An integrated assessment of the Good Environmental Status of Mediterranean Marine Protected Areas

Abstract

Local, regional and global targets have been set to halt marine biodiversity loss. Europe has set its own policy targets to achieve Good Environmental Status (GES) of marine ecosystems by implementing the Marine Strategy Framework Directive (MSFD) across member states. We combined an extensive dataset across five Mediterranean ecoregions including 26 Marine Protected Areas (MPAs), their reference unprotected areas, and a no-trawl case study. Our aim was to assess if MPAs reach GES, if their effects are local or can be detected at ecoregion level or up to a Mediterranean scale, and which are the ecosystem components driving GES achievement. This was undertaken by using the analytical tool NEAT (Nested Environmental status Assessment Tool), allowing an integrated assessment of the status of marine systems. We adopted an ecosystem approach by integrating data from several ecosystem components: the seagrass *Posidonia oceanica*, macroalgae, sea urchins and fish. Thresholds to define the GES were set by dedicated workshops and literature review.

In the Western Mediterranean, most MPAs are in *good/high* status, with *P. oceanica* and fish driving this result within MPAs. However, GES is achieved only at local level, and the Mediterranean Sea is overall in a *moderate* environmental status. Macroalgal forests are overall in bad condition, confirming their status at risk. The results are significantly affected by the assumption that discrete observations over small spatial scales are representative of the total extension investigated. This calls for large-scale, dedicated assessments to realistically detect environmental status changes under different conditions.

Understanding MPAs effectiveness in reaching GES is crucial to assess their role as sentinel observatories of marine systems. MPAs and trawling bans can locally contribute to the attainment of GES showing that they can fulfil MSFD objectives. Building confidence in setting thresholds between GES and non-GES, investing in long-term monitoring, increasing the spatial extent of sampling areas, rethinking and broadening the scope of complementary tools of protection (e.g. Natura 2000 Sites), are indicated as solutions to ameliorate the status of the basin.

Key words: Good Environmental Status, Thresholds, Ecosystem Approach, NEAT, Monitoring, science-policy gap

List of abbreviations:

EC: Ecosystem Component

EU: European Union

FRA: Fishery Restricted Area

GES: Good Environmental Status

MPA: Marine Protected Area

MSFD: Marine Strategy Framework Directive

NEAT: Nested Environmental status Assessment Tool

OC: Other Controls

OECM: Other Effective area-based Conservation Measures

SAU: Spatial Assessment Unit

SDG: Sustainable Development Goals

UN: United Nations

WFD: Water Framework Directive

1. Introduction

Local, regional and global targets have been set to guarantee the long-term sustainability of human activities in the ocean, while protecting marine ecosystems. The Aichi Biodiversity Targets and the UN Sustainable Development Goals (SDGs) (UN, 2015) were designed to reconcile environmental protection with socioeconomic development. Among others, SDG 14 has been specifically introduced for the conservation of the ocean and its sustainable use (Cormier & Elliott, 2017). However, achieving SDGs and, importantly, ensuring that these targets turn into actual biodiversity conservation require substantial steps in bridging the gap between policy and science, rectifying inefficiencies and inadequate management practices (Katsanevakis et al., 2020).

Europe has set its own policy goals to achieve a sustainable development in the European Union (EU) seas, through the implementation of the Water Framework Directive (WFD, 2000/60/CE) and of the Marine Strategy Framework Directive (MSFD, 2008/56/EC), environmental pillars of the EU integrated maritime policy (Fraschetti et al., 2018). The WFD was the first attempt to provide a single system of water management. The MSFD has been conceived to attain the full economic potential of the seas, while integrating environmental protection with a sustainable use of marine resources in a way that they can be preserved in the future, in accordance to SDG 14. Its main objective was to achieve the Good Environmental Status (GES) of marine ecosystems across member states by 2020, using a coordinated approach to monitor and assess their status (Fraschetti et al., 2018). The concept and the normative definitions of GES are based on 11 Descriptors, in line with the Drivers-Activities-Pressures-State-Impact-Welfare-Response approach (Patrício et al., 2016), relating anthropogenic activities and pressures to the state of the marine environment (Elliott et al., 2007). The target is to ensure that no significant risks or impacts are posed on marine biodiversity, marine ecosystems, human health, or legitimate uses of the sea (Smith et al., 2016).

Measuring progress towards meeting targets for ecosystem health is not an easy task and a clear quantitative definition of GES for a marine area is far from being attained (but see Borja et al., 2013). The identification of targets for assessing ecosystems' health requires the adoption of reference conditions, appropriate indicators, systematic monitoring delivering harmonized data with an adequate spatial and temporal coverage, as well as the knowledge of ecosystems' responses to human pressures (Claudet and Fraschetti, 2010). On top of that, ecosystems may shift abruptly in response to environmental perturbations (Oprandi et al., 2020; Scheffer & Carpenter, 2003), but very little information on critical thresholds and on their variability across space and time is available (Boada et al., 2017; Rindi et al., 2017). Our limited knowledge regarding the response of specific structural and functional features of ecosystems to multiple stressors and disturbances (Gissi et al., 2021; Micheli et al., 2013), the inherent spatial and temporal variability in the distribution of ecological features and stressors, and the challenging detection of critical thresholds that lead to regime shifts, are still restraining our potential to quantify and, consequently, achieve and maintain good ecological conditions (Nõges et al., 2016).

Despite its limitations, MSFD offers a strategic framework and an invaluable opportunity for the EU to work towards achieving SDG 14. The MSFD clearly defines MPAs (that include both no-take and buffer zones where human uses, including fishing, are permitted under regulation) as a main tool for implementing marine biodiversity conservation and promoting healthy ecosystems, while providing opportunities for sustainable local development. Also, Natura 2000 Sites are at the core of the biodiversity conservation strategy of the EU (Evans, 2012). They are based on the Habitats and Birds Directives (92/43/EEC; 2009/147/EC) and do not usually include strictly protected zones (Mazaris et al., 2017), having the main target of regulating and managing human activities, contributing to an ecosystem-wide conservation with other national and supranational initiatives (Guidetti et al., 2019).

MPAs play a critical role in the achievement of GES in European seas, even though it is assumed that the GES should be attained also in unprotected areas (Boero et al., 2016): MPAs should be considered sentinel observatories of the effects of multiple human activities, and more broadly of the status of the marine environment as a whole (Grorud-Colvert et al., 2021; Rilov et al., 2020). In addition to MPAs, Fishery Restricted Areas (FRAs) are widely used as fisheries management tools in the framework of different regulatory approaches (Di Lorenzo et al., 2020). FRAs can be considered as ‘Other Effective area-based Conservation Measures’ (OECMs) (Petza et al., 2019) including a vast array of different applications that range from temporary to permanent fishing bans and may regard one or more fishing gears. No-trawl areas have been created in the Mediterranean with the purpose of rebuilding overexploited fishery resources and addressing conflicts between fishery sectors, and their effect on fish biomass has been clearly demonstrated (Dimarchopoulou et al., 2018; Pipitone et al., 2014). Given these results such areas can be considered tools for the attainment of the Good Environmental Status (GES) as required by the EU Marine Strategy Framework Directive (MSFD, 2008/56/EC), more specifically by means of Descriptor D3 on commercially exploited fish. Fish biomass is considered an element of marine waters assessment and of the determination of GES (articles 8 and 9 of MSFD) along with the physical disturbance of the seabed and the extraction of living resources.

The aim of this study is to bridge the science-policy gap by exploring if MPAs and FRAs achieve GES in the Mediterranean Sea, meeting the targets set at EU level. We combined an extensive dataset of well-known interconnected ecosystem components, such as the seagrass *Posidonia oceanica*, macroalgal forests, sea urchins, and fish, across five Mediterranean ecoregions including 26 MPAs, their control areas, and a no-trawl case study to conduct a comparative assessment of environmental health under protected *vs.* unprotected conditions. This was undertaken by implementing the analytical tool NEAT (Nested Environmental status Assessment Tool, http://www.devotes-project.eu/neat/) allowing an integrated assessment of marine environmental status.

This work aims at answering the following questions: (i) do Mediterranean MPAs and FRAs contribute significantly to the achievement of GES? (ii) are their effects local or can they be detected at ecoregions up to a Mediterranean scale? (iii) which are the ecosystem components mostly contributing to GES achievement? and, if no GES is achieved, (iv) which ecosystem components deserve urgent conservation actions? (v) which are the gaps for the identification of health status and thresholds of change? and (vi) how solutions and recommendations can be developed to improve the conceptual framework in defining GES?

2. Material and Methods

2.1 The case studies

The 26 Mediterranean MPAs analyzed in this study are listed in Table 1, reporting the ecoregions they belong to, the year of establishment, the ecosystem components analyzed in each MPA, the surface subject to protection, and the extent of the control areas. Table S.1 shows the complete list of controls. Additional Non-Protected Areas (OC = Other Controls), >20 km distant from the MPAs, were also included in the analyses. The eventual presence of a Natura 2000 Site in control areas is also indicated.

A no-trawl area has been included as a case study and subjected to an *ad hoc* NEAT assessment to evaluate if and to what extent a year-round trawl ban may contribute to the attainment of GES in the Mediterranean. This case study is made up of a no-trawl area created in 1990 in the Gulf of Castellammare (GCAST, NW Sicily, central Mediterranean) and two trawled control areas (the Gulfs of Termini Imerese, GTERM and Sant'Agata, GSANT). Previous studies suggest that fish biomass in GCAST has increased dramatically after the ban (Pipitone et al., 2014). The observed values used in the NEAT assessment (kg km^{-2}) derive from two trawl surveys carried out in 2004-2005 on the continental shelf of the three gulfs. The worst, best and threshold (*moderate/good*) values derive from trawl surveys carried out in the Italian seas from 1994 to 2014 during the MEDITS program (Maiorano et al., 2019). The total fish assemblage and two commercially valuable species (red mullet, *Mullus barbatus* and hake, *Merluccius merluccius*) were chosen as ecosystem components for the analysis. The surface of the three SAUs is 200 km^2 (GCAST), 280 km^2 (GTERM) and 400 km^2 (GSANT), and the whole of each surface was covered by the sampling grid.

2.2 NEAT analyses and experimental design

NEAT allows integrated assessments by assembling data from various response variables and their associated error over different spatial and temporal scales. (Borja et al., 2019; Pavlidou et al., 2019; Kazanidis et al., 2020, Borja et al., 2021). It is based on a hierarchical, nested structure of Spatial Assessment Units (SAUs), i.e. the areas where the environmental status assessment takes place (Borja et al., 2016a; Uusitalo et al., 2016).

Central to the application of NEAT is the need of indicators that are the response variables used to measure the status of each SAU. In addition, each indicator is also assigned to specific ecosystem components and to different MSFD descriptors (Table S.2). The overall assessment is an average of the SAUs, weighted by their surface areas (km^2).

Indicators are transformed into values that range from 0 (worst status) to 1 (best status) using a continuous piecewise linear interpolation (Berg et al., 2019). On this scale, the value of 0.60, identified as threshold value, corresponds to the boundary between GES and non-GES. The indicator values are translated to standardized values with four boundaries among different conditions: *high-good* (value of 0.80), *good-moderate* (value of 0.60), *moderate-poor* (value of 0.40) and *poor-bad* (value of 0.20) (Borja et al., 2016a). Though the transformation function is piecewise linear, the definition of five segments or classes allows a reasonable approximation to non-linear functions (Berg et al., 2019) (Box S.1).

The analyses provide an overall assessment of the environmental status for all SAUs (e.g. the Mediterranean Sea), and a separate assessment for each SAU (e.g. the different MPAs included in the study) or for each of the ecosystem components considered. Each NEAT value has an associated confidence level, which is the probability of being in a determinate class status (*bad, poor, moderate, good, high*). This probability is estimated using the standard error linked to the observed indicator value, which is assumed to represent the mean value of a normal distribution. The resulting assessment was obtained by performing a Monte-Carlo simulation technique with 1,000 iterations and using the standard error to repeat the assessment multiple times with simulated values. In this way, each iteration led to different NEAT values, returning a quantitative estimate of confidence level for the original NEAT values, expressed as the percentage of values falling into the five different assessment classes (Borja et al., 2016b).

The nested structure considered for the NEAT assessment is synthesized in Figure S.1. Each SAU (Level 3) is represented by an MPA or control area hierarchically nested in the Condition (Level 2, protected *vs.* non-protected) and Ecoregion (Level 1), and includes multiple nested Sites (Level 5) exposed to different protection levels (Level 4).

2.3 Selection of indicators and ecosystem components

The ecosystem components *P. oceanica*, Canopy algae, Erect algae, Turf, Barren, Sea urchins, and Fish were selected since a sufficient amount of information regarding their spatial occurrence, current status, temporal trends, and strength of ecological interactions is available through the literature (Guidetti, 2006; Sala et al., 2012; Boada et al., 2017; Thibaut et al., 2017; de los Santos et al., 2019; Fabbrizzi et al., 2020). Each ecosystem component was represented by one or more indicators, selected among variables available from the literature (Table S.2).

Data for the NEAT calculations were provided by the authors, and were collectively organized in a unified dataset. Only data collected during the period 2015-2019 were included to depict the most recent environmental status of the Mediterranean Sea. For each indicator, mean observed values and standard errors were included in the dataset. Overall, we combined a total of 1,249 records, comprising data from five Mediterranean ecoregions.

2.4 Setting thresholds

To set the threshold for each indicator, a combination of literature review and dedicated workshops with experts on different ecosystem components were carried out. We decided to interpret changes of the indicators as non-linear transitions, since there is evidence that linear changes across a gradient of human pressures and conditions rarely occur (Litzow & Hunsicker, 2016) (Box S.1, Table S.2). Fig. 2 and Fig. S.3-8 show the distribution of the values of each indicator across sites (n) within each SAU, grouped by protected and non-protected areas and ecoregions. The thresholds identified for each indicator and outcomes of the NEAT analyses are also included.

2.5 Analyses performed

NEAT analyses were carried out using different spatial extensions for each SAU. More specifically, we used the actual sampled surface area within and outside the protected area *vs.* the total protected area and a non-protected buffer of 5 and 10 km for the controls. Buffer zones of 5 and 10 km were selected according to the literature (Zupan et al., 2018), and allowed to obtain comparable surfaces within and outside MPAs (Table 1).

3. Results

NEAT analyses

As the analyses provide an overall assessment of the environmental status at basin scale, the NEAT outcomes showed that the Mediterranean Sea is overall in a *moderate* environmental status considering Descriptors 1, 4, 5, 6 (corresponding to a value of 0.49, on a scale 0-1), as detected in other studies based on different datasets and approaches (Borja et al., 2019) (Table 2). At the basin scale, MPAs reflected this condition (value of 0.47), while some unprotected areas have been found unexpectedly in a *good* status. The result is mostly due to the generally healthy status of the seagrass *P. oceanica*, which is a priority habitat for protection under the Habitats Directive (Council Directive 92/43/EEC), largely represented also in Natura 2000 Sites and unprotected areas (Figure 1, Table S.1).

At the ecoregion level, a mosaic of conditions was highlighted, confirming that basin scale analyses can capture general trends, but not the regional variability of the selected indicators (Table 2). The Western Mediterranean (value of 0.65) and the Tunisian plateau (value of 0.78) reached the GES, the Aegean and the Adriatic Seas are in a *moderate* status (0.45 and 0.55 respectively) and the Ionian Sea is in a *poor* status (value of 0.35) (Figure 1, Table 2). The good status of the Tunisian plateau is scarcely representative, as the assessment of this ecoregion was based on data limited to one MPA and adjacent controls, despite the high confidence level found in this analysis (over 95%, Table 2).

Zooming to the MPA scale, most MPAs are in a *good/high* status in the Western Mediterranean, coherently with the result obtained regionally (Figure 1, values between 0.65 and 1). Out of their sixteen control areas, six are in a *good/high* status, with three of them being Natura 2000 Sites. Very clear results were also obtained from the analyses testing if no-trawl areas can be considered a tool for the attainment of GES. The output from the NEAT assessment is strikingly clear in showing the effect of the trawl ban (Table 3). The no-trawl area ranks the highest while the two control areas rank low, with GTERM ranking lower than GSANT. As regards the analyzed components, the total fish assemblage seems to suffer more than the two species in the trawled gulfs, and red mullet is in worse condition than hake in GTERM (which overall is the area that ranks the lowest).

In the Adriatic Sea, most MPAs and unprotected areas showed a *moderate* status, as a result of the contrasting conditions in which the different ecosystem components have been found. In the Ionian Sea, the MPAs of Porto Cesareo in Italy and Karaburun in Albania have been found in a *good* status under both protected and unprotected conditions. In the Aegean Sea, *moderate/poor* conditions have been found in both protected and unprotected locations (Figure 1).

All the above results were obtained considering the actual extension of the sampled area (from 0.0004 to 2.52 km^2) that was derived from the sum of the generally low sample effort carried out inside and outside MPAs. The consequence of weighting the analyses on the real extension of the MPAs, and including the buffer areas of 5 and 10 km radius for the controls, as allowed by NEAT, led to a general downgrading of the detected conditions. In particular, both protected and unprotected Western Mediterranean locations (originally identified as *good*) turned into *moderate*, indicating the consequences of assuming the results obtained from limited spatial scales representative of the actual extension of the area of interest (Figure 1; Table 2). As an example, the *high* condition identified in Portofino turned to *good* in the MPA and to *moderate* in the unprotected locations.

Considering the ecosystem components, *P. oceanica* is in the best status (*good/high*, corresponding to a shoot density above the thresholds defined for each depth in Table S.2) across locations and independently from the protection regime and the sampling extent (Figure S.3). The same consideration applies to sea urchins that show *good/high* status (corresponding to densities below 5 ind/m^2 and to biomass below 30, 50, 85 g/m^2, respectively for the Eastern Mediterranean and the Western Mediterranean at low or high nutrient concentration) across geographical areas. The overall status for the density/biomass of sea urchins at the scale of MPAs in the Western Mediterranean turned into *moderate* (Figure 1, Figure S.4) when the sampled area was considered, due to the greater weight of the Medes MPA, which showed a sea urchins biomass of 318 g/m^2. Medes MPA is larger than the other three MPAs of the Western Mediterranean with urchin data (Tavolara, Es Freus, Cote Bleue) taken together. As far as turfs and barrens (Figure S.5 and S.6) are concerned, a *moderate* status (corresponding to a percentage cover between 0 – 5%) has been identified independently from the protection regime and the sample extension, indicating a scarce presence of these habitats across SAUs.

Despite the analyses carried out at the basin scale indicated that canopy and erect algae are in *bad* conditions (below 5 % cover), especially under protected regimes, results from the Western Mediterranean showed that canopies are in a better condition within MPAs, corresponding to a cover above 50% (Figure 2 and S.7). Unexpectedly, in the Adriatic Sea we found that MPAs protect more effectively erect algae, while canopies are apparently in a better condition under a non-protected regime. The same consideration applies to the Ionian Sea. In the Aegean Sea, extensive barrens (cover between 5 – 95%) have been formed by the overgrazing activity of invasive alien rabbitfish regardless of the reef protection status.

Our results stressed the local effect of MPAs on the fish component (Figure S.8 a,b). In addition, MPAs reached a better status compared to unprotected areas only when analyses were weighted on the sample extent. Considering the real extension of MPAs together with the control areas had the consequence of worsening the estimated ecological status of fish in the MPAs, possibly also driven by the very high patchiness of the seascape (at any scale) and thus also of the ecological components inside and outside MPAs.

At the ecoregion level, the fish component is consistently in a better status in the Western Mediterranean compared to unprotected conditions. Fish are in *poor/bad* and *moderate/poor* status (corresponding to a total biomass below 4250 g/125m^2 and to a high-level predator biomass below 3580 g/125m^2) inside MPAs, respectively, in the Ionian and Adriatic Seas. Weighting the analyses on the real MPA extent had the effect of smoothing out differences between protected and unprotected conditions. In general, a worsening of the Adriatic and Ionian Seas respectively to *poor* and *bad* was detected. In the Aegean Sea, the fish component is in *good* state in protected areas and in *poor* state in unprotected areas when considering the sample extension. When weighted, the status of MPAs was reduced to *moderate* (Table 2).

4. Discussion

Despite our analysis shows the challenges in supporting the assessments from a local condition (MPAs) to the basin-ecoregion level for information scarcity, the use of NEAT introduces some interesting insights. Our results show that the Mediterranean Sea is in a *moderate* environmental status for all Descriptors considered. However, a complex pattern of conditions was found, differing across scales and ecosystem components, reflecting the context dependency of the status of marine systems and the different management regimes in the Mediterranean Sea. Zooming at ecoregion scale, the Western Mediterranean Sea was found in GES. This result is possibly driven by the effects of synergistic management actions for biodiversity protection (MPAs, including Natura 2000 Sites) and interventions to improve water quality, documented at national and subnational scales: the increase of wastewater treatment plants from 2003 to 2010 along the Catalonia coast in Spain resulted in significant improvements of water quality, with positive effects on both macroalgal canopies and *P. oceanica (Roca et al., 2015)*. These results are in agreement with Micheli et al. (2013), who detected a medium cumulative impact in the Mediterranean Sea and the lowest cumulative impact score in its Western basin, although areas of high impact exist within this ecoregion, as our NEAT analysis confirms. Most of the MPAs in the Western Mediterranean Sea have been found in *good/high* status. This means that Mediterranean MPAs and FRAs contribute significantly to the achievement of GES. They are already an effective tool for the fulfilment of the MSFD objectives, especially because of their generally positive effect on fish assemblages, and the local restoration of top-down control on herbivores (mostly sea urchins) by predatory fish, which, in turn, allows more structured and abundant macroalgal canopies to develop within MPAs. Our findings are consistent with what has been found in several studies considering single descriptors (mainly fish), comparing protected *vs.* unprotected conditions and confirm that fish, in well enforced protected areas, can reach GES, possibly affecting other ecosystem components even in “crowded” marine environments (Giakoumi et al., 2017).

The Adriatic and Ionian regions, are, respectively, found at a *moderate* and *poor* state. Fraschetti et al. (2018) and Gissi et al. (2017) recently showed the limits and uncertainties in their conservation, management and cumulative impacts assessment. These areas should be prioritized in terms of concrete management actions coordinated at transboundary levels (Gissi et al., 2018), including transparent data sharing to complement information from different research projects and fields (Cavallo et al., 2018; Pınarbaşı et al., 2020) and monitoring programs. In the Adriatic Sea, the GES has not been attained in most MPAs and unprotected areas, despite the effectiveness of protection shown from the literature in MPAs such as Torre Guaceto (Guidetti, 2006). The status found is still suboptimal considering the potential GES of the indicators assessed at Mediterranean scale, stressing the need of integrating more ecosystem components in the analysis to better depict the condition of an area (Borja et al., 2019; Pavlidou et al., 2019; Kazanidis et al., 2020). It is also a paradigmatic example of the need to integrate the decision about the NEAT thresholds, common across sites, with the knowledge of the ecological contingencies (e.g., the frequency and intensity of present-past disturbances, seafloor conditions and spatial context) with the consequence that each site may have thresholds that cannot be exceeded. In this respect, Torre Guaceto, most likely due to its specific environmental features (e.g., habitat types and complexity, depth, etc.), has never been reported to host wide populations of large-sized nekto-benthic predatory fishes (e.g. dusky grouper and brown meagre), independently from the effectiveness of the protection regime (Guidetti et al., 2014). Future analyses that incorporate ‘noisy’ spatial and temporal contingencies may find that system-specific thresholds are more common than universal ones (Dudney & Suding, 2020).

Considering the remaining regions, the *moderate/poor* conditions detected in the Aegean Sea are not surprising, since most MPAs in that area generally suffer from low enforcement (Sini et al., 2017), while several ecological features have been found in a relatively poor state in unprotected areas (Bevilacqua et al., 2020; Sini et al., 2019). In the Ionian Sea, Zakynthos MPA was designated for the protection of sea turtles. The present management scheme has been shown to be ineffective also in protecting other ecosystem components, such as fish populations (Dimitriadis et al., 2018). Although the Tunisian Plateau was found in a good state, the lack of data regarding the status of marine ecosystems and their protection in the entire southern Mediterranean remains a limiting factor in regional assessments and planning studies (Giakoumi et al., 2013; 2017). Recent studies from the southeastern Levant basin (not included in this study) showed that the overall ecological status of the coastal zone in this ecoregion is poor. Shallow reefs are mostly dominated by turf (canopy algae area rare, seagrass is absent) and alien species, even inside the one well-enforced long-term marine reserve, although the fish community inside the reserve was in better condition than outside (Rilov et al., 2018). This region also suffers from an immense loss of native biodiversity (mostly mollusca but also sea urchins), probably due to ocean warming (Rilov, 2016; Yeruham et al., 2019; Albano et al., 2021), and the consequences of takeover by alien species on reef ecosystem functioning can be considerable (Peleg et al 2020). Under the unfolding rapid climate change, in the expending areas where sensitive native species are being lost due to warming and tropical aliens takeover, we might need to adjust some of the criteria for GES (Rilov et al., 2020), as the local biodiversity is and will be completely reshuffled (Edelist et al., 2013).

Very clear results were obtained from the analysis from the no-trawl area. These results, although limited to Italian waters, support the use of year-round trawl bans as a tool for the fulfilment of the MSFD objectives based on Descriptor 3 (i.e., populations of all commercially exploited fish and shellfish are within safe biological limits), but their contribution to GES can actually be much wider: other ecosystem elements and functions may benefit from a healthy fish assemblage, in particular biodiversity, food webs and sea floor integrity (Descriptors 1, 4 and 6, respectively, within the MSFD). Moreover, since all other uses are permitted in the selected case study (Gulf of Castellammare), including small-scale fishing which has economically benefited from the ban applied to the competitive large-scale trawling activity (Whitmarsh et al., 2003), the trawl ban provides an effective area-based management tool for the sustainable use of the marine ecosystem in general at the basin scale (Pipitone et al., 2014).

MPA effects are local, with *P. oceanica* and fish generally in *good/high* status within them (Bevilacqua et al., 2020). Despite a declining trend indicated by global assessments of seagrasses (de los Santos et al., 2019; Marbà et al., 2014), our findings on the health status of *P. oceanica* are aligned with those from a recent review on the ecological status of seagrass beds and other marine ecosystems at the basin scale, where more than 70% of the 700 investigated sites exhibited *good* to *high* status (Bevilacqua et al., 2020) possibly thanks to the latest conservation policies (Burgos et al., 2017). This result demonstrates that despite the intensity of human pressures in the Mediterranean, there are still opportunities for a significant recovery of marine ecosystems if human impacts are locally reduced. Algal forests formed by canopy and erect algae seem to be the most challenging components for conservation, as they were overall found in *bad* condition, both in protected and non-protected areas at the basin scale. This result is in accordance with Gubbay et al. (2016) and Bevilacqua et al. (2020), who found that about two-thirds of subtidal rocky reef sites are classified in moderate/bad conditions. MPAs alone cannot do much for the recovery of canopy algae (Tamburello et al., 2021). Additional conservation actions are needed, such as improvement of water quality, control of indigenous and invasive herbivores (Yeruham et al., 2019), and implementation of restoration actions (De La Fuente et al., 2019; Fraschetti et al., 2021), to stop their loss.

MPAs effects are local since the GES has not been found in most unprotected areas and Natura 2000 Sites, underlining that, despite the fish spillover effect of MPAs, their global effect on the environmental status of surrounding areas is limited (Di Lorenzo et al., 2020). In this respect, it is crucial to rethink and broaden the scope of Natura 2000 Sites to improve their conservation capacity and outcomes (Guidetti et al., 2019; Mazaris et al., 2019; Manea et al., 2020) since, despite being considered the largest conservation network globally, they are often found in a *poor/moderate* status (Table S.1).

Central to attain these results was the challenge of setting thresholds for the ecosystem components included in the analysis. The decision about “what is good” and “what is not” is not trivial (Borja et al., 2013; Hillebrand et al., 2020), even for components like fish that have been the focus of many studies assessing the effectiveness of MPAs (Box S.1). The use of available data from well enforced MPAs was suggested as a possible pathway to set up baselines for fish, but different approaches were adopted for the other ecosystem components such as *P. oceanica*, the thresholds of which were derived from Pergent et al. (1999). In addition, recent studies highlighted that regime shifts may present hysteretic behavior and are highly dependent on regional conditions (Boada et al., 2017; Rindi et al., 2017; Scheffer & Carpenter, 2003), making the identification of a single threshold value not accurate, as required by NEAT (Box S.1). Rapid changes of ecosystems in the Anthropocene are further challenging the way we measure thresholds of changes. Dedicated projects should develop a framework to identify ecological thresholds across environmental conditions and gradients of human pressures, to detect the prevalence of strong nonlinearities (Rindi et al., 2017).

Despite this collaborative effort to enhance sample sizes and broaden the scale and scope of the study, we realized that the majority of ecological studies addressing the patterns of spatial-temporal variability for some of the response variables at Mediterranean scale tend to upscale the results obtained by samples covering just a few square meters to very large extensions. This asks for more investments in systematic surveys and monitoring, under protected and non-protected conditions to provide realistic GES assessments.

It is not only an issue of spatial extension. The knowledge of thresholds is also largely connected with the need for long-term data, as ranges of natural variation are identified and temporal trends emerge with prolonged observation (Gatti et al., 2015; Hughes et al., 2017). The scarcity of long-term datasets and the limited knowledge across space and time hinder our potential to tease apart the natural variability from the effects of human impacts. Our analyses clearly show that data availability is still a challenge in coastal protected and unprotected habitats, despite the effort carried out in these systems (Levin et al., 2014). We found that data availability is scattered across MPAs and systematic monitoring outside MPAs is available mainly for *P. oceanica*, stressing the need for increased monitoring efforts also on other ecosystem components, using an integrated perspective. As stressed by Micheli et al. (2020), at a time when the need for informed mitigation and adaptive action is accelerating, investment in long-term studies has perversely decreased.

Despite these limits, gaps and challenges, many areas, albeit small, show that the GES can be reached with proper management. In this respect, NEAT can facilitate the assessment process of MPAs, allowing to integrate different information and providing an overall overview (Borja et al., 2021). In addition, ensuring a better alignment between different initiatives at Mediterranean level (e.g. MSFD and Ecosystem Approach Strategy) would foster a shared vision and synergistic approaches to enhance the protection and the recovery of the Mediterranean marine environment (Cinnirella et al., 2014) The MSFD represents an opportunity to understand how species, habitats and entire ecosystems respond to environmental changes and ever-growing human pressures. As recommended by Katsanevakis et al. (2020), only a change of vision about the importance of decreasing human pressures aimed at developing a sustainable economy to support healthy socio-ecological systems will allow the achievement of GES both locally and regionally.

Authors contribution

SF developed the initial idea, coordinated all steps of the study, and wrote the final version of this manuscript. SF, EF and LT collected, analyzed data. MCU and AB supported NEAT use. EF, LT, FM, ES, CP, FB, SB, JB, EC, GC, MC, GDA, ADF, SF, SG, IG, PG, SK, MM, MS, were data provider and contributed to the general discussion about the development of the manuscript. All Authors contributed to the final draft.

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Table 1. Spatial Assessment Units (SAUs) included in the dataset for the Mediterranean biogeographic ecoregions. Abbreviated names of MPAs are reported in brackets. YEAR: Year of MPA establishment. EC: available data on Ecosystem Components (P = *P. oceanica*; C = Canopy algae; E = Erect algae; T = Turf; B = Barrens; U = Sea Urchins; F = Fish). DESCRIPT: descriptors associated to each SAU. For each SAU, in the Protected Areas, both the sampled ("Sampled") and the actual surface area ("Real") are indicated (in km^2). Other controls are represented by Non-Protected areas at a distance greater than 10 km from the MPAs. For the Non-Protected areas, in addition to the sampled surface, a buffer zone of 5 and 10 km around the MPA was considered as the counterpart of the Protected real surface (in km^2). The table also shows the ratio ("%") between the sampled surface and the real surface for Protected Areas and between the sampled surface and the buffer surface of 5 km for Non-Protected areas.

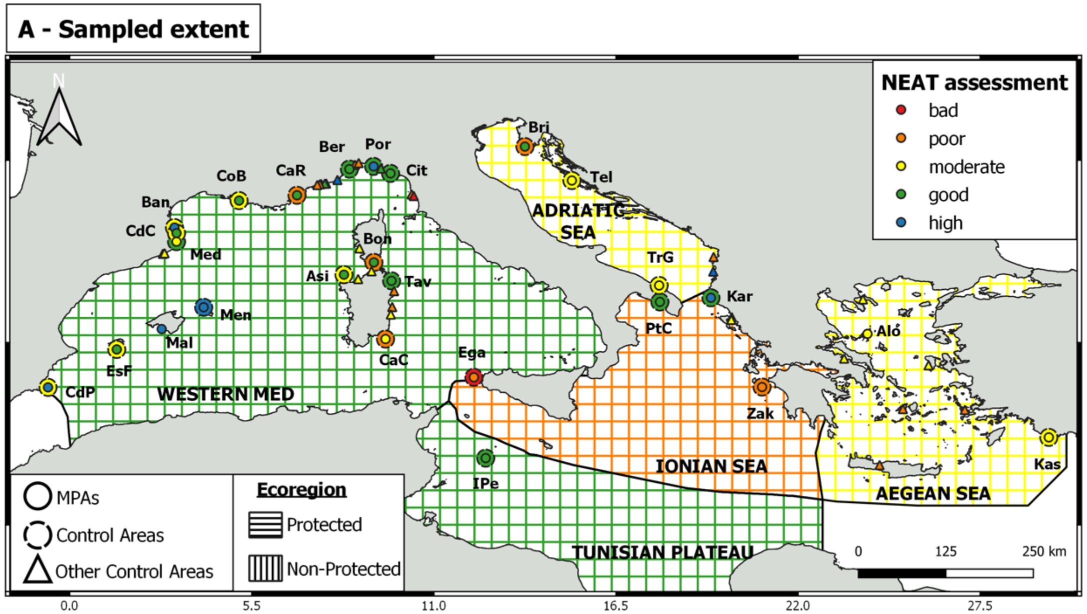
Ecoregion	**SAU**	**YEAR**	**EC**	DESCRIPORS	**PROTECTED**			**NON-PROTECTED**			
					Sampled	**Real**	**%**	**Sampled**	**5km**	**10km**	**%**
Adriatic Sea	**Torre Guaceto (TrG)**	1991	P-C-T-F	D 1,4,5,6	0.004	22.27	0.02	0.002	92.27	234.24	0.002
	Telascica (Tel)	2013	F	D 1,4	0.004	70.00	0.01	0.002	155.27	448.39	0.001
	Brijuni (Bri)	2013	E-T-U-F	D 1,4,5,6	0.002	26.00	0.01	0.002	108.37	257.89	0.002
	Other Controls	-	P	D 1,4,6				0.0004	100.77	382.61	0.0004
Aegean Sea	**Alonissos (Alo)**	1996	C-E-T-B-U-F	D 1,4,5,6	2.25	2315.5	0.10				
	Kas (Kas)	1996	C-E-T-B-U-F	D 1,4,5,6	0.002	165.91	0.001	0.002	238.85	476.98	0.001
	Other Controls		C-E-T-B-U-F	D 1,4,5,6				0.04	2805.23	11253.97	0.001
Ionian Sea	**Zakynthos (Zak)**	1996	C-E-T-B-U-F	D 1,4,5,6	0.01	83.30	0.01	0.01	299.81	854.31	0.003
	Porto Cesareo (PtC)	1997	P-C-U	D 1,4,5,6	0.001	166.54	0.001	0.001	153.37	351.72	0.001
	Karaburun-Sazan (Kar)	2016	P	D 1,4,6	0.0004	127.21	0.0003	0.0004	406.64	912.43	0.0001
	Other Controls	-	P	D 1,4,6				0.0004	74.32	269.88	0.001
Tunisian plateau/ Gulf of Sidra	**Isole Pelagie (IPe)**	2002	C-E-U-F	D 1,4,5,6	0.002	41.00	0.01	0.002	226.87	576.33	0.001
	Other Controls	-	-								
Western	**Cinque Terre (CiT)**	1997	P-C-F	D 1,4,5,6	0.02	45.03	0.04	0.01	111.95	290.43	0.01

Mediterranean Sea	**Portofino (Por)**	1998	P-C-F	D 1,4,5,6	0.02	3.50	0.57	0.01	97.56	250.48	0.01
	Bergeggi (Ber)	2007	P-F	D 1,4,6	0.01	2.06	0.49	0.02	51.76	158.32	0.04
	Asinara (Asi)	2002	U-F	D 1,4,6	0.01	108.03	0.01	0.002	266.82	641.65	0.001
	Tavolara (Tav)	1997	U-F	D 1,4,6	0.01	153.57	0.01	0.004	194.69	451.17	0.002
	Capo Carbonara (CaC)	1998	F	D 1,4	0.01	143.00	0.004	0.002	188.82	480.06	0.001
	Egadi (Ega)	1991	F	D 1,4	0.01	540.17	0.001	0.002	534.27	1127.39	0.0004
	Es Freus (EsF)	2000	P-C-E-T-B-U-F	D 1,4,5,6	0.01	150.00	0.01	0.004	224.32	538.56	0.002
	Menorca (Men)	2000	P-C	D 1,4,5,6	0.002	56.99	0.004	0.001	134.42	345.24	0.001
	Mallorca (Mal)	2000	P-C	D 1,4,5,6	0.002	24.13	0.01				
	Cabo de Palos (CdP)	1995	F	D 1,4	0.01	19.31	0.03	0.003	144.49	396.83	0.002
	Medes (Med)	2001	P-E-U-F	D 1,4,5,6	0.08	5.00	1.60	0.09	139.68	454.12	0.06
	Cap de Creus (CdC)	2001	P-C-F	D 1,4,5,6	0.01	30.73	0.03	0.003	102.66	377.07	0.003
	Bonifacio (Bon)	2009	F	D 1,4	0.01	760.00	0.001	0.002	557.44	1123.57	0.0004
	Banyuls (Ban)	1974	F	D 1,4	0.01	6.50	0.15	0.003	67.86	214.47	0.004
	Cote Bleue (CoB)	2012	C-E-T-B-U-F	D 1,4,5,6	0.01	2.95	0.34	0.01	235.51	518.35	0.004
	Cap Roux (CaR)	1998	F	D 1,4	0.002	4.45	0.05	0.004	87.72	310.32	0.01
	Other Controls		P-F	D1,4,6				0.07	683.91	2425.8	0.01

Table 2. Nested Environmental status Assessment Tool (NEAT) values, considering the actual extension of the sampled area (Table 2a), the real extension of the Marine Protected Areas (MPAs) with the buffered control areas of 5 km (Table 2b) and the real extension of the MPAs with the buffered control areas of 10 km (Table 2c) SAU: Spatial Assessment Unit; PR: protected; MED: whole Mediterranean.

Table 2a	**Sampled extent**											**Table 2b**	**Real extent – buffer 5 km**									
SAU	**Area (km^2)**	**NEAT value**	**Status class**	**Confidence level (%)**	**Erect algae**	**Canopy algae**	**Fish**	***P. oceanica***	**Sea urchins**	**Turf**	**Barren**	**Area (km^2)**	**NEAT value**	**Status class**	**Confidence level (%)**	**Erect algae**	**Canopy algae**	**Fish**	***P. oceanica***	**Sea urchins**	**Turf**	**Barren**
MED	2.78	0.49	mod.	100	0.19	0.02	0.58	0.85	0.79	0.56	0.50	13558.79	0.47	mod.	100	0.23	0.16	0.38	0.77	0.87	0.55	0.53
PR	2.48	0.47	mod.	99.7	0.18	0.02	0.62	0.79	0.79	0.56	0.50	5073.14	0.53	mod.	100	0.17	0.10	0.51	0.85	0.86	0.56	0.50
Aegean	2.25	0.45	mod.	97	0.17	0.002	0.62		0.85	0.56	0.50	2481.48	0.45	mod.	98.3	0.16	0.002	0.59		0.87	0.56	0.49
Adriatic	0.01	0.55	mod.	100	0.52	0.38	0.46	0.66	1.00	0.59		118.27	0.48	mod.	99.9	0.52	0.38	0.39	0.69	1.00	0.51	
Ionian	0.01	0.35	poor	99.8	0.02	0.19	0.20	0.78	0.87	0.41	0.79	377.05	0.70	good	100	0.02	0.16	0.18	0.84	0.72	0.41	0.79
Western Med	0.21	0.65	good	98.7	0.83	0.68	0.67	0.80	0.54	0.64	0.97	2055.34	0.58	mod.	93.6	0.78	0.87	0.51	0.88	0.86	0.70	0.97
Tunisian Plateau	0.002	0.78	good	96.1	0.43	0.80	0.64		1.00			41.00	0.78	good	95.3	0.43	0.80	0.64		1.00		
Non-PR	0.30	0.64	good	100	0.45	0.17	0.39	0.87	0.78	0.54	0.58	8485.65	0.44	mod.	100	0.27	0.20	0.31	0.73	0.88	0.55	0.55
Aegean	0.04	0.41	mod.	99.9	0.16	0.03	0.23		0.94	0.53	0.54	3044.08	0.41	mod.	99.9	0.17	0.03	0.22		0.94	0.54	0.53
Adriatic	0.01	0.42	mod.	91.3	0.36	0.41	0.35	0.45	0.49	0.59		456.68	0.46	mod.	99.6	0.36	0.41	0.37	0.54	0.49	0.58	
Ionian	0.01	0.35	poor	100	0.01	0.22	0.15	0.67	0.96	0.45	0.57	934.14	0.53	mod.	100	0.01	0.41	0.16	0.67	0.96	0.45	0.57
Western Med	0.25	0.69	good	100	0.75	0.51	0.42	0.88	0.66	0.61	0.95	3823.88	0.43	mod.	99.7	0.80	0.67	0.33	0.89	0.79	0.66	0.96
Tunisian Plateau	0.002	0.76	good	96.2	1.00	0.52	0.47		0.90			226.87	0.76	good	97.7	1.00	0.52	0.47		0.90		

Table 2c	Real extent – buffer 10 km										
SAU	**Area (km^2)**	**NEAT value**	**Status class**	**Confidence level (%)**	**Erect algae**	**Canopy algae**	**Fish**	***P. oceanica***	**Sea urchins**	**Turf**	**Barren**
MED	31195.72	0.46	mod.	100	0.23	0.15	0.34	0.75	0.89	0.55	0.54
PR	5073.14	0.53	mod.	100	0.17	0.10	0.51	0.85	0.86	0.56	0.50
Aegean	2481.48	0.45	mod.	98.7	0.16	0.002	0.59		0.87	0.56	0.49
Adriatic	118.27	0.48	mod.	100	0.52	0.38	0.39	0.69	1.00	0.51	
Ionian	377.05	0.70	good	100	0.02	0.16	0.18	0.84	0.72	0.41	0.79
Western Med	2055.34	0.58	mod.	94.6	0.78	0.87	0.51	0.88	0.86	0.70	0.97
Tunisian Plateau	41.00	0.78	good	95.9	0.43	0.80	0.64		1.00		
Non-PR	26122.58	0.44	mod.	100	0.24	0.16	0.31	0.74	0.89	0.54	0.54
Aegean	11730.95	0.40	mod.	93.8	0.16	0.03	0.22		0.93	0.54	0.54
Adriatic	1323.13	0.46	mod.	99.9	0.36	0.41	0.38	0.54	0.49	0.59	
Ionian	2388.34	0.51	mod.	100	0.01	0.39	0.16	0.67	0.96	0.45	0.57
Western Med	10103.83	0.45	mod.	100	0.79	0.68	0.34	0.89	0.79	0.67	0.97
Tunisian Plateau	576.33	0.76	good	96.6	1.00	0.52	0.47		0.90		


A - Sampled extent
NEAT assessment
bad
poor
moderate
good
high
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CdP
WESTERN MED
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Kas
AEGEAN SEA
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TUNISIAN PLATEAU
MPAs
Control Areas
Other Control Areas
Ecoregion
Protected
Non-Protected
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250 km
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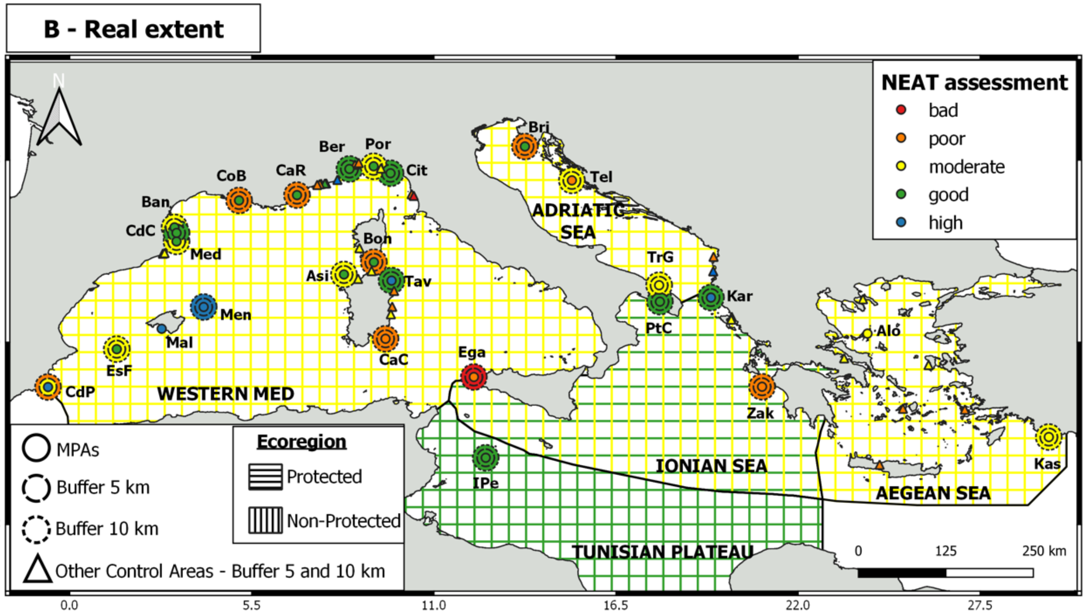
B - Real extent
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WESTERN MED
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IONIAN SEA
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AEGEAN SEA
IPe
TUNISIAN PLATEAU
MPAs
Buffer 5 km
Buffer 10 km
Other Control Areas - Buffer 5 and 10 km
Ecoregion
Protected
Non-Protected
0
125
250 km
44.5
39.0
33.5
0.0
5.5
11.0
16.5
22.0
27.5

Table 3. NEAT output for the Sicilian no-trawl case study. GCAST: no-trawl area; GTERM, GSANT: trawled (control) areas.

SAU	**NEAT value**	**Status class**	**Confidence level (%)**	***Merluccius merluccius***	***Mullus barbatus***	**Total teleosts**
NW Sicily	**0.464**	**mod.**	**100**	**0.533**	**0.438**	**0.423**
GCAST - No trawl	**1.000**	**high**	**100**	**1.000**	**1.000**	**1.000**
GTERM - Ctrl1	**0.164**	**bad**	**99.7**	**0.264**	**0.106**	**0.120**
GSANT - Ctrl2	**0.230**	**poor**	**80.9**	**0.334**	**0.207**	**0.148**

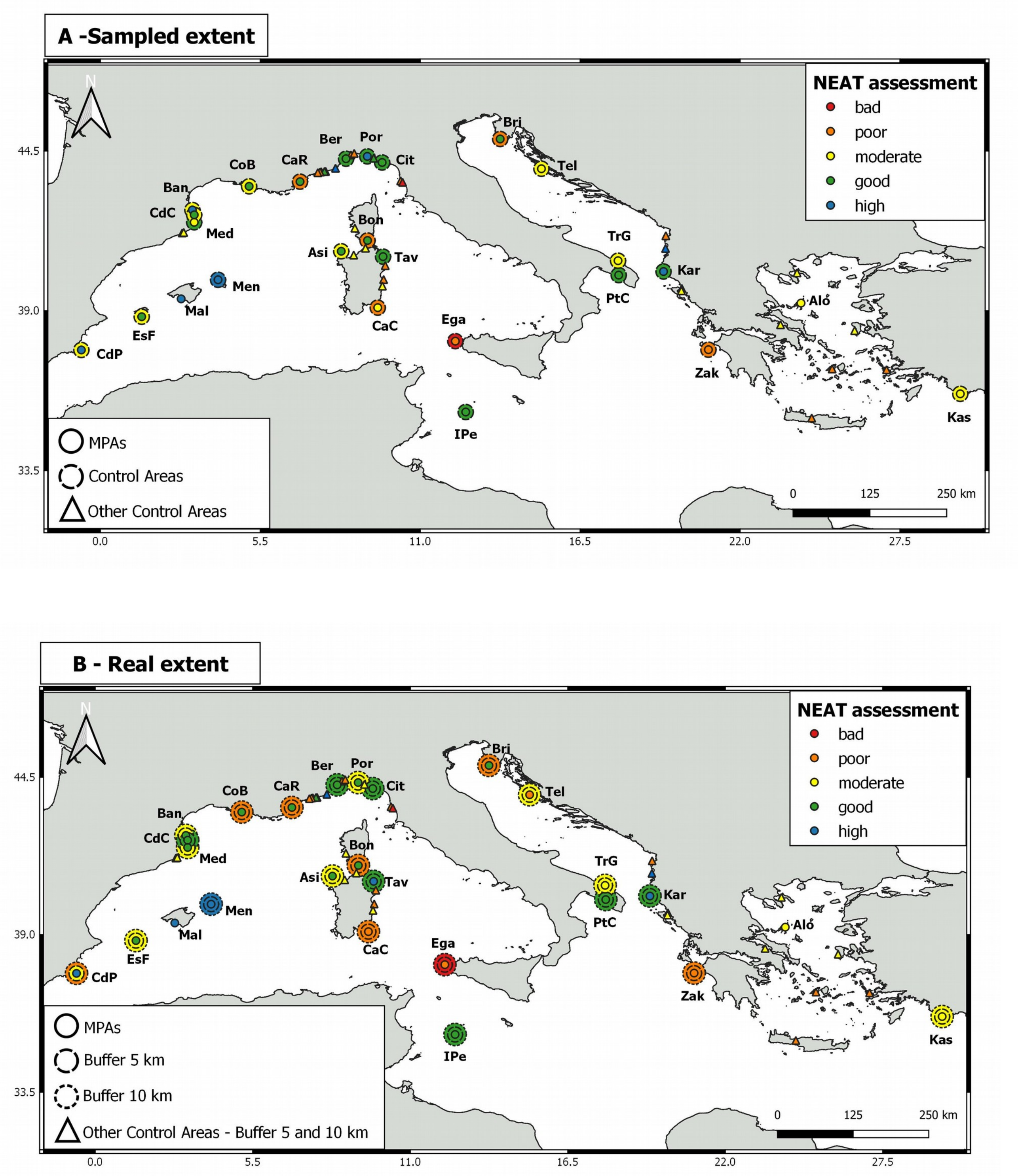

Figure 1. Distribution of the SAUs across the Mediterranean Sea with the assessment resulting from the NEAT analysis, considering the actual extension of the sampled area (Fig. 2A) and the real extension of MPAs with the control areas included with the buffer (Fig. 2B). Colors of the SAUs correspond to their estimated status: red = bad (0.0-0.2), orange = poor (0.2-0.4), yellow = moderate (0.4-0.6), green = good (0.6-0.8), blue = high (0.8-1.0).

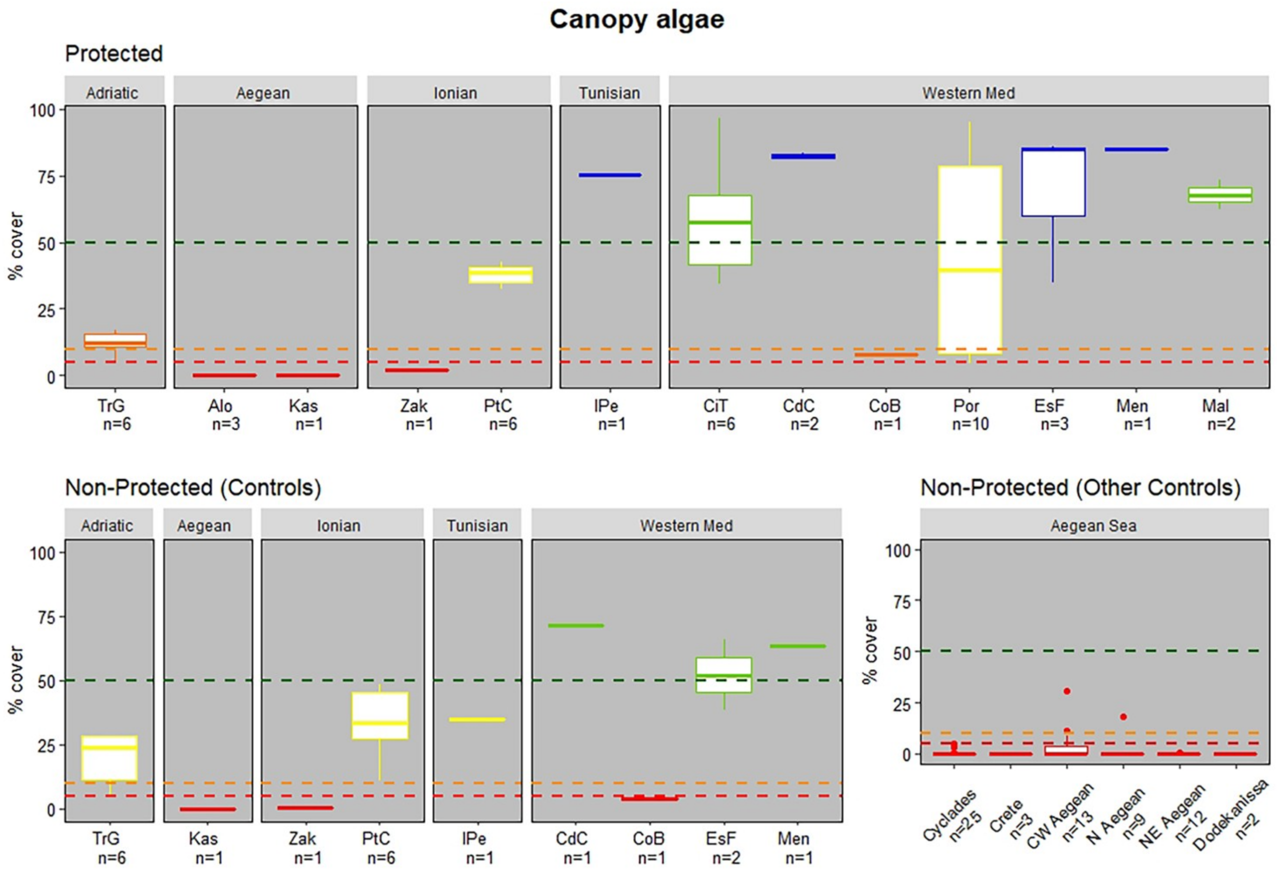

Fig. 2. The figure shows the distribution of the percentage cover values across sites ("n" = number of sites in each SAU) collected for Canopy algae grouped by protected and non-protected areas and ecoregions. Selected thresholds are also included as dashed lines: red = bad/poor (5%); orange = poor/moderate (10%); green = moderate/good (50%). Colors of the boxplots corresponds to the outcomes of the NEAT analyses