Received: 23 May 2023 | Revised: 13 November 2023 | Accepted: 17 November 2023

DOI: 10.1002/aqc.4048

RESEARCH ARTICLE

WILEY

Changes in threats to macroalgal forests (*Cystoseira sensu lato*) at three restoration sites in the Mediterranean Sea

Dóra Fehér[1] | Silvia Bianchelli[2] | Jana Verdura[3,4] | Roberto Danovaro[2] | Brandon P. Anthony[5]

[1]Budapest, Hungary

[2]Department of Life and Environmental Sciences, Polytechnic University of Marche, Ancona, Italy

[3]Universitat de Girona, Girona, Spain

[4]Université Côte d'Azur, CNRS, UMR 7035 ECOSEAS, Nice, France

[5]Department of Environmental Sciences and Policy, Central European University, Vienna, Austria

Correspondence
Brandon P. Anthony, Department of Environmental Sciences and Policy, Central European University, Vienna, Austria.
Email: anthonyb@ceu.edu

Funding information
D.F. was supported by a Central European University Research Grant. S.B. and R.D. were supported through the EASME-EMFF (Sustainable Blue Economy) Project AFRIMED (http://afrimedproject.eu/, grant agreement N. 789059), supported by the European Community Biodiversa+ FORESCUE (Biodiversa2021-134) project, BiodivProtect call on 'Supporting the protection of biodiversity and ecosystems across land and sea'.

Abstract

1. Macroalgal forests, such as *Cystoseira sensu lato*, comprise crucially important habitats in the Mediterranean Sea, providing protection and structural complexity, enhancing productivity, food, shelter and spawning grounds in coastal marine ecosystems. However, due to increasing direct and indirect anthropogenic impacts, these habitats are rapidly declining.
2. Due to their biological and ecological characteristics, the natural recovery of the populations belonging to these species is slow. For this reason, active restoration has been identified as an effective tool for their recovery.
3. Since the mitigation of impacts is one of the prerequisites for restoration success, Modified Threat Reduction Assessments were used to estimate success of conservation measures in three areas of the central and north-western Mediterranean Sea (Costa del Conero, Italy; Cala Bona and Port de la Selva, Spain). In particular, the assessment was conducted to: (i) identify and evaluate the changes in threats to *Cystoseira s.l.* species between 2019 and 2021; and (ii) propose management in relation to the ongoing restoration measures.
4. A total of 13 threats were identified and determined negative Modified Threat Reduction Assessment Indices of approximately −46%, −14% and −13%, respectively, in Costa del Conero, Cala Bona and Port de la Selva. The study's findings, when combined, document the increase of the scale of threats during the second year of the survey period despite the lockdown due to COVID-19.

KEYWORDS
anthropogenic threats, *Cystoseira s.l*, macroalgal forests, marine habitat restoration, Mediterranean Sea, Modified Threat Reduction Assessment

1 | INTRODUCTION

Anthropogenic activities are exerting an increasing impact on Earth's vulnerable and complex systems that pose a risk to biodiversity, ecosystem functioning and services and thus human societies worldwide (Halpern et al., 2008). Therefore, the importance of biodiversity conservation is more urgent than ever. One of the areas with the highest biodiversity around the world is the Mediterranean Sea (Coll et al., 2010; Bianchi et al., 2012). It hosts unique diversity, harbouring a high number of endemic species while also being an

important area for various life history stages (Abdulla et al., 2008). It is also beneficial for human populations as it has a significant importance for its provision of ecosystem services, including commercial fish stocks (Guerriero et al., 2017) and tourism (Drius et al., 2019), as well as contributing to human health. International tourism in the Mediterranean area has grown from 58 million in 1970 to nearly 314 million in 2014; furthermore, by 2030, it is expected to grow to 500 million visitors a year (UNWTO, 2015). However, during recent decades, the pressure of growing human populations, increasing maritime activities and overexploitation of marine resources has caused a loss in marine biodiversity and accelerated the effects of climate change (IUCN, 2020; AFRIMED, 2021). To restore these ecosystems, several restoration projects were funded in recent years (e.g. MERCES, Algal Forest Restoration in the Mediterranean Sea (AFRIMED), ROC-POP Life). One of the objectives of the projects was to develop, implement and validate protocols to effectively restore macroalgal forests (*Cystoseira sensu lato* species) in the Mediterranean Sea while maximizing the delivery of conservation and societal and economic benefits (AFRIMED, 2021).

Habitat destruction has become one of the most recurring threats to biodiversity, especially affecting the midlittoral zone of the world's seas. *Cystoseira s.l.* forests (including the genera *Cystoseira*, *Ericaria* and *Gongolaria*; Molinari Novoa & Guiry, 2020), one of the most important and productive coastal ecosystems across the Mediterranean Sea, are also threatened (Thibaut et al., 2005; Iveša et al., 2016; Mariani et al., 2019; Tamburello et al., 2022). These species are considered ecosystem engineers since they ensure high levels of associated biodiversity and ecosystem functioning by their direct effect on the environment (Bianchelli et al., 2016; Bianchelli & Danovaro, 2020).

All *Cystoseira s.l.* species, except for *Cystoseira compressa*, are listed as 'threatened or endangered' in Annex II of the Barcelona Convention (United Nations Environment Programme/Mediterranean Action Plan; UNEP/MAP, 2009). These species are also under surveillance by the International Union for the Conservation of Nature (IUCN), the Regional Activity Centre for Specially Protected Areas established under the Barcelona Convention and Mediterranean network of Marine Protected Areas (MPAs).

Typically, the change in habitats is a consequence of habitat destruction and also implies a transition from a structurally complex habitat to a less complex one, which in this case are macroalgal canopies replaced by turf-forming seaweeds (Mangialajo et al., 2008) or, in some cases, barren grounds (Colletti et al., 2020). Macroalgal forests play a significant role in primary productivity across coastal regions as well as within complex marine food webs (De La Fuente et al., 2019). These macroalgal forests are composed of habitat forming species that contribute to the reproductive success of many Mediterranean fish species, ensuring shelter and both nursery and feeding grounds (Cheminée et al., 2013).

Here, based on the restoration decision tree outlined in Smith et al. (2023), how the threats to these habitats have changed in three sites of the Mediterranean Sea undergoing restoration interventions were assessed. This research aims to contribute to identifying the change of threats to *Cystoseira s.l.* forests in the Mediterranean and identifying the management options that can maximize restoration success.

2 | METHODOLOGY

2.1 | Modified Threat Reduction Assessment

Modified Threat Reduction Assessments (MTRAs) aim to assess the direct threats of biodiversity within a specified area over a chosen time period as a proxy measure of conservation success (Margoluis & Salafsky, 2001; Anthony, 2008) or across sites of interest (Milatovic et al., 2019). They are particularly useful where little or no baseline data exist for indicators of biodiversity, including in this research's study sites. In order to conduct this assessment, the following assumptions are made: threats to biodiversity are human induced; all threats can be identified and ranked according to the area, intensity and urgency at any point in time; and changes in threats can be measured or estimated (Margoluis & Salafsky, 2001). The MTRA tool also incorporates the IUCN Standard Lexicon of Threats (Salafsky et al., 2008), allowing for comparison across sites (Matar & Anthony, 2010).

The aim of this research was to identify current threats affecting selected *Cystoseria s.l.* macroalgal forests in three AFRIMED sites within the Mediterranean Sea. The MTRA tool was suitable for the research as it does not require previously collected data, is cost and time effective, allows for comparison between sites and can be conducted through online workshops due to travel restrictions (in this case, due to COVID-19 pandemic). According to the MTRA tool, in order to ensure the quality of the data, each participant should: (i) be an expert on *Cystoseira s.l.* species and ecology; (ii) have worked in the area during the entire assessment period; (iii) be able to indicate the scale and nature of threats; and (iv) be familiar with basic concepts such as biodiversity, ecosystem services and habitat conditions of the Mediterranean Sea. The workshop participants were chosen from the AFRIMED project and satisfied the above criteria.

2.2 | Workshop administration

In total, three MTRA workshops were carried out in May 2021 for three assessment areas: (i) Natura 2000 sites (IT5320005, IT5320015, IT5320007) near Costa del Conero (central Adriatic, Italy); (ii) a site in Cala Bona (north-western Mediterranean, Spain); and (iii) within Cap de Creus Natural Park in Port de la Selva (north-western Mediterranean, Spain; Figure 1).

The assessment for each site started with a brief presentation to introduce the research, methodology, key concepts as well as the step-by-step guide of the workshop. For the area at Costa del Conero, Italy, the workshop was conducted through the Zoom online platform and was attended by three participants. Moreover, after the workshop the results were forwarded to participants who were invited but could not make it to the event to validate the results. For the two Spanish sites, two separate assessments were conducted with seven participants and also via Zoom.

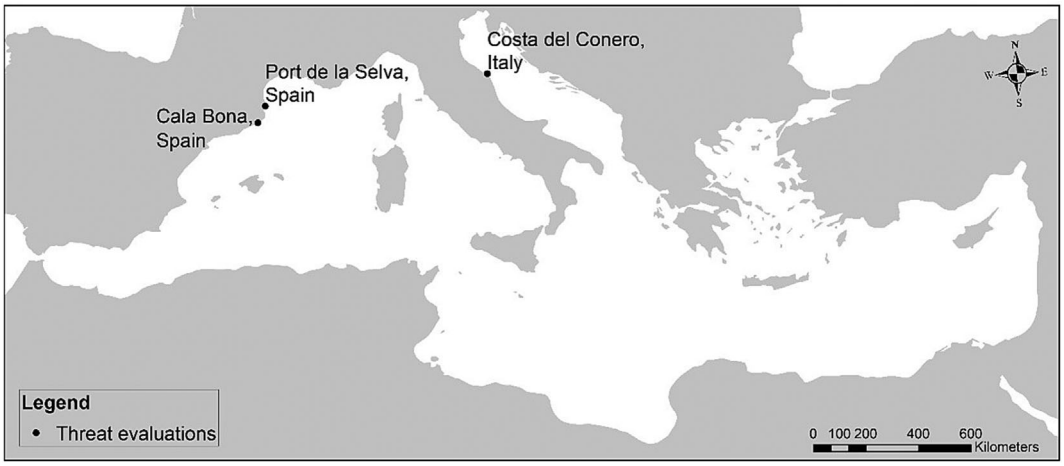

FIGURE 1 Assessed *Cystoseira sensu lato* spp. populations located in the Mediterranean Sea.

The spatial and temporal boundaries of the assessment were collectively determined. The assessment period for all sites was from 2019 until 2021 (day of the workshop), which corresponds to the duration of the AFRIMED project. By utilizing the IUCN Standard Lexicon of Threats, participants were asked to identify all direct threats present at the beginning of the assessment period in the area. As in Anthony (2008), to avoid the possibility of losing nuanced information resulting from threat standardization, the participants were also asked to describe the threats in detail. During the following step, participants were asked to determine what a 100% reduction of each threat would be, following the 100% threat reduction defined by Anthony (2008) as the complete eradication of a given threat. In case the participants claimed that the total elimination of a given threat is not feasible with management intervention, a different definition of a 100% reduction was made referring to the best possible outcome by the management intervention. Subsequently, participants were asked to collectively rank the listed threats based on how they impact the *Cystoseira s.l.* spp. across each site with respect to area, intensity and urgency. The scoring scale was based on the number of identified threats, with number 1 being the minimum scoring. Equal scoring was discouraged. The ranking scores were totalled for each individual threat. After having all the total rankings, participants were asked to review the results and modify them if they felt that it was not an accurate representation of the threats. Then, participants were asked to estimate how much (as a percentage) the threat had changed over the assessment period. If the threat had been completely mitigated, a positive score was given with the maximum score being +100%. By contrast, if the threat had worsened, the score was negative. There was no maximum negative score; therefore, if a threat had worsened by threefold, the threat was given a score of −300%. Moreover, if the given threat was not present at the beginning of the assessment period, but emerged since, then the threat was given a score of −100%. Raw scores were then calculated for each threat where the total ranking was multiplied by the estimated percentage of change (Margoluis & Salafsky, 2001). Lastly, the MTRA index was calculated according to the formula by Margoluis & Salafsky (2001) and Anthony (2008): MTRA index $= \Sigma$ raw scores/total rankings $\times$ 100.

At the end of the assessment, the management interventions and possible reasons for changes in threats were discussed with workshop participants.

2.3 | Semi-structured interviews

To better understand to what degree different threats affect Mediterranean macroalgae at the chosen sites with specific reference to the *Cystoseira s.l.* group of species, and to current restoration methods, two experts from the Polytechnic University of Marche (Italy) and from the University of Girona and the Blanes Centre for Advanced Studies (Spain) were interviewed using semi-structured interviews. Semi-structured interviews allow flexibility as the questions can be modified depending on themes emerging during the interview (Edwards & Holland, 2013). The interviews were then transcribed and analysed according to both the research aims and emerging themes.

The interviews were dedicated to understanding changes occurring in a relatively short time frame (2019–2021, which included the COVID-19 stop of most activities due to temporary lockdowns). Such a time frame allowed a comprehensive assessment of these three marine areas undergoing restoration and were able to single out with high detail all phenomena and processes occurring at the areas investigated.

2.4 | Research ethics protocol

Ethics approval for this research was attained through Central European University and assured voluntary consent, anonymity, confidentiality and no harm. All workshop participants and interviewees were informed of the ethics protocol before the interviews and the MTRAs began.

3 | RESULTS

3.1 | Adriatic Sea, Costa del Conero, Italy

The results of the workshop for the Italian site including the MTRA calculations and the list of identified threats are shown in Table 1. Ten major threats were identified to the area's *Cystoseira s.l.* populations during the assessment period. The MTRA index has a negative value of −46.0% indicating that the total threats had worsened since the beginning of the assessment period. This is largely due to the radically worsened 'problematic native species', which has deteriorated threefold according to the participants. In addition, according to the workshop participants, 'temperature extremes' and 'storms and flooding' have worsened since the beginning of the project. Although the effect of 'fishing and harvesting aquatic resources' has not changed since 2019 it was recognized as the most harmful threat according to the total ranking, followed by 'tourism and recreational areas', which also remained unchanged over the assessment period. 'Shipping lanes', 'garbage and solid waste', 'habitat shifting and alteration', 'invasive non-native/alien species', and 'earthquakes/tsunamis' were also listed as threats to *Cystoseira s.l.* spp. by the participants, although no change was identified during the assessment period. Unexpectedly, the participants gave the same rank to area, intensity and urgency for all threats; therefore, the moderator explained the criteria again, but participants were confident that these estimates were accurate.

3.2 | Cala Bona, Spain

The two different sites that are inhabited by *Ericaria crinita* were assessed independently. The score of the 'area' for both Spanish sites were given the same numbers as the participants claimed that they cannot distinguish and rank between the threats as the area is so small that all of threats effect the same area equally. Therefore, an average was given in both cases.

The results of the Cala Bona MTRA are shown in Table 2. Seven significant threats were identified regarding *Cystoseira s.l.* spp. during the assessment period. The MTRA index has a negative value of −13.5%, indicating that the threats have worsened overall since the beginning of the AFRIMED project here as well. There was a new threat, 'storms and flooding' associated with the assessment period. The participants mentioned that they have always dealt with storms; however, the scales of recent storms seem to be unprecedented. 'Tourism and recreational areas' and 'recreational activities' have also worsened by an estimated −10% and −30%, respectively. Although 'household sewage and urban wastewater' represents the greatest threat to *Cystoseira s.l.* populations, the scale of the threat was not perceived to have changed throughout the assessment period. Additionally, the estimated effects of 'problematic native species', 'housing and urban areas' and 'fishing and harvesting aquatic resources' have not changed in the given time period.

3.3 | Port de la Selva, Spain

In this area, only five major threats were identified affecting *Cystoseira s.l.* spp., which are presented in Table 3. The MTRA index has a value of −13.3%, which again shows that the perceived threats have worsened overall since the beginning of the assessment period. This negative change is due to the perceived change of the intensity of the 'temperature extremes', which has worsened by −50% during the project. The rest of the identified threats such as 'household sewage and urban wastewater', 'problematic native species', 'recreational activities', and 'storms and flooding' remained the same.

TABLE 1 Modified Threat Reduction Assessment (MTRA) workshop results from Costa del Conero, Italy.

No.	Threat	IUCN threat code	Ranking criteria			Total ranking	% threat change	Raw score
			Area	Intensity	Urgency			
1.	Fishing and harvesting aquatic resources	5.4	10	10	10	30	0%	0
2.	Tourism and recreational areas	1.3	9	9	9	27	0%	0
3.	Problematic native species	8.2	8	8	8	24	−300%	−72
4.	Habitat shifting and alteration	11.1	7	7	7	21	0%	0
5.	Garbage and solid waste	9.4	6	6	6	18	0%	0
6.	Storms and flooding	11.4	5	5	5	15	−10%	−1.5
7.	Temperature extremes	11.3	4	4	4	12	−20%	−2.4
8.	Invasive non-native species	8.1	3	3	3	9	0%	0
9.	Shipping lanes	4.3	2	2	2	6	0%	0
10.	Earthquakes/tsunamis	10.2	1	1	1	3	0%	0
		Total	55	55	55	165		−75.9
						MTRA index		**−46.0**

TABLE 2 Modified Threat Reduction Assessment (MTRA) workshop results from the site near Cala Bona, Spain.

No.	Threat	IUCN threat code	Ranking criteria			Total ranking	% threat change	Raw score
			Area	Intensity	Urgency			
1.	Household sewage and urban wastewater	9.1	4	7	7	18	0%	0
2.	Tourism and recreational areas	1.3	4	6	4	14	−10%	−1.4
3.	Recreational activities	6.1	4	4	5	13	−30%	−3.9
4.	Problematic native species	8.2	4	5	3	12	0%	0
5.	Housing and urban areas	1.1	4	2	6	12	0%	0
6.	Fishing and harvesting aquatic resources	5.4	4	3	2	9	0%	0
7.	Storms and flooding	11.4	4	1	1	6	−100%	−6.0
		Total	28	28	28	84		−11.3
						MTRA index		**−13.5**

TABLE 3 Modified Threat Reduction Assessment (MTRA) workshop results from the site of Port de la Selva, Spain.

No.	Threat	IUCN threat code	Ranking criteria			Total ranking	% threat change	Raw score
			Area	Intensity	Urgency			
1.	Temperature extremes	11.3	3	5	5	13	−50%	6
2.	Household sewage and urban wastewater	9.1	3	3	4	10	0%	0
3.	Problematic native species	8.2	3	4	1	8	0%	0
4.	Recreational activities	6.1	3	2	2	7	0%	0
5.	Storms and flooding	11.4	3	1	3	7	0%	0
		Total	15	15	15	45		−6
						MTRA index		**−13.3**

4 | DISCUSSION

4.1 | *Changes in threats to* Cystoseira s.l. *macroalgal forests*

In total, 13 threats were identified during the three workshops. Several common threats were identified across the studied sites (Table 4). Here, a focus on those threats that were identified in at least two of the sites is provided.

The threat represented by 'problematic native species' was recognized in all three sites. In the site in Costa del Conero, the participants reported that the situation has worsened threefold, primarily due to the demographic explosion of native sea urchin populations in the area. The sea urchins belong to the species *Paracentrotus lividus*, which can intensively graze macroalgae over hard substrates and be responsible for the creation of barren grounds (unvegetated hard bottoms) in several Mediterranean coastal areas (Sala et al., 2012). The most likely cause of shifts from macroalgal forests to barren grounds in the Mediterranean Sea, and recognized by both the workshop participants and interviewees, is the overexploitation of the natural predators of sea urchins (Giakoumi et al., 2012; Boada et al., 2017).

Any mitigation management actions are also hindered by the nature of this problem. When sea urchin barrens persist, they create a stable state in the system (Lauzon-Guay et al., 2009), enabling benthic systems to exist with different multiple stable states separated by unstable equilibria (Watson & Estes, 2011). This phenomenon of multiple states coexisting within a given area can be described by hysteresis, which is the inability to reverse to the previous state when a critical parameter is disturbed (Melis et al., 2019). In such cases, reversing such states through passive management (e.g. control of sea urchin population density) and conservation actions is often impossible, and active restoration actions are needed (Cebrian et al., 2021).

The main restoration action that is carried out as part of the restoration project, mentioned by all workshop participants and interviewees, is the replanting of damaged *Cystoseira s.l.* spp. in various suitable habitats, by means of recruitment enhancement. Additionally, Piazzi & Ceccherelli (2019) have demonstrated that harvesting sea urchin populations for commercial reasons in the Mediterranean Sea increased the effects of the *Cystoseira s.l.* restoration. Moreover, others claim that predator removal is most likely to be most effective when it is applied annually as this frequency enhances the probability that extensive habitat recovery has taken place (Sanderson et al., 2015).

TABLE 4 Summary of the identified threats from all workshops.

Threat	IUCN Threat code	Costa del Conero	Cala Bona	Port de la Selva	No. of sites
Problematic native species	8.2	▼	—	—	3
Storms and flooding	5.4	▼	▼	—	3
Tourism and recreational areas	1.3	—	▼		2
Fishing and harvesting aquatic resources	5.4	—	—		2
Temperature extremes (marine heatwaves)	11.3	▼		▼	2
Recreational activities	6.1		▼	—	2
Household sewage and urban wastewater	9.1		—	—	2
Habitat shifting and alteration	11.1	—			1
Garbage and solid waste	9.4	—			1
Invasive non-native species	8.1	—			1
Shipping lanes	4.3	—			1
Earthquakes/tsunamis	10.2	—			1
Housing and urban areas	1.1		—		1
Total	**13**	**10**	**7**	**5**	

Note: ▼ = worsening; — = unchanged over assessment period.

In other coastal ecosystems dominated by brown macroalgae, namely, the kelp forests along the North Atlantic and Pacific Ocean coasts, other approaches have been successfully tested including those related to 'green gravel', consisting of small rocks seeded with kelp and reared in the laboratory until 2–3 cm, before out-planting to the field (Fredriksen et al., 2020; https://www.greengravel.org/).

At Cala Bona, workshop participants also highlighted the role of native populations of herbivorous dreamfish (*Sarpa salpa*) grazing in the area, as has been pointed out in other areas of the Mediterranean Sea (Gianni et al., 2017). Although the participants did not report any changes in the threat over the assessment period, they emphasized the importance to further study grazing activity effects on *Cystoseira s.l.* restoration success. However, this threat is solely based on field observations and whether the scale of the present herbivory is significant remains untested. To fully understand the effect of the most crucial common threat, that is, the grazing of problematic native species, further research would be needed on the effect of the different types of herbivories present at the investigated sites. This is especially important due to the link between the success of the restoration and the number of herbivores present.

The threat of 'storms and flooding' has also been recognized in all three sites that were examined during the workshops. Participants mentioned the damaging effect of storms regarding the viability of the *Cystoseira s.l.* populations. At the Costa del Conero site, the effects of more frequent and stronger storms worsened by an estimated 10%, while in Cala Bona, it was recognized as a threat that had emerged since the beginning of the project. Naturally, storms have occurred before the start of the project as well; however, it was not considered as a threat because it did not significantly damage the populations by creating stronger wave actions. In Port de la Selva, there was no change reported regarding the threat.

During recent years, there has been a significant increase in the number and intensity of storms in the Mediterranean Sea (Amores et al., 2020). These severe sea storms have had damaging effects as they cause the movement of gravel and even larger rocks that crush soft benthic organisms such as macroalgae (Rindi et al., 2020). Even the smallest erosion of *Cystoseira s.l.* populations may enable habitat shifts to sea grass and turf-dominated assemblages. These turfs are characterized by fast growth and multiple reproductive events; therefore, it is relatively easy for them to outcompete *Cystoseira s.l.* species, which are sensitive to changes and have a slow rehabilitation (Benedetti-Cecchi et al., 2001). These shifts from canopy to turf-dominated habitats usually go hand in hand with a decrease in biodiversity, species composition and biomass (Wernberg et al., 2016). Consequently, there is a decrease in the ecological, aesthetic and economic value of the habitat (Benedetti-Cecchi et al., 2001).

The effect of 'tourism and recreational areas' is considered one of the top threats in both Costa del Conero and Cala Bona. However, while in Costa del Conero no changes were reported, in Cala Bona the conditions worsened since the beginning of the project (−10%). Although due to the global pandemic, and associated lockdown through the summer of 2020, there were fewer (if any) international tourists visiting the sites, the number of domestic tourists increased tremendously in 2021 and afterwards. In fact, although Cala Bona used to be a small fishing town, nowadays it is a popular holiday destination for both locals and international tourists with many hotels, restaurants, bars and clubs.

Mediterranean countries are the world's leaders in tourism, receiving more than 400 million tourists in 2019 (decreased to 139 million in 2021; Statista, 2022), with Spain ranking second, while Italy is the third most popular destination within the entire Mediterranean region (UNWTO, 2017). During the workshops, it emerged that the Mediterranean tourist season is usually the busiest

from June to September. There are several potential impacts associated with the high levels of coastal tourism, which are especially prevalent during this period. These include increased littering (UNEP/MAP, 2015), insufficient sewage treatment capacity (Kent et al., 2002) and emerging contaminants from sunscreens (Tsui et al., 2014; Varella et al., 2022).

The impact of 'fishing and harvesting aquatic resources' was mentioned in Costa del Conero and in Cala Bona and was ranked as the top priority threat for the former. Direct damage from fisheries affecting the coastal areas such as beam trawls, dredges and anchors was mentioned during the workshop and supported by evidence elsewhere (De Biasi & Pacciardi, 2008; de Juan & Lleonart, 2010). Linked to the threat of 'problematic native species', overfishing of predators of herbivores that predate on *Cystoseira s.l.* has one of the most crucial cascading effects on benthic communities, as the presence of herbivores can lead to a reduction in local macroalgae populations (Williams & Polunin, 2001). Human-induced top-predator alterations triggering cascading effects are not rare in marine environments as the same phenomenon was shown by Byrnes et al. (2006), whereby they demonstrated similar cascading risk effects in kelp forests following human-induced marine predator removal.

Two additional factors related to fishery and/or harvesting natural resources (also coupled) were also reported during the workshops.

1. In the Costa del Conero area, hydraulic dredging (by industrial vessels) collects bivalves (mainly *Chamelea gallina*) prompting sediment resuspension and enhancing water column turbidity, thus possibly impairing *Cystoseira s.l.* spp. growth and juvenile settlement.
2. Artisanal fishery (and also traditional harvesting by local inhabitants, regulated by per capita quotas, of the wild mussel *Mytilus galloprovincialis*) coupled with storms of 2021 destroyed parts of the *M. galloprovincialis* belt leaving room for colonization by *P. lividus*, whose population exploded (as already occurred in other geographical areas; see Ling et al., 2015).

These findings suggest governance and fisheries regulations weaknesses in the investigated areas of the Mediterranean. The evidence of poorly regulated fisheries in the Mediterranean Sea is widely documented (Vasilakopoulos et al., 2014), as is evidence of the negative impacts of the fishing industry on trophic food webs (Colloca et al., 2017). This lack of adequate management measures regarding Mediterranean fisheries is causing a general concern among scholars and non-governmental organizations (Amengual & Alvarez-Berastegui, 2018). Due to the presence of multi-species, multi-fleets fisheries, management is indeed challenging especially in a rapidly changing ecosystem such as the Mediterranean Sea (Mackinson et al., 2009). This issue requires an urgent update of the management regime in Mediterranean fisheries to prevent unregulated fishing.

'Temperature anomalies' (marine heatwaves) were reported from Costa del Conero of the Adriatic Sea (central Mediterranean Sea) and Port de la Selva (north-west Mediterranean Sea). For both sites, in the last years, the effects were reported to have worsened by −20% and −50%, respectively. These marine heatwaves are increasingly frequent and have the strongest effects on kelp and fucoid populations (Wernberg et al., 2016). Climate change is causing an increase in the frequency and intensity of marine heatwaves and mass mortality events of marine organisms in the Mediterranean Sea. This basin has experienced exceptional thermal conditions in recent years, resulting in the onset of five consecutive years of widespread mass mortality events across the basin (Garrabou et al., 2022). These marine heatwaves affected thousands of kilometres of coastline from the surface to 45 m, thus fully impacting the range of bathymetric distribution of macroalgal forests, extending down to 50 m water depth (Vergés et al., 2009; Garrabou et al., 2022). Moreover, they are projected to further increase in the coming decades (Oliver et al., 2018). Due to the semi-enclosed form of the Mediterranean basin, shifting to more favourable climatic conditions is limited (Burrows et al., 2014). This projection is especially critical for sessile organisms such as *Cystoseira s.l.* spp., which can be extremely sensitive to changes in the environment, and their populations are already fragmented, which further diminishes their adaptive capability (Verdura et al., 2021). Significant reductions in settlement of various *Cystoseira s.l.* species have been observed after a few days of exposure to abnormally high temperatures (Capdevila et al., 2015; Verdura et al., 2018; Monserrat et al., 2022). Moreover, photosynthetic efficiency of adults was also proven to be reduced after 2 weeks of exposures at 28°C, while after 25 days even the tissues were damaged in the population of Port de la Selva (Verdura et al., 2021). To tackle the impacts of marine heatwaves in the Mediterranean, Verdura et al. (2021) suggest that open and connected habitats (with greater water exchange as opposed to enclosed or semi-enclosed habitats) could represent a climatic refugia for macroalgal species. Consequently, they support the identification of possible contemporary climatic refugia being prioritized for conservation and restoration strategies (Verdura et al., 2018). However, the habitat vulnerability for marine heatwaves should be first assessed for a successful management outcome (Wood et al., 2019).

The impact of 'recreational activities' such as motorboats, jet-skis, dive boats, spearfishing and scuba divers were reported from both sites in Spain with no change in the threat reported from Port de la Selva, whereas there has been an estimated −30% change in this threat at Cala Bona. Although international tourism had decreased due to the global COVID-19 pandemic, the number of local tourists has rebounded dramatically, exacerbating this threat. Moreover, nowadays, extreme sports such as diving and surfing are popular; therefore, many people would like to enjoy these activities at the coast. These activities can involve mechanical disturbance, which can damage both old and recruited *Cystoseira s.l.* plantations.

Contemporaneously, the growing number of households over time is potentially increasing sewage pollution (Fraschetti et al., 2006) and nutrient enrichment (Arevalo et al., 2007). There might be the case of local and temporary sewage problems in some Mediterranean localities (Köcke et al., 2010). According to our interviewed experts,

sewage and wastewater from the coastal bars in Cala Bona are directly discharged to the coastal waters or in other areas, possibly coupled with the impacts of recreational boats, which necessitates more targeted management for protecting the coastal waters and preventing serious effects.

4.2 | Interactions between conservation and restoration efforts

Once populations are destroyed over larger areas, the natural restoration of *Cystoseria s.l.* ecosystems is challenging due to their natural short dispersion capacity and ongoing anthropogenic impacts (Mangialajo et al., 2008; Melis et al., 2019). Apart from the nature and scale of the different threats, the potential restoration opportunities were also discussed during the workshops. It was noted that as many *Cystoseira s.l.* species are classified as endangered or threatened, the disturbance of remaining healthy populations should be minimized for the purpose of being used as donor populations for restoration (Gianni et al., 2017). These restoration approaches might include either passive (protection) or active (recruitment enhancement) tools. Among the active restoration approaches, recruitment enhancement techniques (Verdura et al., 2018) are considered relatively non-destructive as less than 5% of the donor individual (only fertile parts) is being collected for the sake of the restoration (Gianni et al., 2017). Moreover, high rates of long-term restoration success of these techniques based either on in situ and ex situ recruitment has been demonstrated (Gran et al., 2022; Galobart et al., 2023).

In recent years, the scientific progress and achievements in the restoration of *Cystoseira s.l.* is contributing to the ongoing global effort to restore macroalgal-dominated forests (such as kelp forests) and, more broadly, to achieving the goals of ecological restoration on a global scale, as pursued by the 2021–2030 UN Decade on Ecosystem Restoration (Eger et al., 2022). Among the factors potentially threatening the restoration success, intense herbivory has been proven to impact transplanted macroalgal populations and prevent the recovery of *Cystoseira s.l.* (Tamburello et al., 2019). For this reason, the removal of commercial sea urchin or herbivorous fish species can be crucial for the success of the restoration interventions (Piazzi & Ceccherelli, 2019). Nevertheless, since not all sea urchin species are edible, promoting removal and harvesting of predatory species is not always cost effective nor the most easy or sustainable management tool (Piazzi & Ceccherelli, 2017).

Lastly, eradication of pollution was mentioned to be another factor essential for *Cystoseira s.l.* recruitment and therefore the recovery of *Cystoseira s.l.* beds (De Caralt et al., 2020). This is because even subtle pollutant concentration (nutrients, pesticides, heavy metals) can seriously compromise mid-term and long-term viability of *Cystoseira s.l.* forests by reducing the fertility of adults and the survival of recruits (de Caralt et al., 2020).

As Cebrian et al. (2021) demonstrated, in the presence of such stressors, restoration actions are often hindered; therefore, restoration projects should include regular identification, prioritization and adequate mitigation of threats. This component of threat assessment in the restoration project cycle is essential in this study's assessed sites of *Cystoseira s.l.*, but would be useful in other areas, especially where multiple threats are manifested (Gann et al., 2019).

5 | CONCLUSION

The MTRA tool and semi-structured interviews were utilized to identify 13 threats across three sites of the Mediterranean Sea characterized by the presence of relevant macroalgal brown forests (*Cystoseira s.l.*) and undergoing restoration. These threats were ranked by experts according to their area, their urgency and intensity as well as a percentage of change from 2019 to 2021.

Overall, seven of the 13 threats were reported across more than one site, and none of threats was observed as having positive mitigation, that is, all were unchanged or worsening. Two threats, 'problematic native species' and 'storms and flooding', were noted for all three sites that were examined by the MTRA tool. Interviewees also highlighted the problem of extensive herbivory of these problematic native species. Other threats that were observed at multiple sites included tourism and recreational areas, fishing and harvesting aquatic resources, heatwaves, recreational activities and household sewage, and urban wastewater.

The most popular restoration method in the area is recruitment enhancement of *Cystoseira s.l.* spp. to adequate sites where the threats are minimized as far as possible. However, evidence has shown that for the most successful restoration projects, the management of herbivores should be included in the restoration action (e.g. harvesting regulation of herbivory species, such as sea urchins) (Tamburello et al., 2019; Cebrian et al., 2021). Based on interviews and MTRA results, management interventions and protection measures are insufficient or lacking in all the sites (e.g. Natura 2000 sites). As highlighted by interviewees, even though almost all *Cystoseira s.l.* species are protected under Barcelona and Bern Conventions (Bern Convention, 1979), specific management actions on *Cystoseira s.l.* forests should be enforced within Mediterranean MPAs and Special Areas of Conservation such as the Natura 2000 sites.

This study utilizing the MTRA tool has shown that failing to recognize the necessity of ongoing threat assessment and mitigation at *Cystoseira s.l.* restoration sites may significantly hinder efforts to restore such macroalgal forests to ecosystems dependent on their presence and function. By tracking threat change, researchers and practitioners can better understand the dynamics of systems responding to management interventions and adapt to these changing conditions to increase both efficiency and effectiveness.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Brandon P. Anthony https://orcid.org/0000-0001-7033-4936

REFERENCES

Abdulla, A., Gomei, M., Maison, E. & Piante, C. (2008). *Status of marine protected areas in the Mediterranean Sea*, Malaga; France: IUCN; WWF.

AFRIMED. (2021). http://afrimed-project.eu/ [Accessed 6th May 2021].

Amengual, J. & Alvarez-Berastegui, D. (2018). A critical evaluation of the Aichi biodiversity target 11 and the Mediterranean MPA network, two years ahead of its deadline. *Biological Conservation*, 225(September 2018), 187–196. https://doi.org/10.1016/j.biocon.2018.06.032

Amores, A., Marcos, M., Carrió, D.S. & Gómez-Pujol, L. (2020). Coastal impacts of storm Gloria (January 2020) over the north-western Mediterranean. *Natural Hazards and Earth System Sciences*, 20(7), 1955–1968. https://doi.org/10.5194/nhess-20-1955-2020

Anthony, B.P. (2008). Use of modified threat reduction assessments to estimate success of conservation measures within and adjacent to Kruger National Park, South Africa. *Conservation Biology*, 22(6), 1497–1505. https://doi.org/10.1111/j.1523-1739.2008.01030.x

Arevalo, R., Pinedo, S. & Ballesteros, E. (2007). Changes in the composition and structure of Mediterranean rocky–shore communities following a gradient of nutrient enrichment: descriptive study and test of proposed methods to assess water quality regarding macroalgae. *Marine Pollution Bulletin*, 55(1–6), 104–113. https://doi.org/10.1016/j.marpolbul.2006.08.023

Benedetti-Cecchi, L., Pannacciulli, F., Bulleri, G., Moschella, P., Airoldi, L., Relini, G. et al. (2001). Predicting the consequences of anthropogenic disturbance: large-scale effects of loss of canopy algae on rocky shores. *Marine Ecology Progress Series*, 214, 137–150. https://doi.org/10.3354/meps214137

Bern Convention. (1979). Convention on the conservation of European wildlife and natural habitats. Strasbourg, Council of Europe, European Treaty Series, 104.

Bianchelli, S., Buschi, E., Danovaro, R. & Pusceddu, A. (2016). Biodiversity loss and turnover in alternative states in the Mediterranean sea: a case study on meiofauna. *Scientific Reports*, 6, 34544. https://doi.org/10.1038/srep34544

Bianchelli, S. & Danovaro, R. (2020). Impairment of microbial and meiofaunal ecosystem functions linked to algal forest loss. *Scientific Reports*, 10(1), 19970. https://doi.org/10.1038/s41598-020-76817-5

Bianchi, C.N., Morri, C., Chiantore, M., Montefalcone, M., Parravicini, V. & Rovere, A. (2012). Mediterranean sea biodiversity between the legacy from the past and a future of change. In: Stambler, N. (Ed.) *Life in the Mediterranean sea: a look at habitat changes*. New York: Nova Science Publishers, pp. 1–55.

Boada, J., Arthur, R., Alonso, D., Pagès, J.F., Pessarrodona, A., Oliva, S. et al. (2017). Immanent conditions determine imminent collapses: nutrient regimes define the resilience of macroalgal communities. *Proceedings of the Royal Society B*, 284(1851), 20162814B. https://doi.org/10.1098/rspb.2016.2814

Burrows, M.T., Schoeman, D.S., Richardson, A.J., Molinos, J.G., Hoffmann, A., Buckley, L.B. et al. (2014). Geographical limits to species-range shifts are suggested by climate velocity. *Nature*, 507(7493), 492–495. https://doi.org/10.1038/nature12976

Byrnes, J., Stachowicz, J.J., Hultgren, K.M., Hughes, A.R., Olyarnik, S.V. & Thornber, C.S. (2006). Predator diversity strengthens trophic cascades in kelp forests by modifying herbivore behaviour. *Ecology Letters*, 9(1), 61–71. https://doi.org/10.1111/j.1461-0248.2005.00842.x

Capdevila, P., Linares, C., Aspillaga, E., Navarro, L., Kersting, D.K. & Herreu, B. (2015). Recruitment patterns in the Mediterranean deep-water alga *Cystoseira zosteroides*. *Marine Biology*, 162(6), 1165–1174. https://doi.org/10.1007/s00227-015-2658-0

Cebrian, E., Tamburello, L., Verdura, J., Guarnieri, G., Medrano, A., Linares, C. et al. (2021). A roadmap for the restoration of Mediterranean macroalgal forests. *Frontiers in Marine Science*, 8, 709219. https://doi.org/10.3389/fmars.2021.709219

Cheminée, A., Sala, E., Pastor, J., Bodilis, P., Thiriet, P., Mangialajo, L. et al. (2013). Nursery value of *Cystoseira* forests for Mediterranean rocky reef fishes. *Journal of Experimental Marine Biology and Ecology*, 442 (April 2013), 70–79. https://doi.org/10.1016/j.jembe.2013.02.003

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais Lasram, F., 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

Colletti, A., Savinelli, B., Di Muzio, G., Rizzo, L., Tamburello, L., Fraschetti, S. et al. (2020). The date mussel *Lithophaga lithophaga*: biology, ecology and the multiple impacts of its illegal fishery. *Science of the Total Environment*, 744(20 November 2020), 140866. https://doi.org/10.1016/j.scitotenv.2020.140866

Colloca, F., Scarcella, G. & Libralato, S. (2017). Recent trends and impacts of fisheries exploitation on Mediterranean stocks and ecosystems. *Frontiers in Marine Science*, 4, 244. https://doi.org/10.3389/fmars.2017.00244

De Biasi, A.M. & Pacciardi, L. (2008). Macrobenthic communities in a fishery exclusion zone and in a trawled area of the middle Adriatic sea (Italy). *Ciencias Marinas*, 34(4), 433–444. https://doi.org/10.7773/cm.v34i4.1382

De Caralt, S., Verdura, J., Vergés, A., Ballesteros, E. & Cebrian, E. (2020). Differential effects of pollution on adult and recruits of a canopy-forming alga: implications for population viability under low pollutant levels. *Scientific Reports*, 10, 17825. https://doi.org/10.1038/s41598-020-73990-5

de Juan, S. & Lleonart, J. (2010). A conceptual framework for the protection of vulnerable habitats impacted by fishing activities in the Mediterranean high seas. *Ocean and Coastal Management*, 53(11), 717–723. https://doi.org/10.1016/j.ocecoaman.2010.10.005

De La Fuente, G., Asnagi, V., Chiantore, M., Thrush, S., Povero, P., Vassallo, P. et al. (2019). The effect of *Cystoseira* canopy on the value of midlittoral habitats in NW Mediterranean, an energy assessment. *Ecological Modelling*, 404, 1–11. https://doi.org/10.1016/j.ecolmodel.2019.04.005

Drius, M., Bongiornni, L., Depellegrin, D., Menegon, S., Pugnetti, A. & Stifler, S. (2019). Tackling challenges for Mediterranean sustainable coastal tourism: an ecosystem service perspective. *Science of the Total Environment*, 652, 1302–1317. https://doi.org/10.1016/j.scitotenv.2018.10.121

Edwards, R. & Holland, J. (2013). *What is qualitative interviewing?* Research methods series, London, UK; New Delhi, India: Bloomsbury. ISBN 978-1-78093-852-3

Eger, A.M., Marzinelli, E.M., Christie, H., Fagerli, C.W., Fujita, D., Gonzalez, A.P. et al. (2022). Global kelp forest restoration: past lessons, present status, and future directions. *Biological Reviews*, 97(4), 1449–1475. https://doi.org/10.1111/brv.12850

Fraschetti, S., Gambi, C., Giangrande, A., Musco, L., Terlizzi, A. & Danovaro, R. (2006). Structural and functional response of meiofauna rocky assemblages to sewage pollution. *Marine Pollution Bulletin*, 52(5), 540–548. https://doi.org/10.1016/j.marpolbul.2005.10.001

Fredriksen, S., Filbee-Dexter, K., Norderhaug, K.M., Steen, H., Bodvin, T., Coleman, M.A. et al. (2020). Green gravel: a novel restoration tool to combat kelp forest decline. *Scientific Reports*, 10(1), 3983. https://doi.org/10.1038/s41598-020-60553-x

Galobart, C., Ballesteros, E., Golo, R. & Cebrian, E. (2023). Addressing marine restoration success: evidence of species and functional

diversity recovery in a ten-year restored macroalgal forest. *Frontiers in Marine Science*, 10. https://doi.org/10.3389/fmars.2023.1176655

Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Jonson, J. et al. (2019). International principles and standards for the practice of ecological restoration. Second edition. *Restoration Ecology*, 27(S1), S1–S46. https://doi.org/10.1111/rec.13035

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

Giakoumi, S., Cebrian, E., Kokkoris, G.D., Ballesteros, E. & Sala, E. (2012). Relationships between fish, sea urchins and macroalgae: the structure of shallow rocky sublittoral communities in the Cyclades, eastern Mediterranean. *Estuarine, Coastal and Shelf Science*, 109, 1–10. https://doi.org/10.1016/j.ecss.2011.06.004

Gianni, F., Bartolini, F., Pey, A., Laurent, M., Marints, G.M., Airoldi, L. et al. (2017). Threats to large brown algal forests in temperate seas: the overlooked role of native herbivorous fish. *Scientific Reports*, 7(1), 6012. https://doi.org/10.1038/s41598-017-06394-7

Gran, A., Movilla, J., Ballesteros, E., Sales, M., Bolado, I., Galobart, C. et al. (2022). Assessing the expansion and success of a restored population of *Gongolaria barbata* (Stackhouse) Kuntze (Fucales, Phaeophyceae) using high-precision positioning tools and size distribution frequencies. *Mediterranean Marine Science*, 23(4), 907–916. https://doi.org/10.12681/mms.30500

Guerriero, G., Rabbito, D., Alwany, M.A., Madonna, A., Temraz, T.A., Sulaiman, O.O. et al. (2017). Fisheries and biodiversity along Mediterranean sea: Italian and Egyptian coast overview. *Euro-Mediterranean Journal for Environmental Integration*, 2(1), 3279. https://doi.org/10.1007/s41207-017-0027-8

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), 948–952. https://doi.org/10.1126/science.1149345

IUCN Red List. (2020). The IUCN red list of threatened species. Populations of loggerhead turtles worldwide. Version 2020-2. Accessed: 2020.12.09. https://www.iucnredlist.org/search?query=loggerhead%20turtle&searchType=species [Accessed 9th December 2020].

Iveša, L., Djakovac, T. & Devescovi, M. (2016). Long-term fluctuations in *Cystoseira* populations along the west Istrian coast (Croatia) related to eutrophication patterns in the northern Adriatic sea. *Marine Pollution Bulletin*, 106(1-2), 162–173. https://doi.org/10.1016/j.marpolbul.2016.03.010

Kent, M., Newnham, R. & Essex, S. (2002). Tourism and sustainable water supply in Mallorca: a geographical analysis. *Applied Geography*, 22(4), 351–374. https://doi.org/10.1016/S0143-6228(02)00050-4

Köcke, M., Farré, M., Martínez, E., Gajda-Schrantz, K., Ginebreda, A., Navarro, A. et al. (2010). Integrated ecotoxicological and chemical approach for the assessment of pesticide pollution in the Ebro river delta (Spain). *Journal of Hydrology*, 383(1-2), 73–82. https://doi.org/10.1016/j.jhydrol.2009.12.029

Lauzon-Guay, J.S., Scheibling, R.E. & Barbeau, M.A. (2009). Modelling phase shifts in a rocky subtidal ecosystem. *Marine Ecology Progress Series*, 375. https://doi.org/10.3354/meps07758

Ling, S.D., Scheibling, R.E., Rassweiler, A., Johnson, C.R., Shears, N., Connell, S.D. et al. (2015). Global regime shift dynamics of catastrophic sea urchin overgrazing. *Philosophical Transactions of the Royal Society B*, 370(1659), 20130269. https://doi.org/10.1098/rstb.2013.0269

Mackinson, S., Deas, B., Beveridge, D. & Casey, J. (2009). Mixed-fishery or ecosystem conundrum? Multispecies considerations inform thinking on long-term management of North sea demersal stocks. *Canadian Journal of Fisheries and Aquatic Sciences*, 66(7), 1107–1129. https://doi.org/10.1139/F09-057

Mangialajo, L., Chiantore, M. & Cattaneo-Vietti, R. (2008). Loss of fucoid algae along a gradient of urbanisation, and structure of benthic assemblages. *Marine Ecology Progress Series*, 358, 63–74. https://doi.org/10.3354/meps07400

Margoluis, R. & Salafsky, N. (2001). *Is our project succeeding? A guide to threat reduction assessment for conservation*. Washington DC: Biodiversity Support Program.

Mariani, S., Cefalì, M.E., Chappuis, E., Terradas, M., Pinedo, S., Torras, X. et al. (2019). Past and present of Fucales from shallow and sheltered shores in Catalonia. *Regional Studies in Marine Science*, 32(November 2019), 100824. https://doi.org/10.1016/j.rsma.2019.100824

Matar, D. & Anthony, B.P. (2010). Application of modified threat reduction assessments in Lebanon. *Conservation Biology*, 24(5), 1174–1181. https://doi.org/10.1111/j.1523-1739.2010.01575.x

Melis, R., Ceccherelli, G., Piazzi, L. & Rustici, M. (2019). Macroalgal forests and sea urchin barrens: structural complexity loss, fisheries exploitation and catastrophic regime shifts. *Ecological Complexity*, 37 (January 2019), 32–37. https://doi.org/10.1016/j.ecocom.2018.12.005

Milatovic, L., Anthony, B.P. & Swemmer, A. (2019). Estimating conservation effectiveness across protected areas in Limpopo province, South Africa. *Koedoe*, 61(1), a1530. https://doi.org/10.4102/koedoe.v61i1.1530

Molinari Novoa, E.A. & Guiry, M.D. (2020). Reinstatement of the genera *Gongolaria* Boehmer and *Ericaria* Stackhouse (Sargassaceae, Phaeophyceae). *Notulae Algarum*, 172, 1–10.

Monserrat, M., Comeau, S., Verdura, J., Alliouane, S., Spennato, G., Priouzeau, F. et al. (2022). Climate change and species facilitation affect the recruitment of macroalgal marine forests. *Scientific Reports*, 12(1), 18103. https://doi.org/10.1038/s41598-022-22845-2

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), 1324. https://doi.org/10.1038/s41467-018-03732-9

Piazzi, L. & Ceccherelli, G. (2017). Concomitance of oligotrophy and low grazing pressure is essential for the resilience of Mediterranean subtidal forests. *Marine Pollution Bulletin*, 123(1–2), 197–204. https://doi.org/10.1016/j.marpolbul.2017.08.061

Piazzi, L. & Ceccherelli, G. (2019). Effect of sea urchin human harvest in promoting canopy forming algae restoration. *Estuarine, Coastal and Shelf Science*, 219, 273–277. https://doi.org/10.1016/j.ecss.2019.02.028

Rindi, F., Gavio, B., Diaz-Tapia, P., Di Camillo, C.G. & Romagnoli, T. (2020). Long-term changes in the benthic macroalgal flora of a coastal area affected by urban impacts (Conero Riviera, Mediterranean sea). *Biodiversity and Conservation*, 29(7), 2275–2295. https://doi.org/10.1007/s10531-020-01973-z

Sala, E., Ballesteros, E., Dendrinos, P., Di Franco, A., Ferretti, D., Foley, D. et al. (2012). The structure of Mediterranean rocky reef ecosystems across environmental and human gradients, and conservation implications. *PLoS ONE*, 7(2), e32742. https://doi.org/10.1371/journal.pone.0032742

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H. et al. (2008). A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology*, 22(4), 897–911. https://doi.org/10.1111/j.1523-1739.2008.00937.x

Sanderson, J.C., Ling, S.D., Dominguez, J.G. & Johnson, C.R. (2015). Limited effectiveness of divers to mitigate "barrens" formation by culling sea urchins while fishing for abalone. *Marine and Freshwater Research*, 67(1), 84–95. https://doi.org/10.1071/MF14255

Smith, C.J., Verdura, J., Papadopoulou, N., Fraschetti, S., Cebrian, E., Fabbrizzi, E. et al. (2023). A decision-support framework for the restoration of *Cystoseira* sensu lato forests. *Frontiers in Marine Science*, 10, 1159262. https://doi.org/10.3389/fmars.2023.1159262

Statista. (2022). Number of international tourist arrivals in Europe from 2010 to 2021, by region. https://www.statista.com/statistics/261702/international-tourist-arrivals-in-europe-by-region/ [Accessed 23rd February 2023].

Tamburello, L., Chiarore, A., Fabbrizzi, E., Colletti, A., Franzitta, G., Grech, D. et al. (2022). Can we preserve and restore overlooked macroalgal forests? *Science of the Total Environment*, 806(Pt 4), 150855. https://doi.org/10.1016/j.scitotenv.2021.150855

Tamburello, L., Papa, L., Guarnieri, G., Basconi, L., Zampardi, S., Scipione, M.B. et al. (2019). Are we ready for scaling up restoration actions? An insight from Mediterranean macroalgal canopies. *PLoS ONE*, 14(10), e0224477. https://doi.org/10.1371/journal.pone.0224477

Thibaut, T., Pinedo, S., Torras, X. & Ballesteros, E. (2005). Long-term decline of the populations of Fucales (*Cystoseira* spp. and *Sargassum* spp.) in the Albères coast (France, north-western Mediterranean). *Marine Pollution Bulletin*, 50(12), 1472–1489. https://doi.org/10.1016/j.marpolbul.2005.06.014

Tsui, M.M.P., Leung, H.W., Wai, T.-C., Yamashita, N., Taniyasu, S., Liu, W. et al. (2014). Occurrence, distribution and ecological risk assessment of multiple classes of UV filters in surface waters from different countries. *Water Research*, 67, 55–65. https://doi.org/10.1016/j.watres.2014.09.013

UNEP/MAP. (2009). Report of the 16th Ordinary Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols. Marrakesh, Morocco, 3–5 November 2009, UNEP, Mediterranean Action Plan, Athens, p. 321.

UNEP/MAP. (2015). Marine litter assessment in the Mediterranean – 2015. Athens, Greece: United Nations Environment Program/Mediterranean Action Plan.

UNWTO. (2015). Tourism in the Mediterranean: 2015 edition. https://www.e-unwto.org/doi/pdf/10.18111/9789284416929 [Accessed 8th November 2023].

UNWTO. (2017). Tourism highlights, 2017. https://www.e-unwto.org/doi/pdf/10.18111/9789284419029 [Accessed 24th June 2021].

Varella, S., Danovaro, R. & Corinaldesi, C. (2022). Assessing the eco-compatibility of new generation sunscreen products through a combined microscopic-molecular approach. *Environmental Pollution*, 1(314), 120212. https://doi.org/10.1016/j.envpol.2022.120212

Vasilakopoulos, P., Maravelias, C.D. & Tserpes, G. (2014). The alarming decline of Mediterranean fish stocks. *Current Biology*, 24(14), 1643–1648. https://doi.org/10.1016/j.cub.2014.05.070

Verdura, J., Sales, M., Ballesteros, E., Cefalì, M.E. & Cebrian, E. (2018). Restoration of a canopy-forming alga based on recruitment enhancement: Methods and long-term success assessment. *Frontiers in Plant Science*, 9, 1832. https://doi.org/10.3389/fpls.2018.01832

Verdura, J., Santamaria, J., Ballesteros, E., Sale, D.A., Cefali, M.E., Golo, R. et al. (2021). Local-scale climatic refugia offer sanctuary for a habitat forming species during a marine heatwave. *Journal of Ecology*, 109(4), 1758–1773. https://doi.org/10.1111/1365-2745.13599

Vergés, A., Alcoverro, T. & Ballesteros, E. (2009). Role of fish herbivory in structuring the vertical distribution of canopy algae *Cystoseira* spp. in the Mediterranean sea. *Marine Ecology Progress Series*, 375, 1–11. https://doi.org/10.3354/meps07778

Watson, J.C. & Estes, J.A. (2011). Stability, resilience, and phase shifts in rocky subtidal communities along the west coast of Vancouver island, Canada. *Ecological Monographs*, 81(2), 215–239. https://doi.org/10.1890/10-0262.1

Wernberg, T., Bennett, S., Babcock, R.C., de Bettignies, T., Cure, K., Depczynski, M. et al. (2016). Climate-driven regime shift of a temperate marine ecosystem. *Science*, 353(6295), 169–172. https://doi.org/10.1126/science.aad8745

Williams, I.D. & Polunin, N.V.C. (2001). Large-scale associations between macroalgal cover and grazer biomass on mid depth reefs in the Caribbean. *Coral Reefs*, 19(4), 358–366. https://doi.org/10.1007/s003380000121

Wood, G., Marzinelli, E.M., Coleman, M.A., Campbell, A.H., Santini, N.S., Kajlich, L. et al. (2019). Restoring subtidal marine macrophytes in the Anthropocene: trajectories and future-proofing. *Marine and Freshwater Research*, 70(7), 936–951. https://doi.org/10.1071/MF18226

How to cite this article: Fehér, D., Bianchelli, S., Verdura, J., Danovaro, R. & Anthony, B.P. (2024). Changes in threats to macroalgal forests (*Cystoseira sensu lato*) at three restoration sites in the Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 34(1), e4048. https://doi.org/10.1002/aqc.4048