dominant species; S_i the score of abandoned fishing lines occurrence, given by the average occurrence of abandoned fishing lines recorded (0–1). Resulting scores were then divided into the three classes to define the complexity ($I_{\text{complexity}}$) and impact (I_{impact}) extents of gorgonian forests (Low = 2 ≤ Index ≤ 3; Mid = 4; and High = 5 ≤ Index ≤ 6). Grid cells with both high complexity and high impact scores (as defined in Table 3) were defined as Areas of Special Interest (ASI) and mapped to inform biodiversity conservation.

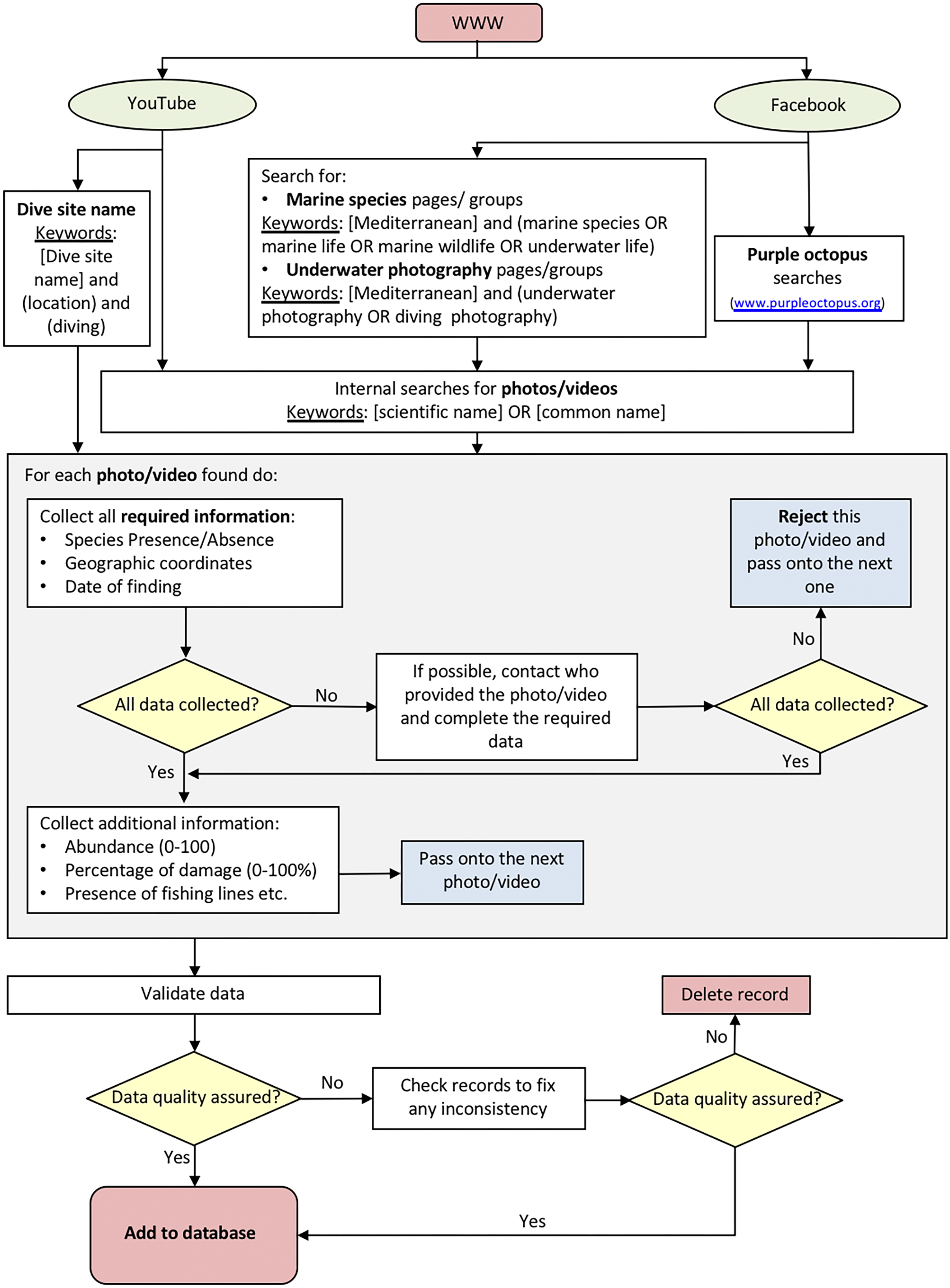

FIGURE 1 Summary of the steps followed to retrieve multi-source information from the world wide web on species distribution, abundance, health and impacts

TABLE 2 Data on 12 variables collected from four different data sources: World wide web (WWW) (823 records), diving questionnaires (DQ) (145 records), citizen science (CS) (3370 records), scientific publications (SCI) (348 records)

Variables	Source of data			
	WWW	DQ	CS	SCI
Presence/absence of focal species	X	X	X	X
Location of sighting	X[a]	X	X	X
Date of sighting	X[a]	X	X	X
Abundance of focal gorgonian species	X	X	X	X[a]
Presence of abandoned fishing lines	X	X	X	X[a]
Depth of sighting	X[a]	X	X	
Damage to focal species	X	X		X[a]
Mucilage presence	X	X		X[a]
Water temperature	X[a]	X[a]		X[a]
Evidence of nursery area	X			X[a]
Presence of epibionts	X			X[a]
Poor diving behaviour	X			

[a]Case dependant.

TABLE 3 Metrics used in the creation of the indices and threshold used to assign the scores 1–3 (low, medium, and high)

Indices	Score 1 (low)	Score 2 (medium)	Score 3 (high)
Gorgonian forest complexity index ($I_{complexity}$)			
Species number (S_{sp})	1	$2 \le S_{sp} \le 3$	$4 \le S_{sp} \le 7$
Abundance class (S_{ab})	1, 2	5, 10	50, 100
Gorgonian forest impact index (I_{impact})			
Damage class (S_d)	0, 10	25, 50	75, 99, 100
Average occurrence of abandoned fishing lines (S_l)	0	$0 \le S_l \le 0.5$	≥0.6

2.3.2 | Geographical analysis

All mapping and geographical analyses were carried out using QGIS (QGIS Development Team, 2019). The European coastline layer for spatial analyses was obtained from the European Environment Agency (www.eea.europa.eu). Records were aggregated in cells of a 15-arc minute grid (=0.25°; 27.78 km) to analyse the data set at a coarse scale, by a 54-arc second grid (=0.9°; 10 km) for indices analyses, and a 15-arc second grid (=0.004°; 463 m) for finer scale analyses at the scale of a single dive site. Metrics and indices were quantified and compared inside and outside MPAs.

2.3.3 | Statistical analysis

All statistical analyses were carried out in R v3.2.1 (R Core Team, 2019). All data were tested for homogeneity using Levene's test and for normality of residuals with a Shapiro–Wilk test and found to be heterogeneous and non-normal. Differences between abundance and damage classes (dependent variables) inside and outside MPAs boundaries and between the seven focal species (fixed variables) were tested using a Generalized Least Squares fitting model (GLS; nmle package; Pinhero et al., 2019), with a maximum-likelihood ratio test. The *p*-values of the models for abundance were calculated using a type III sums of squares model because of significant interactions between variables, while the *p*-values of the model for damage/impact were calculated using a type II sums of squares model because of no inherent hierarchy. A Kolmogorov–Smirnov test was used to test for significant interactions between the variables and differences in abundance for each species inside and outside MPAs. Multiple pairwise comparisons between species for abundance and damage were investigated using a Tukey post-hoc test (glht with Tukey method; multcomp package Hothorn et al., 2008).

Changes in the indices (dependent variable) inside and outside MPAs and between the seven gorgonian forest-associated species (fixed variables) were analysed using a Generalized Linear Model (GLM; MASS package Venables & Ripley, 2002) with gamma error distribution fit for the complexity index ($I_{complexity}$) and with a Poisson error distribution fit for the impact index (I_{impact}). In both models, factor *p*-value was calculated using a chi-squared maximum-likelihood ratio test. A GLM with binomial error structure was used to investigate the differences in occurrence of abandoned fishing lines inside and outside MPA boundaries, and *p*-value was calculated using a chi-squared maximum-likelihood ratio test.

3 | RESULTS

3.1 | Geographical distribution of records

Thirty-two per cent (229 of 714) of grid cells with gorgonians present were inside MPA boundaries (Figure 2). Citizen science data provided the highest number of records and covered the widest geographical distribution covering 71.9% of grid cells with data. WWW data covered 17.6% of the grid cells, scientific literature covered 7.4% and SCUBA diver questionnaires produced 3.1% of grid cells with data. Of 629 emails sent to promote the questionnaire, 169 (26.9%) were returned undelivered, four (0.6%) received automatic replies and eight (1.3%) received an answer. A total of 52 questionnaires were returned completed, with information regarding the focal gorgonian species. Integrating data entries from multiple sources allowed us to reduce geographical gaps and provide a greater geographical coverage for the study region (Appendix S1). Particularly, when combining WWW and SCUBA diver questionnaires data, 141 and 14 new 15″-grid cells resulted, respectively, when compared to citizen science and scientific literature data.

3.2 | Species distribution, abundance and gorgonian forest complexity

The database compiled for this study contained information on geographical distribution, abundance and ecological condition of *E. cavolini*, *E. singularis*, *E. verrucosa*, *L. sarmentosa*, *P. clavata*, *C. rubrum* and *Savaglia savaglia* in Italian coastal waters. The resulting database included 4686 records (Data available https://doi.org/10.5061/dryad.kh189326t, located, and mapped across 714 x 15″-grid cells (Figure 3a and Appendix S4) observed between 1993 and 2019. The largest proportion of cells received only one species (35.7%), whereas 27.8% had two species and 17.9% had three species recorded (Figure 3b). Cells with more than three species were less abundant (4 = 10.4%; 5 = 5.7%; 6 = 1.8%). Only three grid cells (0.5%) included all seven species at Capo Caccia MPA, Catania and Portofino MPA.

Most surveys were conducted within the conventional depth limits for recreational SCUBA diving and do not accurately represent the biological depth limits for the focal species. The average depth was 27.2 (±16.9 SD) metres (Appendix S5). *Eunicella cavolini* was the dominant species in 32.3% of the grid cells, followed by *P. clavata* (31.8%); and *E. singularis* (16.5%). *Corallium rubrum*, *S. savaglia* and *E. verrucosa* were only dominant in 7.4%, 7.1% and 4.3% of the grid cells, respectively, and *L. sarmentosa* was the least abundant species, only being the dominant species in 1.2% of grid cells (Appendix S4).

The seven gorgonian species showed different specific patterns of distribution in Italian coastal waters. *Paramuricea clavata* was the most locally abundant and geographically widespread species in Italian coastal waters with an abundance mode of 100 (>51 individuals) being found in 48.9% of the 714 grid cells (Appendix S4a). *Corallium rubrum* also had an abundance mode of 100 and was observed in 29.6% of the grid cells (Appendix S4b). Despite being the most widely distributed species (51.3% grid cells), *E. cavolini* had an overall mode abundance of 50 (11–51 individuals) (Appendix S4c), similarly for *E. singularis*, which was found in 36.3% of grid cells (Appendix S4d). *Savalia savaglia* (Appendix S4e) and *E. verrucosa* (Appendix S4f) were among the least abundant species with a mode abundance of 2 (two individuals) and were also found in only 18.1% and 14.7%, respectively, of grid cells. *Leptogorgia sarmentosa* was the rarest species having an abundance mode of 1 (1 individual) and only being found in 5.7% of grid cells (Appendix S4f). The post-hoc test confirmed *P. clavata* having a significantly ($p<.001$) higher abundance than all other focal gorgonian species.

Considering the three main basins of the Mediterranean Sea, gorgonian forests displayed a higher complexity in the Tyrrhenian Sea, with only Tremiti Islands displaying a high complexity in the Adriatic Sea, and Santa Caterina and Catania in the Ionian Sea (Figure 3c). A total of 61.4% of the 54′-grid cells displayed high gorgonian forest complexity ($I_{complexity}>5$). Only 19.6% of the 54′-grid cells displayed low complexity ($I_{complexity}<3$), with the Adriatic Sea exhibiting the lowest gorgonian forest complexity (Figure 4b).

3.3 | Are habitat-forming gorgonians more abundant and more complex inside or outside MPAs?

Abundance was significantly higher outside of MPAs compared with inside (L-ratio = 4.75; df = 1; $p<.05$) and was significantly different

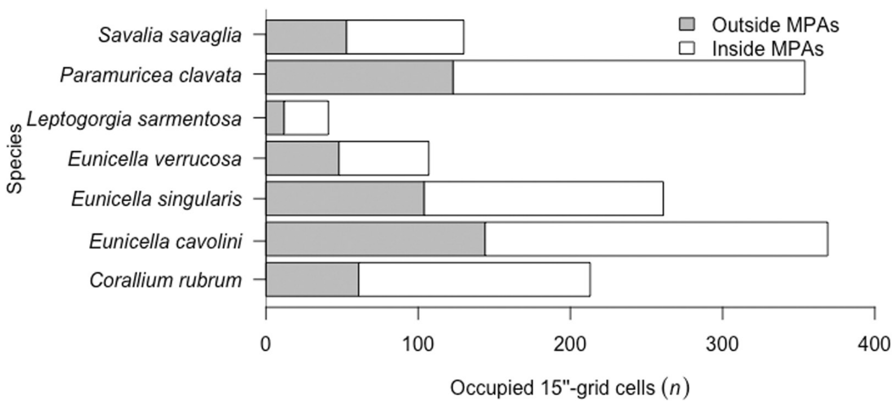

FIGURE 2 The number of 15″ grid cells inside and outside of marine protected areas with focal gorgonian species presence recorded

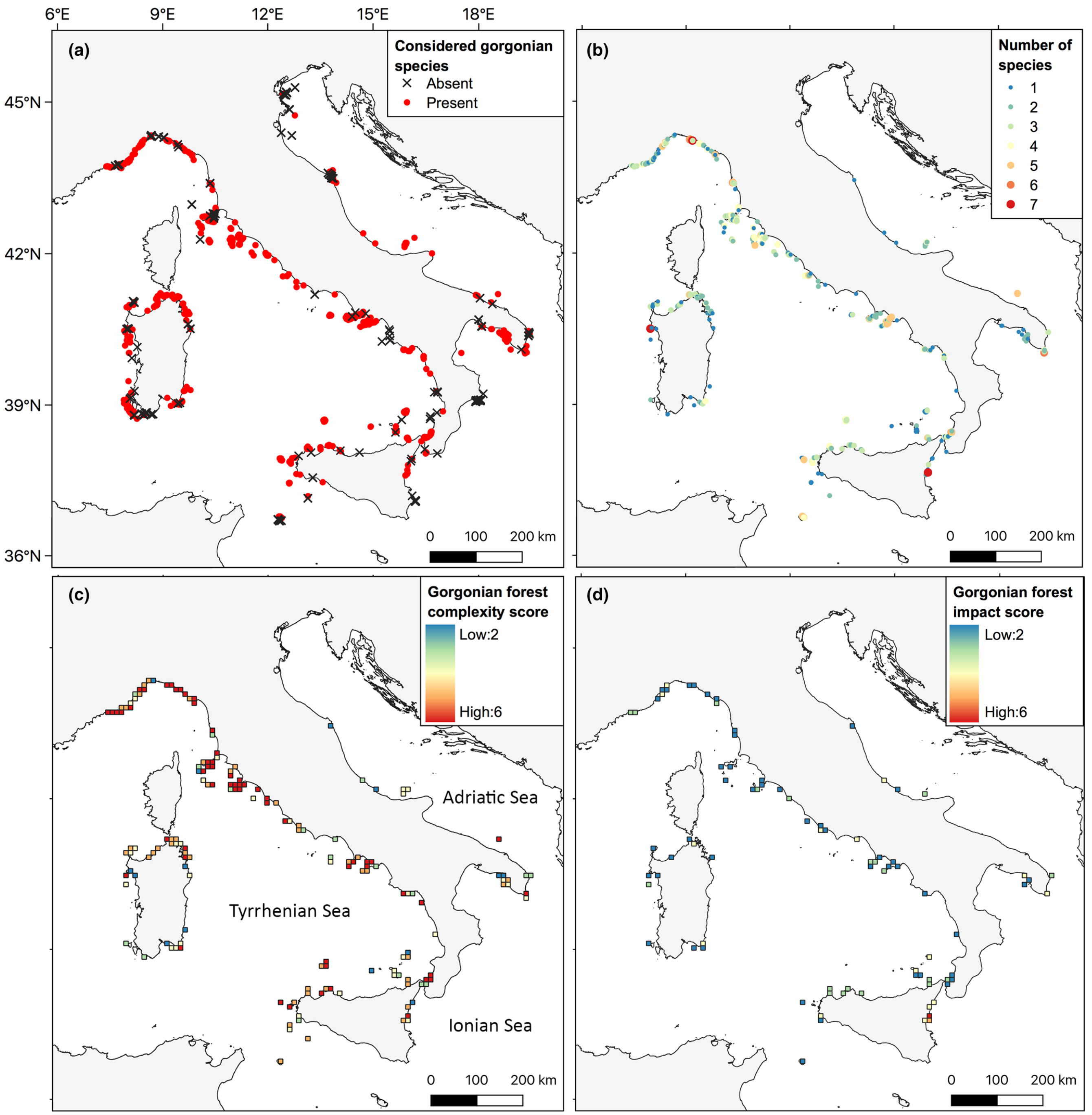

FIGURE 3 Geographical distributions across 714 × 15″-grid cells in Italian coastal waters for: (a) the presence and absence of focal gorgonian species; (b) the number of focal gorgonian species; (c) gorgonian forest complexity index score ($I_{complexity}$); and (d) gorgonian forest impact index score (I_{impact})

between species (L-ratio = 90.90; df = 6; $p < .01$) (Figure 4a and Appendix S6). A significant interaction between protection and species was also discovered (L-ratio = 20.92; df = 6; $p < .01$). The complexity index was also significantly higher outside MPA boundaries ($I_{complexity}$ $F_1 = 35.421$, $p < .001$); however, no significant difference in the index was found when compared across the seven focal species of habitat-forming gorgonians ($I_{complexity}$ $F_6 = 8.609$, $p > .1$). Despite not being statistically significant, *C. rubrum*, *P. clavata*, *E. cavolini* and *E. singularis* supported a higher complexity score than other species (Figure 4b).

3.4 | Do gorgonian forests inside MPAs have significantly less damage than outside areas?

Protection did not have a significant effect on damage ($F_1 = 0.02$; $p > .5$), although the proportion of damage differed significantly between species (L-ratio = 33.99; df = 6; $p < .001$) with *P. clavata* showing significantly higher damage than *E. cavolini*, *E. singularis* and *S. savaglia* (Figure 4c). No significant interactions were found between protection and species for damage (L-ratio = 3.35; df = 6; $p > .5$). Unexpectedly, gorgonian forest impact scores along the Italian coastline were low overall, with 76.3% of the 54′-grid cells exhibiting low impact scores (I_{impact} <3) and only 4.4% displaying high impact (I_{impact} >5) (Figure 3d and Appendix S7). The three locations with high gorgonian forest impact were as follows: Catania, Ventimiglia and Aeolian Islands. Of these, only one 54′-grid cell (1.1%) in proximity to the location of Catania, showed very high gorgonian forest impact (Figure 3d). Analysis revealed that impact index was significantly higher outside MPA boundaries (I_{impact} F_1 = 51.499; $p < .001$); however, no significant difference in the index was found when compared across the seven focal species of habitat-forming gorgonians (I_{impact} F_6 = 2.799; $p > .5$) (Figure 4d). Despite not being statistically significant, *C. rubrum*, *P. clavata*, *E. cavolini and E. singularis* received a higher impact score than other species.

A total of 128 videos of the 476 videos analysed from the WWW showed the presence of abandoned fishing lines amounting to 30.1% of the 269 grid cells examined. The occurrence of abandoned fishing lines was significantly higher outside MPAs than inside MPAs (F^{1} = 22.558, $p < .001$) (Appendix S8). Locations with very high occurrence of abandoned fishing lines included as follows:

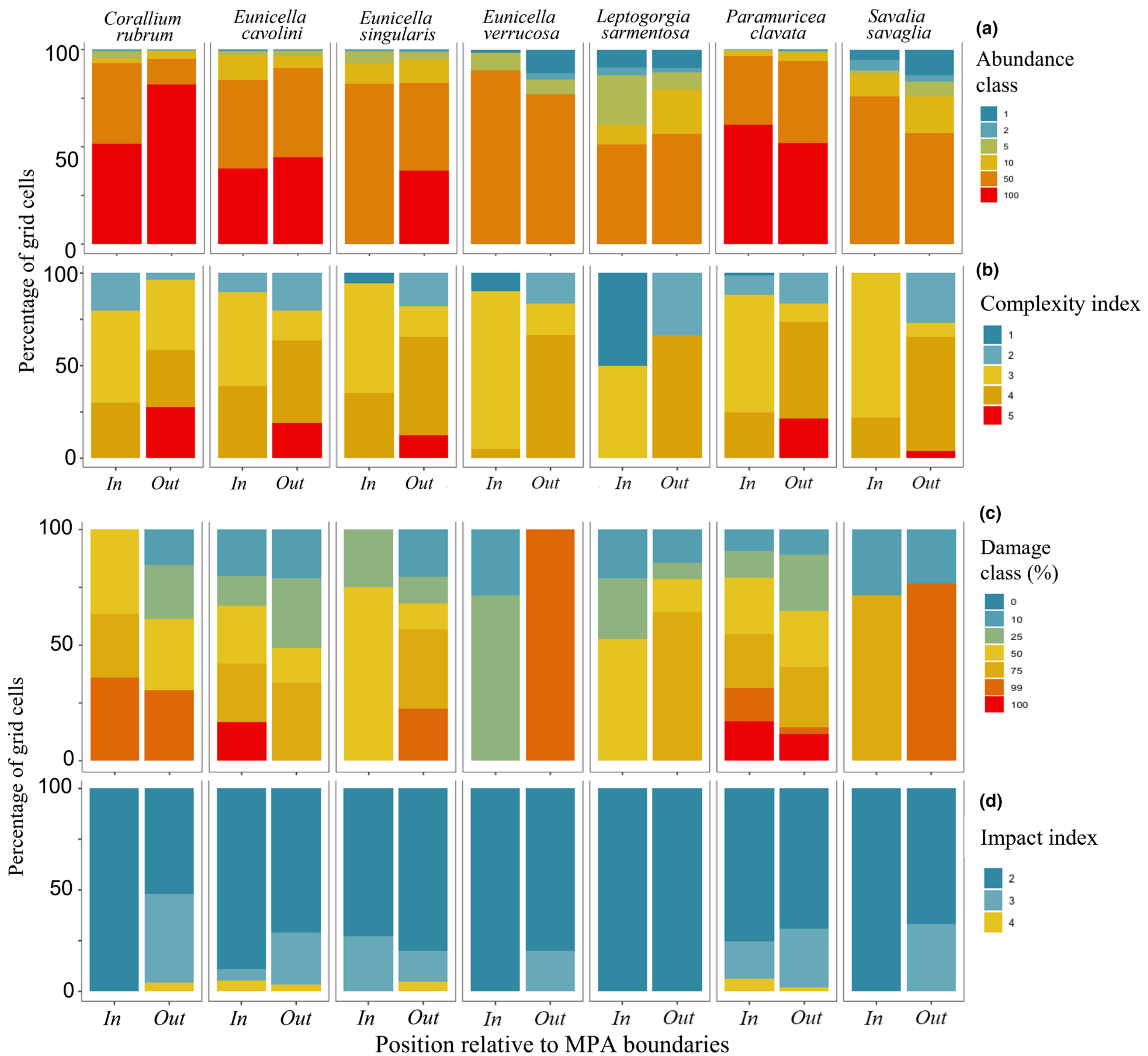

FIGURE 4 Metrics by proportion of grid cells for seven focal gorgonian species showing: (a) abundance class*; (b) forest complexity index (low, medium, high); (c) damage class (0% damage for a healthy undamaged colony to 100% for a dead colony); and (d) impact index (low, medium, high) inside and outside of MPAs in Italian coastal waters. *Abundance classes for all species except *Corallium rubrum* [1 = 1 individual, 2 = 2 individuals, 5 = 3–5 individuals, 10 = 5–10 individuals, 50 = 11–50 individuals and 100 = >51]; for *C. rubrum* [1 = an isolated specimen, 2 = some scattered specimens, 5 = several scattered specimens, 10 = one crowded area, 50 = some crowded areas and 100 = several crowded areas]

Capo Carbonara MPA, Giannutri Island, Tor Paterno MPA, Marzara del Vallo, Latina, Ortona, Catania and Taormina (Figure 5). Among these locations, the dive site Secca di Mezzo Canale (Lat 42.226, Long 10.9238) in Giannutri Island stood out for the large amount and variety of marine litter including abandoned fishing lines.

3.5 | Identifying areas of special interest for gorgonian forest conservation

Grid cells with both high complexity and high impact scores were defined as Areas of Special Interest (ASI) for further investigation and potential for conservation action. About 167 ASIs were identified in the study area (Figure 6a). Of these areas, 80 (47.9%) were found within MPA boundaries, and 87 (52.1%) were found outside MPAs (Figure 6b). Only two 54′-grid cells of ASI showed both high complexity and impact and they were found to be Ventimiglia and Catania, which were found respectively inside and outside MPA boundaries.

4 | DISCUSSION

4.1 | Gorgonian forests patterns in Italian coastal waters

Results from this study represent the most complete and up-to-date baseline data of the distribution, abundance and ecological state of major habitat-forming gorgonian species in Italian coastal waters. The mapped geographical distributions of the seven focal habitat-building species provide: (1) evidence to support decision making in marine spatial planning and for designing place-based actions for addressing marine biodiversity conservation targets; and (2) additional data to enhance the reliability of species and habitat distribution modelling including development of forecasts (Bensoussan et al., 2010; Boavida et al., 2016), and (3) critical data for the evaluation of damaged gorgonian forests and the magnitude of threat from fishing gear (Sini et al., 2015). Differences in the mapped species distribution patterns are linked to environmental conditions (e.g. substrate type, depth and current regimes) and consistent with species habitat preferences (Gori et al., 2011; Linares et al., 2008; Rossi & Gili, 2009). Our geographical analysis of species distributions identified three locations in which all seven focal species were found as follows: Capo Caccia MPA, Portofino MPA and Catania. Special attention should be given to these three sites for their national and international ecological relevance (Follesa et al., 2013) as areas of importance for biodiversity conservation. Catania, being the only one of these locations existing outside of place-based protection.

Leptogorgia sarmentosa was the least abundant and most narrowly distributed species associated with low complexity marine forests creating valuable structural habitat on otherwise barren soft bottom substrates along the Adriatic coastline (Gori et al., 2011). The rarity and local structural importance of *L. sarmentosa* may result in under-evaluation of the conservation importance of this species where it is currently listed as 'least concern' under the IUCN Mediterranean Red List (IUCN, 2016). The iconic red coral, *C. rubrum*, also exhibited a narrow range which may in part be a consequence of historically

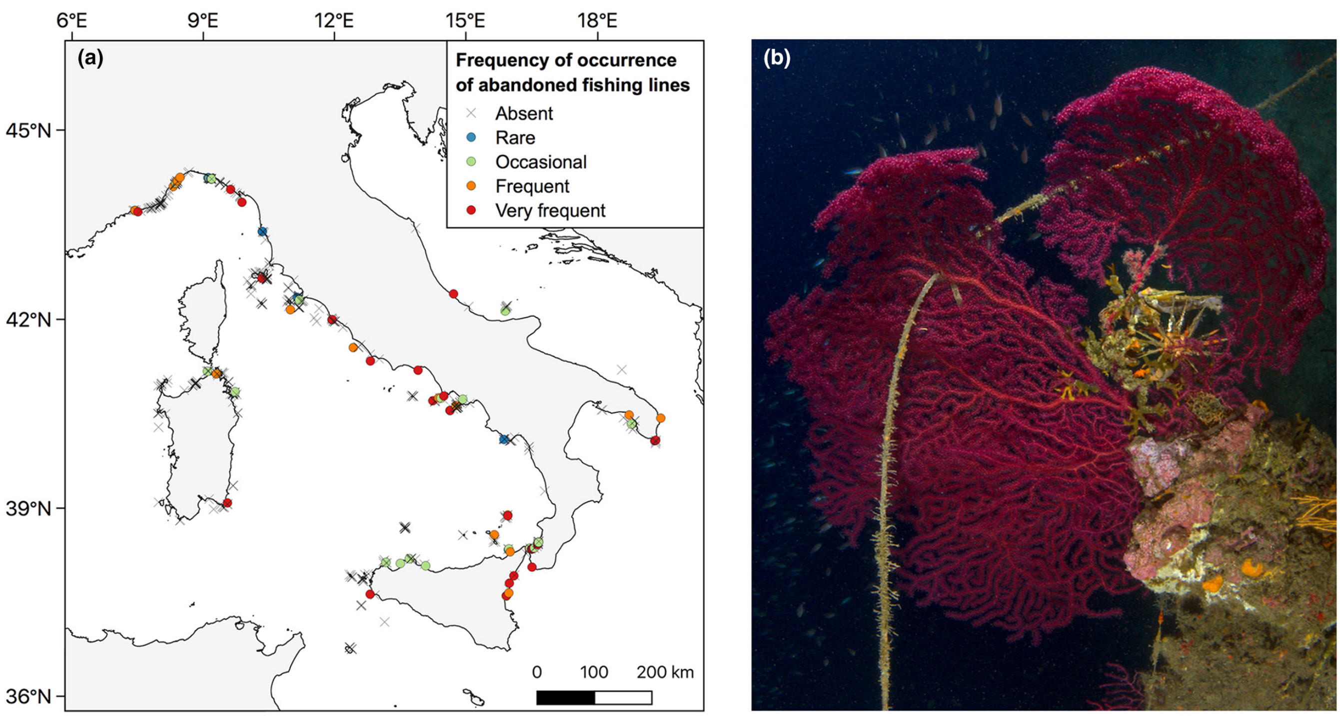

FIGURE 5 (a) frequency of occurrence classes for abandoned fishing gears observed on gorgonians in Italian coastal waters, and (b) rope draped over gorgonian in area Marina Protetta capo Milazzo (photo by Santi Cassisi)

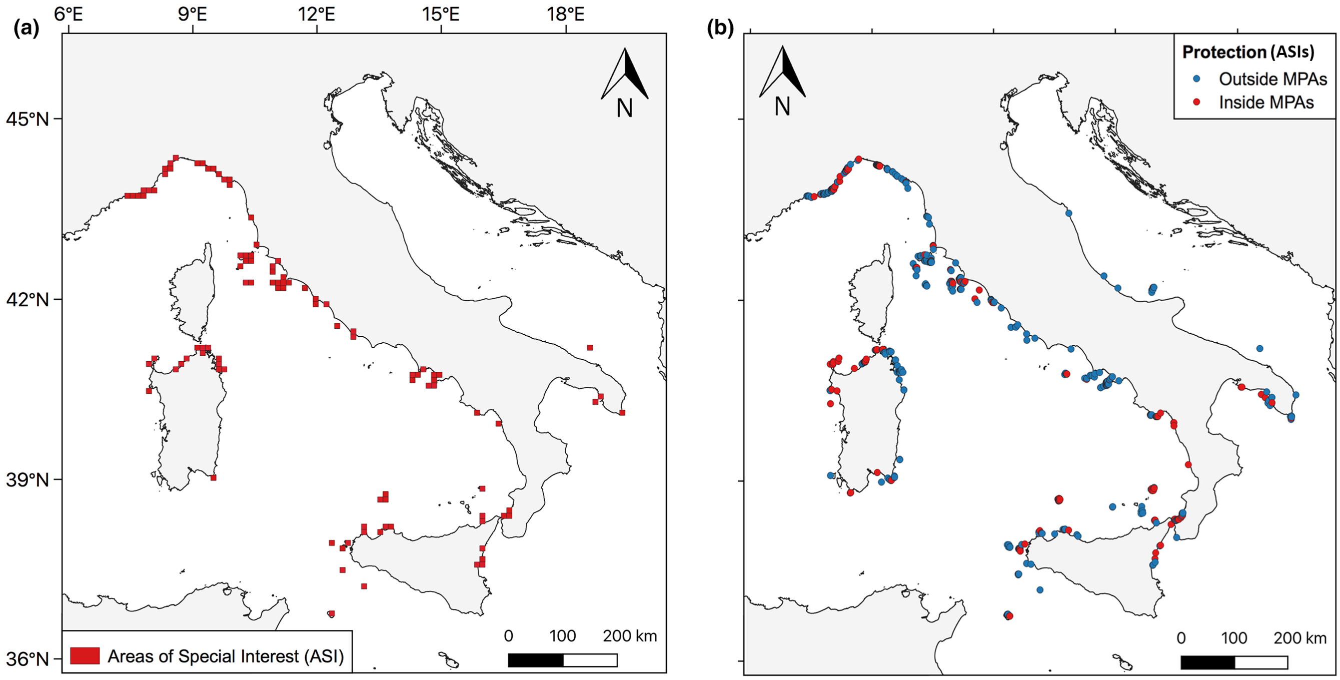

FIGURE 6 (a) Identified areas of special interest (ASI) for gorgonian forests in Italian coastal waters, summarized in 54′-grid cells. (b) Locations inside and outside of the existing MPA network

high rates of harvest especially of shallow water colonies (Santangelo & Abbiati, 2001). The range of depths at which observation of red coral were collected in this study, suggested that abundant colonies of *C. rubrum* may be present below the conventional depth limits for most recreational SCUBA diving (Torrents et al., 2008), highlighting a need for survey techniques (towed video, ROV) that will increase the spatial knowledge of this keystone species at increased depth.

The purple gorgonian, *P. clavata*, exhibited the highest abundance class, the broadest geographical distribution and highest forest complexity in Italian coastal waters. *Paramuricea clavata* is a major characterizing and structurally important species of Mediterranean coralligenous habitats; its canopies reduce the range of environmental variability, supporting a wide range of key associated biota and therefore increasing biodiversity (Ponti et al., 2016; Rossi, 2013; Valisano et al., 2016). However, *P. clavata* was also the only species to experience significantly higher damage than most of the other focal species. This observation is further highlighting an already documented trend of increased damage from human activity for this structurally important species (Ponti et al., 2016). *Paramuricea clavata* is a slow-growing, long-lived, low fecundity, low dispersal and low recruitment species (Gori et al., 2017; Palma et al., 2018), which has been severely affected by mass mortality events (Bally & Garrabou, 2007; Cerrano et al., 2000; Gambi et al., 2010). Mortality has been mainly attributed to thermal stress events (Cerrano & Bavestrello, 2008; Coma et al., 2009; Crisci et al., 2011; Linares et al., 2008) and infection by *Vibrio* spp. bacteria (Vezzulli et al., 2013), coupled with reduced food availability due to water stratification (Huete-Stauffer et al., 2011; Martin et al., 2002). Mortalities are usually size dependant, with larger colonies being more affected leading to a decrease in the structural complexity of habitat (Linares et al., 2013; Linares & Doak, 2010). Results from this study support the role of *P. clavata* as a major habitat-forming species and reinforce the case for implementation of targeted conservation strategies to protect this ecologically important species. *Paramuricea clavata* is currently listed as 'vulnerable' under the IUCN Mediterranean Red List yet is not listed under any other legal instrument (IUCN, 2016; Otero et al., 2017). Italian legislation has no specific national laws for the protection of habitat-forming gorgonian species (Otero et al., 2017).

Alongside international and national legal tools, marine policies of reducing local stressors (e.g. fishing and agricultural run-offs) have been shown to lessen the effects of global stressors (e.g. marine heatwaves) (Micheli et al., 2013), and could play a vital role in limiting further damage to gorgonian forests. Actions to reduce the incidence of entanglement of gorgonians with fishing gear which cause tissue necrosis and subsequent aggregation of fouling organisms thus inhibiting the recovery of the colonies (Bavestrello et al., 1997; Ruitton et al., 2019) is a feasible management action. The index of impact highlighted a spatial trend of geographically patchy patterns of damage, likely reflecting local cumulative human impacts; however, further research is needed to examine the exposure to threats and stressors. The historical patterns of recorded damage to gorgonian forests as revealed by records of mucilage events and mortality uncovered in our study could be modelled to examine co-occurrence with past marine heatwaves using satellite timeseries data (Bianchi et al., 2019). Similarly, patterns of impacts to gorgonian forests from fishing gear could be investigated with information of patterns of fishing activity using fishing vessel tracks or proximity to highly populated urban areas. Alongside prioritizing high-low complexity and impact sites for conservation action, the index of impacts and complexity allows us to also consider gorgonian forests characterized by high resistance or high resilience to stressors. These areas could be used as study sites for understanding genetic traits expressed by different gorgonian populations, which could be useful evidence for restoration programs (Fava et al., 2010; Mokhtar-Jamaï et al., 2013). The mapping of indices of complexity and impact provide a tool to inform the design of adaptive monitoring strategies and create a set of sentinel sites to track condition and threats to give early warning of ecological changes.

4.2 | Comparing inside and outside of MPAs

Overall, only 32% of records were found within MPA boundaries, with higher abundances and complexity of the focal gorgonian species occurring outside MPAs. At the time of writing, only 8.79% of the Italian Exclusive Economic Zone (EEZ) was protected, and only 0.6% of Italian MPAs had been evaluated for management effectiveness as required by the European Marine Strategy Framework Directive (2008/56/EC) (UNEP-WCMC, 2019). Results from this study highlight the need for the designation of further areas of protection in locations with abundant and well-developed gorgonian forests in Italian coastal waters (Halpern et al., 2010), and to conduct regular monitoring programs inside existing MPAs to evaluate their effectiveness (Fraschetti et al., 2002). The ASI proposed in this study could be used to inform the implementation of new MPAs and Other Effective Area-based Conservation Measures (OECM) to promote greater regional resilience of gorgonian populations. Despite the suboptimal effectiveness of MPAs in protecting gorgonian forests, significantly less abandoned fishing lines were found inside MPA boundaries. This suggests some effectiveness of MPAs in reducing local anthropogenic impact (Roberts et al., 2005), although the effect of MPAs in reducing other local pressures to gorgonian forests (i.e. eutrophication, anchoring, sedimentation, damage caused by recreational SCUBA diving) still needs to be assessed. Additionally, it is important to consider that the occurrence of abandoned fishing lines was used as a proxy for fishing effort because of the absence of reliable data on coastal fisheries. Further investigations at a local site level are recommended where local knowledge on fishing effort, practices and regulations can be considered. The ASIs identified in this project present a list of sites with both high complexity and potentially high exposure to human impacts that warrants further investigation.

4.3 | Evaluation of multi-source methodology

The multi-source approach proved to be an effective method to investigate patterns of species distribution, abundance and state over broad temporal and spatial scales, highlighting the power of public involvement in marine research (Cerrano et al., 2017; Schläppy et al., 2017; Turicchia et al., 2021). All four data sources when integrated displayed a high complementarity, providing compelling evidence on the value of multi-source-approaches in marine subtidal monitoring. The proposed multi-source approach has potential to provide a structured, repeatable and inclusive monitoring tool for gorgonian forests, and other marine organisms within and outside MPAs.

This study highlighted the great potential of WEK in gathering large data sets of species distribution, without the costs and issues of fieldwork (Di Camillo et al., 2018). WEK also provided a wealth of additional information valuable to conservation decision-making such as the locations of *Scyliorhinus stellaris* (Linnaeus, 1758) nursery habitat (mermaid purses attached to gorgonians), observations of mucilage on stressed gorgonians and the dominant colour of *P. clavata* colonies (Appendix S9). Data collection and processing, however, is very time-consuming and results are still limited by search terms. The use of Artificial Intelligence (AI) in identifying focal species and extracting relevant information promises to increase the cost-effectiveness and human labour involved and would be extremely valuable to fully exploit the biological monitoring potential of the WWW (August et al., 2020). The data set produced as part of this study could be used to train a neural network for initial recognition of gorgonians in videos/photographs, laying the first stepping-stones for AI to be implemented in subtidal ecosystems in Italian coastal waters. In addition, videos collected in this study could be used to trial Structure from Motion photogrammetry methods, such as the one developed by Palma et al. (2018), with the potential to derive morphometrics and biomass of gorgonian forests from amateur recorded media.

5 | CONCLUSIONS

In times of rapid global change and financial constraints, the multi-source data integration framework proved to be an effective tool for the collection and repurposing of under-utilized observations across a broad geographical and temporal scale to support decision making in marine conservation. The approach offers a more inclusive participatory model for crowdsourcing marine data while also increasing ocean literacy. The findings suggest that several habitat-forming gorgonian species receive insufficient protection under both international and local conservation measures, with special concern for the structurally important *P. clavata*, with widespread damage occurring across Italian coastal waters. Understanding the efficacy of the existing MPAs for gorgonians and the potential for greater conservation measures to ensure future resilience of gorgonian forests presents a high applied research priority for the region. Our nation-wide data set, maps and indices hold great potential for informing targeted conservation actions, marine spatial planning, habitat-modelling, and to provide a baseline dataset for applied research projects, monitoring, and future comparative studies.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Dryad at https://doi.org/10.5061/dryad.kh189326t (https://datadryad.org/stash/share/ghYIxsXK-CF00PwDa0G7W85nITEdfPxxqCYOji_wVQQ).

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REFERENCES

August, T. A., Pescott, O. L., Joly, A., & Bonnet, P. (2020). AI naturalists might hold the key to unlocking biodiversity data in social media imagery. *Patterns*, *1*(7), 100116. https://doi.org/10.1016/j.patter.2020.100116

Ballesteros, E. 2003. Le coralligène en Mèditerranèe: dèfinition de la biocènose coralligenè, de ses principaux "constructeurs," de sa richesse et de son rôle en ècologie benthique, et analyse des principales menaces. Plan d'Action stratègique pour la conservation de la biodiversitè dans la Region Mèditerraneènnee. Regional Activity Center for Specially Protected Areas, Tunis, Tunisia.

Bally, M., & Garrabou, J. (2007). Thermodependent bacterial pathogens and mass mortalities in temperate benthic communities: A new case of emerging disease linked to climate change. *Global Change Biology*, *13*, 2078–2088. https://doi.org/10.1111/j.1365-2486.2007.01423.x

Bavestrello, G., Cerrano, C., Zanzi, D., & Cattaneo-Vietti, R. (1997). Damage by fishing activities in the gorgonian coral *Paramuricea clavata* in the Ligurian Sea. *Aquatic Conservation*, *7*, 253–262. https://doi.org/10.1002/(SICI)1099-0755(199709)7:3<253::AID-AQC243>3.0.CO;2-1

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), 431–444. https://doi.org/10.1016/j.ecss.2010.01.008.

Betti, F., Bavestrello, G., Bo, M., Ravanetti, G., Enrichetti, F., Coppari, M., Cappanera, V., Venturini, S., & Cattaneo-Vietti, R. (2020). 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

Bianchi, C. N., Azzola, A., Bertolino, M., Betti, F., Bo, M., Cattaneo-Vietti, R., Cocito, S., Montefalcone, M., Morri, C., Oprandi, A., & Peirano, A. (2019). Consequences of the marine climate and ecosystem shift of the 1980-90s on the Ligurian Sea biodiversity (NW Mediterranean). *The European Zoological Journal*, *86*(1), 458–487. https://doi.org/10.1080/24750263.2019.1687765

Boavida, J., Assis, J., Silva, I., & Serrão, E. A. (2016). Overlooked habitat of a vulnerable gorgonian revealed in the Mediterranean and eastern Atlantic by ecological niche modelling. *Scientific Reports*, *6*, 36460. https://doi.org/10.1038/srep36460

Cánovas-Molina, A., Montefalcone, M., Bavestrello, G., Cau, A., Bianchi, C. N., Morri, C., Canese, S., & Bo, M. (2016). A new ecological index for the status of mesophotic megabenthic assemblages in the Mediterranean based on ROV photography and video footage. *Continental Shelf Research*, *15*(121), 13–20. https://doi.org/10.1016/j.csr.2016.01.008

Casas-Güell, E., Teixidó, N., Garrabou, J., & Cebrian, E. (2015). Structure and biodiversity of coralligenous assemblages over broad spatial and temporal scales. *Marine Biology*, *162*(4), 901–912. https://doi.org/10.1007/s00227-015-2635-7

Cebrian, E., Tomas, F., López-Sendino, P., Vilà, M., & Ballesteros, E. (2018). Biodiversity influences invasion success of a facultative epiphytic seaweed in a marine forest. *Biological Invasions*, *20*(10), 2839–2848. https://doi.org/10.1007/S10530-018-1736-x

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*, 73–82. https://doi.org/10.1080/02757540801979648

Cerrano, C., Bavestrello, G., Bianchi, C. N., Cattaneo-Vietti, R., Bava, S., Morganti, C., Morri, C., Picco, P., Sara, G., Schiaparelli, S., Siccardi, A., & Sponga, F. (2000). A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (north- western Mediterranean), summer 1999. *Ecology Letters*, *3*, 284–293. https://doi.org/10.1046/j.1461-0248.2000.00152.x

Cerrano, C., Danovaro, R., Gambi, C., Pusceddu, A., Riva, A., & Schiaparelli, S. (2010). Gold coral (*Savalia savaglia)* and gorgonian forests enhance benthic biodiversity and ecosystem functioning in the mesophotic zone. *Biodiversity and Conservation*, *19*, 153–167. http://doi.org/10.1007/S10531-009-9712-5

Cerrano, C., Milanese, M., & Ponti, M. (2017). Diving for science-science for diving: Volunteer scuba divers support science and conservation in the Mediterranean Sea. *Aquatic Conservation*, *27*(2), 303–323. https://doi.org/10.1002/aqc.2663

Coma, R., Pola, E., Ribes, M., & Zabala, M. (2004). Long-term assessment of temperate octocoral mortality patterns, protected vs. unprotected areas. *Ecological Applications*, *14*, 1466–1478.

Coma, R., Ribes, M., Serrano, E., Jimnez, E., Salat, J., & Pascual, J. (2009). Global warming- enhanced stratification and mass mortality events in the Mediterranean. *Proceedings of the National Academy of Sciences of the USA*, *106*, 6176–6181. https://doi.org/10.1073/pnas.0805801106

Council Directive 92/43/EEC (1992) Conservation of natural habitats and of wild fauna and flora. OJL *206*, pp. 7–50

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*, 23814. https://doi.org/10.1371/journal.pone.0023814

Cupido, R., Cocito, S., Barsanti, M., Sgorbini, S., Peirano, A., & Santangelo, G. (2009). Unexpected long-term population dynamics in a canopy-forming gorgonian coral following mass mortality. *Marine Ecology Progress Series*, *394*, 195–200. https://doi.org/10.3354/meps08260

Darmaraki, S., Somot, S., Sevault, F., Nabat, P., Narvaez, W. D., Cavicchia, L., Djurdjevic, V., Li, L., Sannino, G., & Sein, D. V. (2019). Future evolution of marine heatwaves in the Mediterranean Sea. *Climate Dynamics*, *53*(3), 1371–1392.

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., Bavestrello, G., Krzelj, M., & Cerrano, C. (2018). Building a baseline for habitat-forming corals by a multi-source approach, including web ecological knowledge. *Biodiversity and Conservation*, *27*(5), 1257–1276. https://doi.org/10.1007/S10531-017-1492-8

Di Minin, E., Tenkanen, H., & Toivonen, T. (2015). Prospects and challenges for social media data in conservation science. *Frontiers in Environmental Science*, *3*(63), 1–6. https://doi.org/10.3389/fenvs.2015.00063

Earp, H. S., & Liconti, A. (2020). Science for the future: The use of citizen science in marine research and conservation. In S. Jungblut, V. Liebich, & M. Bode (Eds.), *YOUMARES 9 – The ocean: Our research, our future*. Springer. https://doi.org/10.1007/978-3-030-20389-4_1

Fava, F., Bavestrello, G., Valisano, L., & Cerrano, C. (2010). Survival, growth and regeneration in explants of four temperate gorgonian species in the Mediterranean Sea. *The Italian Journal of Zoology*, *77*(1), 44–52. https://doi.org/10.1080/11250000902769680

Follesa, M. C., Cannas, R., Cau, A., Pedoni, C., Pesci, P., & Cau, A. (2013). Deep-water red coral from the Island of Sardinia (North-Western Mediterranean): A local example of sustainable management. *Marine and Freshwater Research*, *64*(8), 706–715. https://doi.org/10.1071/MF12235

Fraschetti, S., Terlizzi, A., Micheli, F., Benedetti-Cecchi, L., & Boero, F. (2002). Marine protected areas in the Mediterranean Sea: Objectives, effectiveness and monitoring. *Marine Ecology*, *23*, 190–200. https://doi.org/10.1111/j.1439-0485.2002.tb00018.x

Galil, B. S. (2019). The spread of non-indigenous species in the Mediterranean–a threat to cold-water corals? In *Mediterranean cold-water corals: Past, present and future* (pp. 513–516). Springer.

Gambi, M. C., Barbieri, F., Signorelli, S., & Saggiomo, V. (2010). Mortality events along the Campania coast (Tyrrhenian Sea) in summers 2008 and 2009 and relation to thermal conditions. *Biologia Marina Mediterranea*, *17*, 126.

Gori, A., Bavestrello, G., Grinyó, J., Dominguez-Carrió, C., Ambroso, S., & Bo, M. (2017). Animal forests in deep coastal bottoms and continental shelf of the Mediterranean Sea. In *Marine animal forests: The ecology of benthic biodiversity hotspots* (pp. 1–27). Springer. https://doi.org/10.1007/978-3-319-17001-5_5-1

Gori, A., Rossi, S., Berganzo, E., Pretus, J. L., Dale, M. R., & Gili, J. M. (2011). Spatial distribution patterns of the gorgonians *Eunicella singularis*, *Paramuricea clavata*, *and Leptogorgia sarmentosa* (cape of Creus, northwestern Mediterranean Sea). *Marine Biology*, *158*(1), 143–158. https://doi.org/10.1007/s00227-010-1548-8

Halpern, B. S., Lester, S. E., & McLeod, K. L. (2010). Placing marine protected areas onto the ecosystem-based management seascape. *Proceedings of the National Academy of Sciences*, *107*(43), 18312–18317. https://doi.org/10.1073/pnas.0908503107

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*(3), 346–363. http://multcomp.R-forge.R-project.org

Huete-Stauffer, C., Vielmini, I., Palma, M., Navone, A., Panzalis, P., Vezzulli, L., & Cerrano, C. (2011). Paramuricea clavata (Anthozoa, Octocorallia) loss in the marine protected area of Tavolara (Sardinia, Italy) due to a mass mortality event. *Marine Ecology*, *32*, 107–116. https://doi.org/10.1111/j.1439-0485.2011.00429.x

IUCN (2016) The IUCN Red List Of Anthozoans In The Mediterranean. https://www.iucn.org/downloads/anzothoa_fact_sheet_final_baja.pdf Retrieved 17/07/2019.

Jarić, I., Correia, R. A., Brook, B. W., Buettel, J. C., Courchamp, F., Di Minin, E., Firth, J. A., Gaston, K. J., Jepson, P., Kalinkat, G., & Ladle, R. (2020). iEcology: Harnessing large online resources to generate ecological insights. *Trends in Ecology & Evolution*, *35*(7), 630–639. https://doi.org/10.1016/j.tree.2020.03.003

Kipson, S., Fourt, M., Teixidó, N., Cebrian, E., Casas, E., Ballesteros, E., Zabala, M., & Garrabou, J. (2011). Rapid biodiversity assessment and monitoring method for highly diverse benthic communities: A case study of Mediterranean coralligenous outcrops. *PLoS ONE*, *6*(11), e27103. https://doi.org/10.1371/journal.pone.0027103

Linares, C., Cebrian, E., Kipson, S., & Garrabou, J. (2013). Does thermal history influence the tolerance of temperate gorgonians to future warming? *Marine Environmental Research*, *89*, 45–52. https://doi.org/10.1016/j.marenvres.2013.04.009

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

Martin, Y., Bonnefort, J. L., & Chancerelle, L. (2002). Gorgonians mass mortality during the 1999 late summer in French Mediterranean coastal waters: The bacterial hypothesis. *Water Research*, *36*, 779–782. https://doi.org/10.1016/S0043-1354(01)00251-2

Micheli, F., Halpern, B. S., Walbridge, S., Ciriaco, S., Ferretti, F., Fraschetti, S., Lewison, R., Nykjaer, L., & Rosenberg, A. A. (2013). Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: Assessing current pressures and opportunities. *PLoS ONE*, *4*, 8–12. https://doi.org/10.1371/journal.pone.0079889

Milazzo, M., Chemello, R., Badalamenti, F., Camarda, R., & Riggio, S. (2002). The impact of human recreational activities in marine protected areas: What lessons should be learnt in the Mediterranean Sea? *Marine Ecology*, *23*, 280–290. https://doi.org/10.1111/j.1439-0485.2002.tb00026.x

Mistri, M., & Ceccherelli, V. U. (1995). Damage and partial mortality in the gorgonian *Paramuricea clavata* in the strait of Messina (Tyrrhenian Sea). *Marine life. Marseille*, *5*, 43–49.

Mokhtar-Jamaï, K., Coma, R., Wang, J., Zuberer, F., Féral, J. P., & Aurelle, D. (2013). Role of evolutionary and ecological factors in the reproductive success and the spatial genetic structure of the temperate gorgonian *Paramuricea clavata*. *Ecology and Evolution*, *3*(6), 1765–1779. https://doi.org/10.1002/ece3.588

Otero, M. M., Numa, C., Bo, M., Orejas, C., Garrabou, J., Cerrano, C., Kruic´, P., Antoniadou, C., Aguilar, R., Kipson, S., Linares, C., Terrn-Sigler, A., Brossard, J., Kersting, D., Casado-Ameza, P., Garca, S., Goffredo, S., Ocaa, O., Caroselli, E., … Zalp, B. (2017). *Overview of the conservation status of Mediterranean anthozoans* (p. 73). IUCN.

Palma, M., Rivas Casado, M., Pantaleo, U., Pavoni, G., Pica, D., & Cerrano, C. (2018). Sfm-based method to assess gorgonian forests (*Paramuricea clavata* [cnidaria, octocorallia]). *Remote Sensing*, *10*(7), 1154. https://doi.org/10.3390/rS10071154

Pinheiro, J, Bates, D, DebRoy, S, Sarkar, D; R Core Team (2019) Nlme: Linear and nonlinear mixed effects models. R package version 3:1–140. https://CRAN.R-project.org/package=nlme

Ponti, M., Grech, D., Mori, M., Perlini, R. A., Ventre, V., Panzalis, P. A., & Cerrano, C. (2016). The role of gorgonians on the diversity of vagile benthic fauna in Mediterranean rocky habitats. *Marine Biology*, *163*, 120. https://doi.org/10.1007/s00227-016-2897-8

Ponti, M., Leoni, G., & Abbiati, M. (2011). Geographical analysis of marine species distribution data provided by diver volunteers. *Biologia Marina Mediterranea*, *18*, 282–283.

Ponti, M., Perlini, R. A., Ventra, V., Grech, D., Abbiati, M., & Cerrano, C. (2014). Ecological shifts in Mediterranean coralligenous

assemblages related to gorgonian forest loss. *PLoS ONE*, *9*, 102782. https://doi.org/10.1371/journal.pone.0102782
Ponti, M., Turicchia, E., Ferro, F., Cerrano, C., & Abbiati, M. (2018). The understorey of gorgonian forests in mesophotic temperate reefs. *Aquatic Conservation*, *28*, 1153–1166. https://doi.org/10.1002/aqc.2928
QGIS Development Team (2019) QGIS geographic information system. Open Source Geospatial Foundation Project. http://qgis.osgeo.org
R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/
Roberts, C. M., Hawkins, J. P., & Gell, F. R. (2005). The role of marine reserves in achieving sustainable fisheries. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1453), 123–132. https://doi.org/10.1098/rstb.2004.1578
Rodrigues, L. C., van den Bergh, J. C., Loureiro, M. L., Nunes, P. A., & Rossi, S. (2016). The cost of Mediterranean Sea warming and acidification: A choice experiment among scuba divers at Medes Islands, Spain. *Environmental and Resource Economics*, *63*, 289–311. https://doi.org/10.1007/S10640-015-9935-8
Rossi, S. (2013). The destruction of the 'animal forests' in the oceans: Towards an over-simplification of the benthic ecosystems. *Ocean and Coastal Management*, *84*, 77–85. https://doi.org/10.1016/j.ocecoaman.2013.07.004
Rossi, S., & Gili, J. M. (2009). The cycle of gonadal development of the soft bottom-gravel gorgonian Leptogorgia sarmentosa in the NW Mediterranean Sea. *Invertebrate Reproduction and Development*, *53*, 175–190.
Ruitton S, Belloni B, Marc C, Boudouresque C (2019) Ghost med: Assessment of the impact of lost fishing gear in the French Mediterranean Sea. 3rd symposium on the conservation of coralligenous and other calcareous bio-constructions. January 2019, Antalya, Turkey. https://hal.archives-ouvertes.fr/hal-02112113
Santangelo, G., & Abbiati, M. (2001). Red coral: Conservation and management of an over-exploited Mediterranean species. *Aquatic Conservation*, *11*, 253–259. https://doi.org/10.1002/aqc.451
Santangelo, G., Cupido, R., Cocito, S., Bramanti, L., Priori, C., Erra, F., & Iannelli, M. (2015). Effects of increased mortality on gorgonian corals (cnidaria, Octocorallia): Different demographic features may lead affected populations to unexpected recovery and new equilibrium points. *Hydrobiology*, *759*, 171–187. https://doi.org/10.1007/S10750-015-2241-1
Schläppy, M. L., Loder, J., Salmond, J., Lea, A., Dean, A. J., & Roelfsema, C. M. (2017). Making waves: Marine citizen science for impact. *Frontiers in Marine Science*, *4*, 146. https://doi.org/10.3389/fmars.2017.00146
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
Smale, D. A., Wernberg, T., Oliver, E. C., Thomsen, M., Harvey, B. P., Straub, S. C., Burrows, M. T., Alexander, L. V., Benthuysen, J. A., Donat, M. G., & Feng, M. (2019). Marine heatwaves threaten global biodiversity and the provision of ecosystem services. *Nature Climate Change*, *9*(4), 306–312.
Thiel, M., Penna-Díaz, M. A., Luna-Jorquera, G., Salas, S., Sellanes, J., Stotz, W., et al. (2014). Citizen scientists and marine research: Volunteer participants, their contributions, and projection for the future. *Oceanography and Marine Biology*, *52*, 257–314.
Toivonen, T., Heikinheimo, V., Fink, C., Hausmann, A., Hiippala, T., Järv, O., Tenkanen, H., & Di Minin, E. (2019). Social media data for conservation science: A methodological overview. *Biological Conservation*, *233*, 298–315. https://doi.org/10.1016/j.biocon.2019.01.023
Torrents, O., Tambutté, E., Caminiti, N., & Garrabou, J. (2008). Upper thermal thresholds of shallow vs. deep populations of the precious Mediterranean red coral *Corallium rubrum* (L.): Assessing the potential effects of warming in the NW Mediterranean. *Journal of Experimental Marine Biology and Ecology*, *357*(1), 7–19. https://doi.org/10.1016/j.jembe.2007.12.006
Turicchia, E., Ponti, M., Rossi, G., Milanese, M., Di Camillo, C. G., & Cerrano, C. (2021). The reef check mediterranean underwater coastal environment monitoring protocol. *Frontiers in Marine Science*, *8*(620368), 1–14. https://doi.org/10.3389/fmars.2021.620368.
UNEP-WCMC (2019) Protected area profile for Italy from the world database of protected areas, August 2019. www.protectedplanet.net
Valisano, L., Notari, F., Mori, M., & Cerrano, C. (2016). Temporal variability of sedimentation rates and mobile fauna inside and outside a gorgonian garden. *Marine Ecology—An Evoloutionary Perspective*, *37*, 1303–1314. https://doi.org/10.1111/maec.12328
Venables, W. N., & Ripley, B. D. (2002). *Modern applied statistics with S* (4th ed.). Springer.
Verdura, J., Linares, C., Ballesteros, E., Coma, R., Uriz, M. J., Bensoussan, N., & Cebrian, E. (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), 5911. https://doi.org/10.1038/S41598-019-41929-0
Vezzulli, L., Pezzati, E., Huete-Stauffer, C., Pruzzo, C., & Cerrano, C. (2013). 16SrDNA pyrosequencing of the Mediterranean gorgonian *Paramuricea clavata* reveals a link among alterations in bacterial holobiont members, anthropogenic influence and disease outbreaks. *PLoS ONE*, *8*, e67745. https://doi.org/10.1371/journal.pone.0067745
Vieira, E. A., de Souza, L. R., & Longo, G. O. (2020). Diving into science and conservation: Recreational divers can monitor reef assemblages. *Perspectives in Ecology and Conservation*, *18*(1), 51–59. https://doi.org/10.1016/j.pecon.2019.12.001

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Author contributions: All authors conceived and designed the study; A.L. gathered the data and completed the analysis; all authors contributed to the writing, which was led by A.L.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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