How good is your marine protected area at curbing threats?

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A R T I C L E I N F O

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A B S T R A C T

Marine protected areas (MPAs) are key tools to mitigate human impacts in coastal environments, promoting sustainable activities to conserve biodiversity. The designation of MPAs alone may not result in the lessening of some human threats, which is highly dependent on management goals and the related specific regulations that are adopted. Here, we develop and operationalize a local threat assessment framework. We develop indices to quantify the effectiveness of MPAs (or individual zones within MPAs in the case of multiple-use MPAs) in reducing anthropogenic extractive and non-extractive threats operating at local scale, focusing specifically on threats that can be managed through MPAs. We apply this framework in 15 Mediterranean MPAs to assess their threat reduction capacity. We show that fully protected areas effectively eliminate extractive activities, whereas the intensity of artisanal and recreational fishing within partially protected areas, paradoxically, is higher than that found outside MPAs, questioning their ability at reaching conservation targets. In addition, both fully and partially protected areas attract non-extractive activities that are potential threats. Overall, only three of the 15 MPAs had lower intensities for the entire set of eight threats considered, in respect to adjacent control unprotected areas. Understanding the intensity and occurrence of human threats operating at the local scale inside and around MPAs is important for assessing MPAs effectiveness in achieving the goals they have been designed for, informing management strategies, and prioritizing specific actions.

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1. Introduction

The effects of human coastal activities often combine into cumulative impacts on many marine ecosystems (Halpern et al., 2015, 2008). Marine protected areas (MPAs) represent the most common tool used in marine spatial planning to mitigate human impacts on marine ecosystems (Lubchenco and Grorud-Colvert, 2015; Lubchenco et al., 2003) and are being increasingly used worldwide both for conservation and fisheries management (Boonzaier and Pauly, 2015). Understanding how MPAs target threats they've been designed to address is essential to inform decision-making and optimize conservation outcomes (Guarderas et al., 2008; Hockings et al., 2004). Some MPAs are located in regions of high cumulative human impact, as shown both in the Mediterranean Sea (Coll et al., 2012; Rodríguez-Rodríguez et al., 2015) and in the Atlantic (Batista et al., 2014). This led to debate about their appropriateness at effectively reducing threats (Agardy et al., 2011; Jameson et al., 2002; Rodríguez-Rodríguez et al., 2015).

Most studies that aimed at evaluating MPAs effectiveness at reducing threat intensities were based on large scale assessments, with resolutions of 500 m (Batista et al., 2014) or 1 km^2 grid cells (Micheli et al., 2013; Portman and Nathan, 2015). Little emphasis has been given on mapping MPAs' specific threats acting at smaller spatial scales – possibly with some heterogeneity across MPA zones in the case of multiple-use MPAs–, those at which MPAs and their respective management actions are primarily designed to operate in (MPAs being a local spatial management tool; Olsen et al., 2013). This can result in difficulties to translate research findings into management actions, compromising potential benefits of MPAs (Agardy et al., 2011; Freed and Granek, 2014; Kearney et al., 2012; Mills et al., 2010).

The effectiveness of MPAs in reducing threats should be assessed at a local scale, where protection schemes are implemented. To achieve this goal, it is crucial to understand the differences in occurrence and intensity of human activities between the protected and unprotected areas (Claudet and Guidetti, 2010; Portman and Nathan, 2015). This helps to determine whether an MPA is actually successful in mitigating threats or whether the trends observed are merely an indicator of what is occurring outside of the protected area, at larger scales (Hargreaves-Allen et al., 2011).

Two broad types of MPAs exist. First, fully protected areas (FPAs); where all extractive activities (e.g., fishing) are prohibited and where some non-extractive actives (e.g., diving) can be allowed. They are also known as no-take areas or marine reserves. Second, partially protected areas (PPAs); where some activities are prohibited (e.g., spearfishing), others regulated (e.g., fishing with trammel nets) and others allowed (e.g., boating). Those PPAs can be further classified down according to the impact allowed and regulated uses have on species and habitats (Horta e Costa et al., 2016). Different levels of partial protection, together with full protection, can be combined spatially within multiple-use MPAs. Accordingly, the capacity of MPAs to reduce threats will differ depending on their type, design, regulations and level of enforcement (Di Franco et al., 2016; Guidetti et al., 2008; Scianna et al., 2015). Therefore, information on the intensity of threats within each MPA zone and in the surrounding external areas is necessary to assess MPA effectiveness in reducing threats.

Obtaining detailed information on threats is resource demanding, both in terms of time and costs, as the sources of information are largely heterogeneous (Levin et al., 2014). There is a need for a reliable, cost-effective method to assess the threat-reduction capacity of MPAs, robust to the heterogeneity of data sources and associated levels of confidence based on data quality. In addition, methods need to be standardized across MPAs as to allow both threat comparisons, among different zones within individual MPAs, and across MPAs.

Here, we developed a cost-effective framework to quantify threats at local scale and assess how MPAs are good (or not) at mitigating extractive and non-extractive local area-based threats (Fig. 1). We trialed the framework on 15 Mediterranean MPAs. MPAs in the Mediterranean Sea are a good model since this basin combines a high intensity of human uses (Claudet and Fraschetti, 2010; Portman and Nathan, 2015) together with a high conservation priority (Coll et al., 2010). This information is essential to inform local management as well as forthcoming regional marine spatial planning (European Commission, 2017).

2. Materials and methods

2.1. Data collection

We first identified human threats that affect marine ecosystems at a local scale and that can be managed by the MPA staff through regulations. This allowed the identification of 8 threats (Table 1). Threats were either assigned to extractive (i.e., professional and recreational fishing) or non-extractive uses (i.e., activities related to touristic frequentation).

We then developed indicators for each threat accounting for both availability of the data and the quality of the information given. The set of indicators selected was tailored to the data context of the study case, here the Mediterranean, where data availability can be poor in some regions. Data relevant for quantifying threat indicators were collected by means of questionnaires distributed to local managers and scientists. Local expert had to preferably obtain threat indicator values from scientific studies, technical reports or other official documents. When such sources were not available, expert opinion was considered. Three levels of confidence were applied for the estimated threat values (qualitative: high, medium, low). Threat indicator values were considered as high confidence when they were obtained directly from recent quantitative data (e.g., from monitoring data), as medium confidence when estimated from less recent quantitative data and as low confidence when no quantitative data were available and local experts of the particular MPA provided the estimation of the threat indicator value.

Threat indicators were quantified both within and outside 15 coastal MPAs in the Mediterranean Sea (MPAs listed in Appendix A). In case of multiple-use MPAs (n = 13), data was obtained for each full (no-take/no-entry or no-take zones) or partial protection level. We used two approaches to delineate the outside area, depending on the characteristics of the threat: i) for commercial fishing with trawlers and purse seiners a 10 km radius surrounding the MPAs was applied, while ii) for all other threats originating closer to the shore the coastal section at a maximum distance from the shore equal to the MPAs most offshore limit was considered (Fig. C.1.). This specific outside areas were chosen following consultations with at least one expert of each MPA. The two approaches aimed to reflect the nature and occurrence of that threat in order to avoid over- or underestimation of threat intensities, respectively, in the outside areas.

The total size of each zone within each MPA was obtained directly from managers and/or from management plans, while the outside surface areas were calculated using QGIS 2.8/1 (QGIS Development Team, 2015).

All the raw data collected in this study can be found in Appendix B.

2.2. Threat indices

2.2.1. Threat intensity

Using the raw threat values (Table B.1), we calculated the intensity TI_{ijk} of each threat i within each protection level j (full protection, partial protection and no protection-outside) for each MPA k, as follows:

$$TI_{ijk} = T_{ijk} / A_{jk}$$

where T_{ijk} is the value of threat i in zone j of MPA k, and A_{jk} is the area (km^2) of zone j in MPA k. We have then normalized threat intensity values (TI) by diving each value with the maximum threat intensity

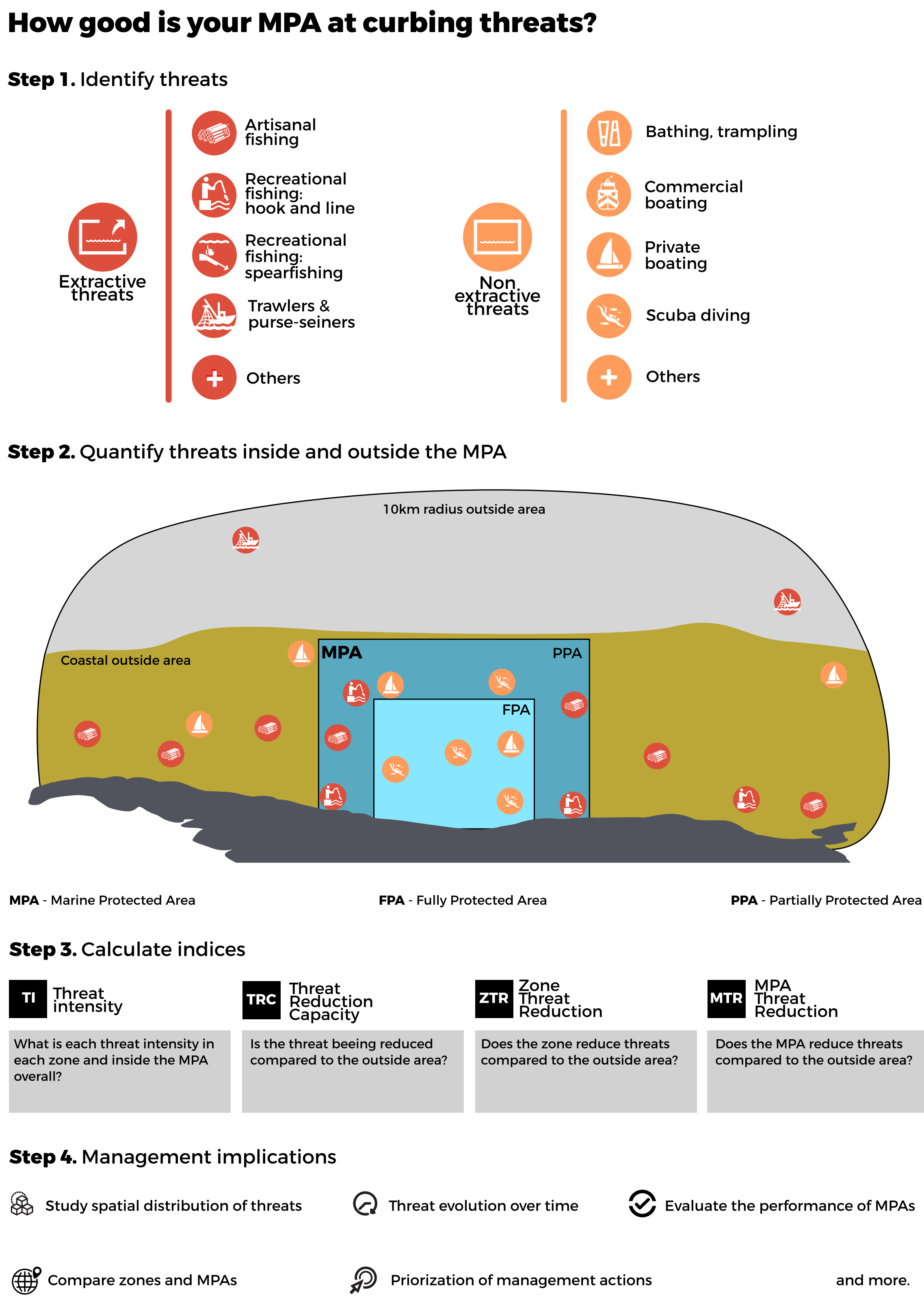

Fig. 1. The framework to assess how good are marine protected areas (MPAs) at curbing threats.

value (TI) of each threat, which resulted in a standardized scale of [0;1]. These normalized values were then used to calculate the mean threat intensity of each threat in each protection level to explore the variability of threat intensity among protection levels. Detailed descriptive statistics of the normalized threat intensity index can be found in Appendix C.

2.2.2. *Threat reduction capacity*

The threat reduction capacity TR_{ijk} of each protection level j (excluding the outside area) of each MPA k was calculated as:

$$TR_{ijk} = -\left(1 - {TI_{ijk}}/{TI_{o,ik}}\right)$$

Table 1
Local threats that can affect marine protected area (MPA) effectiveness and that can be managed by the MPA regulations. Indicators were chosen considering trade-offs between reliability and data availability. Weights reflect the potential impact of a given activity on both species and habitats and were rescaled after Horta e Costa et al. (2016).

Threat	Threat indicator	Scaled weight
Extractive threats		
Recreational fishing: hook and line	Number of people (nb/year)	0.56
Recreational fishing: spearfishing	Number of people (nb/year)	0.33
Artisanal fishing: professional fishing except trawlers/purse-seiners	Number of boats (nb/year)	0.82
Commercial fishing: professional fishing trawlers/purse-seiners	Number of boats (nb/year)	1
Non-extractive threats		
Tourism: bathing/trampling	Number of people (nb/year)	0.11
Tourism: scuba-diving	Number of dives (nb/year)	0.11
Tourism: private boating	Number of private boats (nb/year)	0.22
Tourism: commercial boating	Number of commercial touristic boats (nb/year)	0.22

where TI_{ijk} is the intensity of threat i inside zone j of MPA k, and $TI_{o,ik}$ is the threat intensity of threat i outside of the MPA k. A negative value of TR indicates that the threat intensity is reduced inside the protected area relative to the outside; a positive value of TR indicates that the threat intensity is higher inside the MPA relative to the outside. The mean threat reduction capacity values (TR_{ijk}) were used to compare the reduction capacity of the fully and partially protected zones for every threat. Detailed descriptive statistics of the threat reduction capacity index can be found in Appendix C.

2.2.3. Zone threat reduction score

The zone threat reduction score (zT) was calculated as:

$$\mathrm{zT_{jk}} = \frac{\sum_i \mathrm{TR_{ijk}} * \mathrm{w_i}}{\sum_i \mathrm{w_i}},$$

where TR_{ijk} is the threat reduction capacity defined above and w_i is the weight associated to threat i (Table 1). The weights for each threat were derived from Horta e Costa et al. (2016) and were rescaled to values between 0 and 1, with 1 being the weight assigned to the threat with the greatest ecological impact (i.e. trawling). The weights were used to discriminate between different potential ecological impacts of each threat and were obtained with expert knowledge, but based on previous studies (see detailed explanation in Appendix A of Horta e Costa et al., 2016).

2.2.4. MPA threat reduction score

The MPA threat reduction score $mpaT$ was calculated as:

$$\mathrm{mpaT}_k = \frac{\sum_j \mathrm{zT}_{jk} * \mathrm{A}_{jk}}{\sum_j \mathrm{A}_{jk}},$$

where zT_{jk} is the threat reduction score of zone j of MPA k, and A_{jk} is the surface area of zone j of MPA k. When the zone or MPA threat reduction score is negative, threats are being effectively reduced inside the zone and/or MPA compared to outside. When the threat reduction score is positive the MPA is actually enhancing threats rather than reducing them.

2.2.5. Local threat index

To account for the context in which MPAs are sited we calculated a local threat index lTI as follows:

$$lTI_{ik} = \frac{TI_{o,ik}}{\max TI_{o,i}},$$

where the $TI_{o,ik}$ is the intensity of threat i outside MPA k and $\max TI_{o,\,i}$ is the maximum intensity value of threat i recorded from all the outside areas of all considered MPAs. The local threat index ranges from 0 to 1, indicating a local low and high intensity, respectively, of a particular threat in the area outside an MPA compared to the broader context.

2.2.6. MPA local threat index

Local threat indices were aggregated at each MPA scale to calculate the MPA local threat index $mpa.lTI$ as follows:

$$\mathrm{mpa.}\ lTI_\mathrm{k} = \frac{\sum_\mathrm{i} lTI_{ik} * \mathrm{w_i}}{\sum_\mathrm{i} \mathrm{w_i}}$$

where lTI_{ik} is the local threat index of threat i of MPA k, as calculated above, and w_i is the weight of threat i. The values of the MPA local threat indices were normalized by dividing by the maximum local threat index value, resulting in a standard scale of 0–1, with low scores indicating a low local threat intensity, that is an overall low intensity of threats in the area outside the MPA, when compared to threat intensities in area outside the other MPAs in the region.

2.3. Data analyses

The relationship between the MPA threat reduction score ($mpaT$) and the MPA local threat index ($mpa.lTI$) were explored using a linear model. Additionally, the relationship between the threat reduction score, $mpaT$, and the age and size of the MPA were also tested with a regression to investigate whether these design characteristics affect the threat reduction capacity of MPAs.

The data on the confidence level associated with each threat type and zone protection level was analysed using chi-square tests to assess whether there is an association between data quality and zone type or threat type, respectively.

All analyses were conducted using R (R Development Core Team, 2016). The R script is available in Appendix D.

3. Results

Mean threat intensities (TI) differed among protection levels threat type (Fig. 2). Fully protected zones had no extractive threats (by definition), however they had the highest intensity of all non-extractive threats. On average, the intensity of non-extractive threats was 2.6 and 16 times greater in fully protected zones compared to partially protected zones and the area outside of the MPAs, respectively.

All threats were present in partially protected zones, with the highest levels of both recreational and artisanal fishing (Fig. 2). In the area outside MPAs, the intensity of extractive threats was up to 18 times greater than the intensity of non-extractive threats.

The threat reduction capacity (TR) differed across protection level and threat type (Fig. 3). Fully protected areas removed all extractive threats, while on average, partially protected zones did not reduce extractive threats. The intensities of large commercial fisheries (trawling and purse-seine) were reduced in partially protected zones compared to the outside, yet the intensities of artisanal and recreational fishing were approximately 4.9 times greater than in the surrounding areas. All non-extractive threats were increased within fully and partially protected zones, compared to the outside surrounding areas.

The mean zone threat reduction score (zT) for non-extractive threats was, on average, 4.8 greater for fully protected zones compared to partially protected zones, yet this value was highly variable (Fig. 3).

The MPA threat reduction score ($mpaT$) ranged between −0.8 and 116 (Fig. 4). Overall, only three MPAs reduced all threats relative to the outside. Five MPAs reduced all extractive threats and two MPAs reduced all non-extractive threats relative to their outside area.

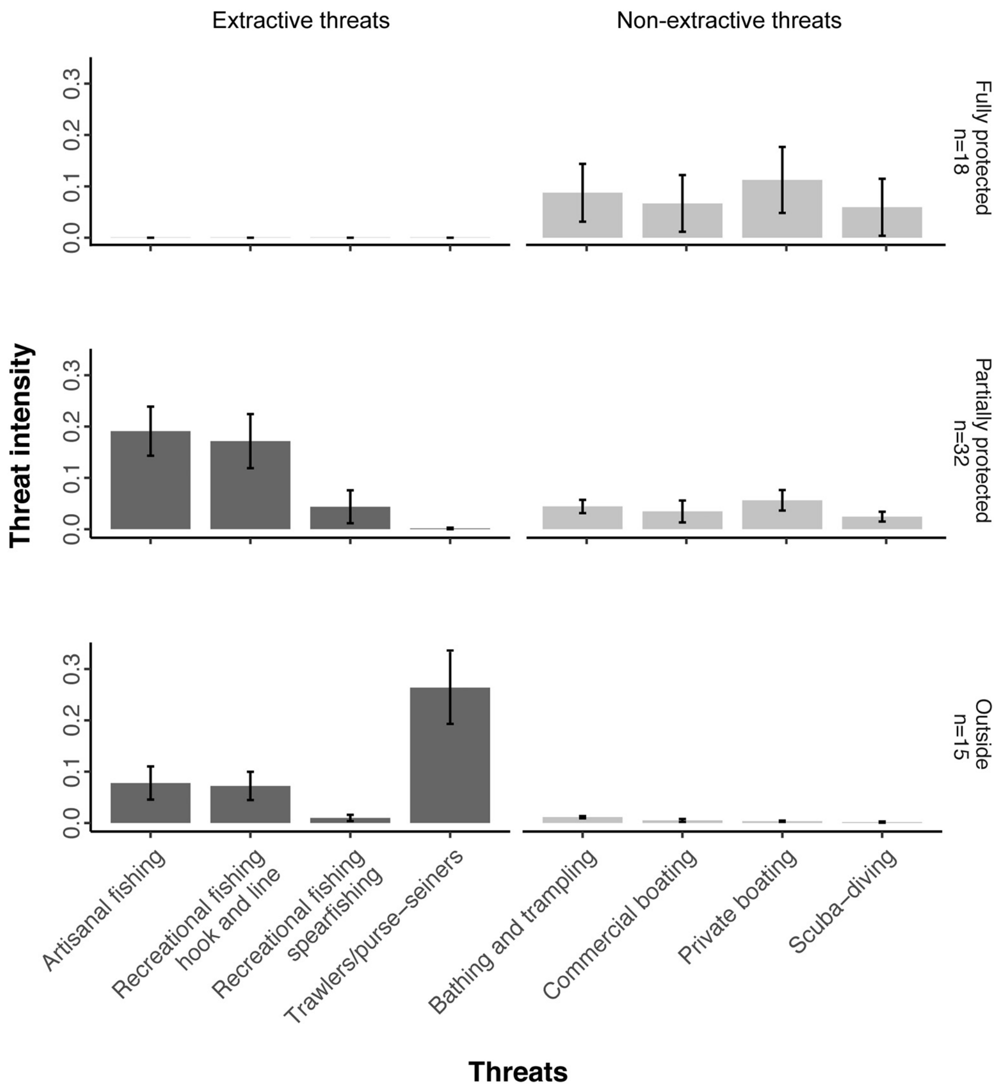

Fig. 2. Mean threat intensities (± SE) across fully protected, partially protected and outside zones of 15 marine protected areas.

The intensity of threats in the areas outside of MPAs varied greatly among MPAs (Fig. C.2 in Appendix C). There were no significant relationship between the MPAs' threat reduction score (*mpaT*) and the MPA local threat index (*mpa.lTI*), indicating that the capacity of MPAs to reduce threats was independent on the intensity of threats in their surrounding areas ($p > 0.05$, see Fig. C.3 in Appendix C). Likewise, there were no significant relationships between the MPA threat reduction score and the age or size of the MPA ($p > 0.05$, see Figs. C.4 and C.5 in Appendix C).

The confidence levels associated with estimates of threat intensities differed among zones of MPAs and the outside areas (chi-squared test, $\chi^2 = 153.54$, $p < 0.001$). More than half of the values from the areas outside were given low confidence (Fig. 5). In contrast within the MPAs, the majority of threat values had high confidence, 65% and 50% in fully and partially protected zones, respectively.

Confidence levels also differed among threats (chi-squared test, $\chi^2 = 233.63$, $p < 0.001$). For all extractive threats, the greatest proportion of values had high confidence (Fig. 6). Scuba-diving and commercial boating were among the non-extractive threats with the highest proportion of high confidence, while the values attributed to private boating and bathing had low confidence.

4. Discussion

This study was designed to provide a framework of the effectiveness of MPAs at curbing threats at the scale they are designed, developing indices of the intensity of threats at the scale of single MPAs (Fig. 1). The information provided was scaled to support management actions designed to enhance the success of each MPA in achieving its goals (Hockings et al., 2004).

Our most compelling result is that threats can indeed increase in MPAs compared to outside areas. Even if absent for fully protected zones, many extractive threats were larger in partially protected zones compared to outside. Contrary to fully protected zones, partially protected zones do not necessarily have the objective to eliminate threats (e.g., via a fishing ban), but to regulate their intensity towards sustainable levels. Implementing management strategies that allow and maintain ecologically sustainable uses ensures long-term benefits from ecosystem services benefiting local economies and, hence, local communities (Roberts et al., 2005). In the Mediterranean Sea, the regulatory regimes of partially protected areas vary from MPA to another, however there are some common modalities (Portman et al., 2012).

Artisanal and recreational fishing are permitted in partially protected zones of many MPAs, although most of the time subjected to restrictions in the type of gear allowed. The intensity of artisanal and recreational fishing was up to 4.8 times higher inside partially

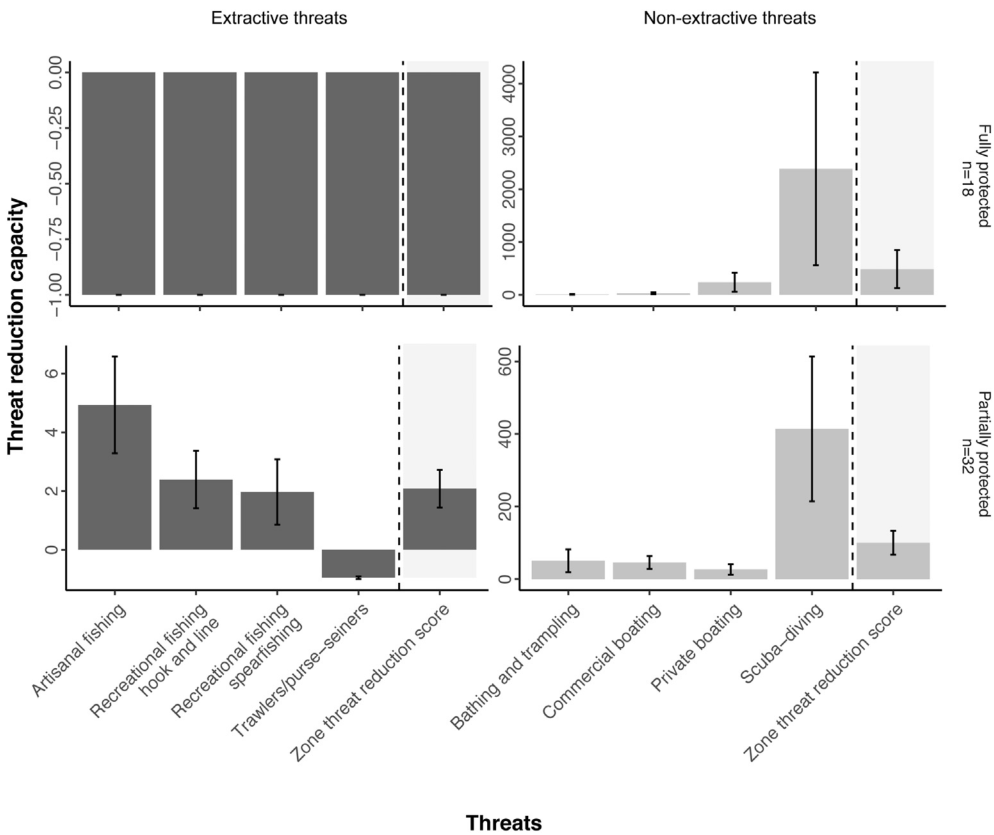

Fig. 3. Mean threat reduction capacity (± SE) for each threat across zones of different protection levels. The last bar of each panel represents the zone threat reduction score (*zT*). Negative values of the threat reduction capacity indicate that the threat is reduced in the marine protected area (MPA) relative to the outside, while positive values indicate that threats are higher inside the MPA relative to the outside.

protected zones compared to outside control areas. While the regulatory regime in partially protected zones may be stricter than in the surrounding outside areas, the former still attract more fishers and hence increase fishing pressure. Most of the partially protected zones considered in this study surround fully protected areas (Appendix A) and may attract fishermen. Full protection enhance fish abundance and size (Guidetti et al., 2014; Sala et al., 2012), often resulting in the spillover of larvae and adults to adjacent unprotected areas (Di Franco et al., 2012, 2015; Di Lorenzo et al., 2016; Garcia-Rubies et al., 2013; Goñi et al., 2010; Stobart et al., 2009), hence concentrating fishing effort (Kellner et al., 2007; Stelzenmüller et al., 2007).

The intensity of non-extractive threats was also higher within MPAs than in the areas outside, and at least 4 times higher in fully protected zones compared to partially protected zones. By definition, fully protected areas are places aiming to protect the full spectrum of biodiversity by limiting all kinds of extractive and destructive activity within them (Allison et al., 1998), yet this does not exclude all human activity. Indeed, most fully protected zones allow and, as we show here, *attract* visitation with the intent of non-extractive activities (Thurstan et al., 2012). Increasing non-extractive touristic activities are viewed as a positive socioeconomic output of MPAs in the Mediterranean Sea and worldwide (Leisher et al., 2007; Pascual et al., 2016), as they promote education, support employment and generate revenue (Hargreaves-Allen et al., 2011; Pascual et al., 2016; Spalding et al., 2017). Increasing tourism is, therefore, often listed as a looked-for objective of MPAs (Hargreaves-Allen et al., 2011). Thurstan et al. (2012) suggest that unless all activities are adequately managed, regulation of extractive activities alone may not guarantee the levels of biodiversity protection expected from fully protected zones.

Only three MPAs were effective in reducing the intensity of threats in respect to adjacent unprotected areas. Examining the context in which MPAs are established is, nevertheless, central to understanding the capacity of MPAs in addressing threats and their conservation potential (Portman and Nathan, 2015). The majority of MPAs in this study are multiple-use MPAs that accommodate a variety of uses. This type of MPAs is common for densely populated systems (Agardy et al., 2003), such as the Mediterranean Sea, where reducing all threats is unlikely. Portman and Nathan (2015) showed that the variety of activities occurring within the Mediterranean MPAs is often greater than in the coastal unprotected areas of many Mediterranean countries. Yet, multiple use MPAs and particularly partially protected areas alone are now the most common type of MPAs being implemented worldwide (Claudet, 2017). They are being established to meet the international targets of protection (Agardy et al., 2016), with the stated objectives of biodiversity conservation. Our results point that the achievability of their goals should be questioned, as here, we show that not only the variety, but also intensity of threats is generally greater within MPAs than in the areas outside (see also Mora et al., 2006) that leads to the low threat reduction capacity of MPAs.

The capacity to reduce (or not) threats was not dependent on the threat local context, the age or the size of the MPA. This suggests that the relationship between threat-intensity and reduction-capacity is mainly a function of management objectives and capacity (Gill et al., 2017), corresponding regulations (Horta e Costa et al., 2016) and enforcement (Guidetti et al., 2008) of each MPA rather than the magnitude of the outside threat intensities or design features. Hargreaves-Allen et al. (2017) examined the differences in threats inside and outside coral reef MPAs and they showed that MPAs with reduced threats had more staff and invested more funds into active management. Indeed, management has been identified as one of the most important factors affecting the effectiveness of MPAs (Gill et al., 2017). Understanding how different management regimes affect the threat reduction capacity of zones in multiple-use MPAs should be further investigated as it could shed light onto the highly variable responses we have observed among protection levels.

Our framework uses threats, and their respective indicators, that are most common and were easily obtained in the Mediterranean MPAs. While we were able to trial our framework using the information

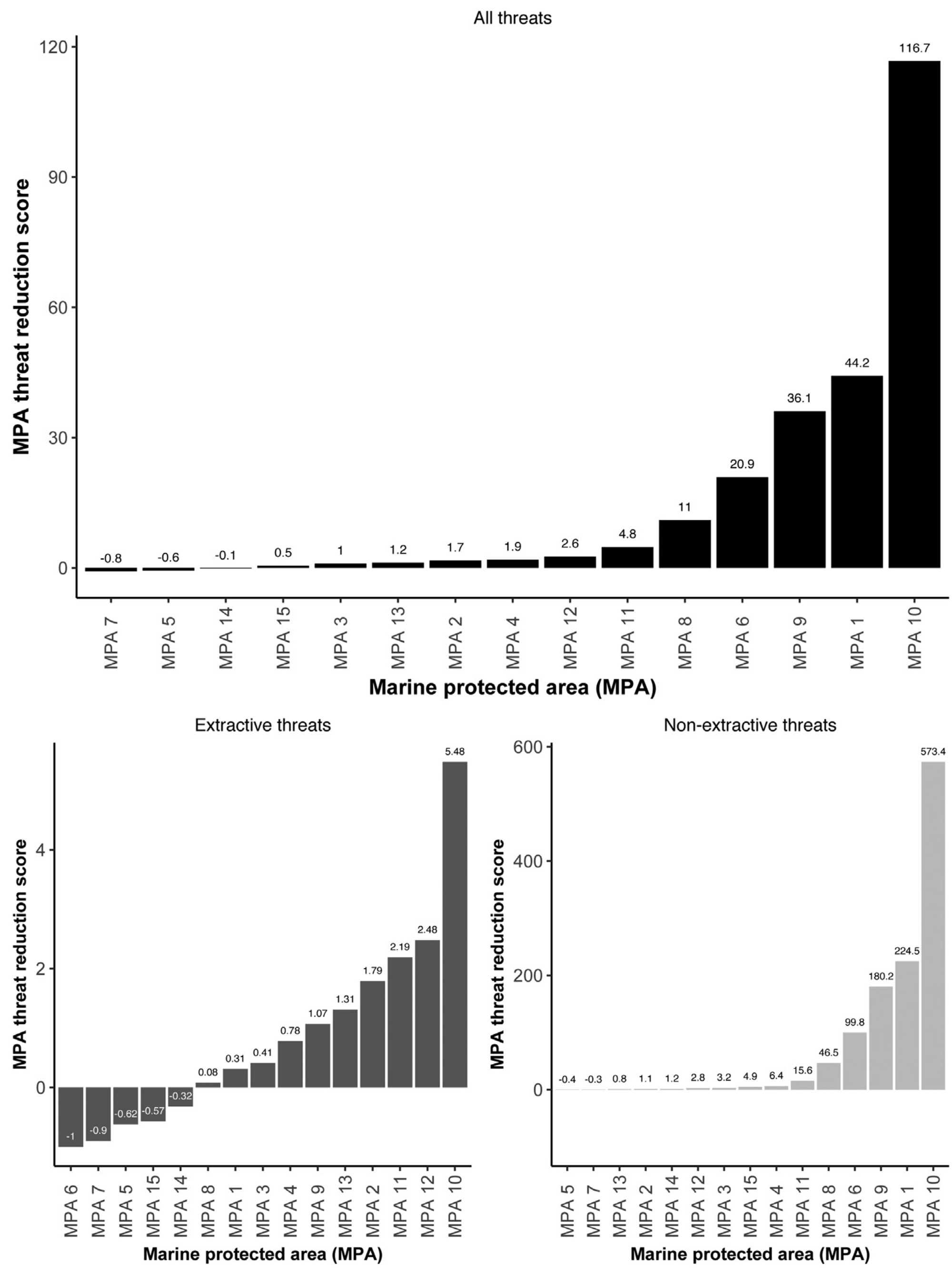

Fig. 4. Threat reduction score of marine protected areas (MPAs) for all threats combined (top panel), extractive (bottom left panel) and non-extractive threats (bottom right panel). Negative values of the threat reduction score indicate that threats are being effectively reduced within an MPA relative to the outside, while positive threat reduction score values indicate that the MPA is not effective at reducing threats compared to the outside.

available, the assessment of the MPAs threat reduction capacity could be refined with more detailed and robust data. Besides, we do acknowledge that other types of threats may be present in other systems yet this issue can be easily overcome, as our framework can be adapted to suit a variety of systems, by incorporating new threats and their corresponding indicators.

We did not include poaching as one of the threats in our framework. Poaching levels can often be higher than assumed in MPAs (Bergseth, 2017) and represent an important threat to the effectiveness of MPAs. While we initially planned to collect data on poaching, we faced strong difficulties to quantitatively standardize this threat across MPAs. If standardized data can be obtained across a range of MPAs, this can easily be added in the framework as an additional threat.

Our results point out that we have greater confidence about what is happening inside MPAs than in their surrounding areas. The low confidence associated with threat values in the unprotected, outside, areas might have affected the precision of our results. The areas outside MPAs are usually less monitored or completely unmonitored and estimating threat values for these areas was challenging. Good management should require regular monitoring, both for the ecological and environmental status of the MPA habitats (Fraschetti et al., 2013), but also should incorporate monitoring of the main activities that can lead to potential threats both inside and beyond the borders of the MPA (Claudet and Guidetti, 2010; Hargreaves-Allen et al., 2017; Parravicini et al., 2013).

Evaluating the success of MPAs is essential to maximize their conservation potential (Agardy et al., 2016; Pomeroy et al., 2005), especially within an adaptive management framework (Scianna et al., 2015). Contrary to previous assessments (Coll et al., 2012; Micheli

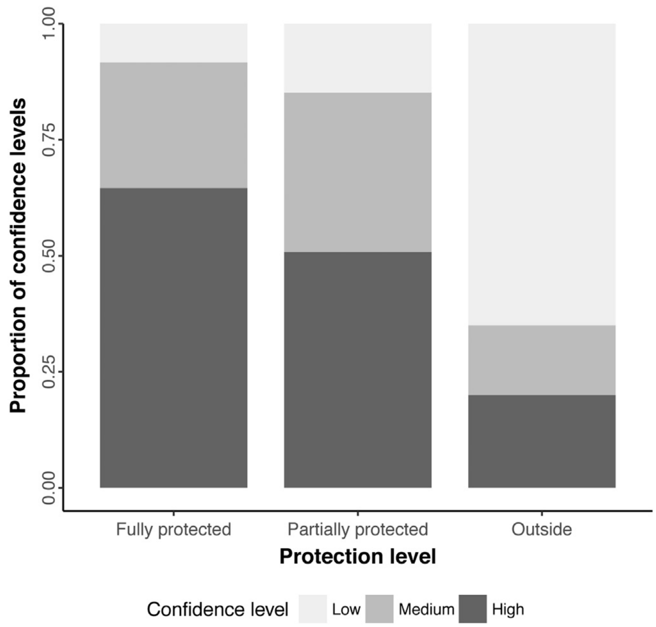

Fig. 5. Level of confidence (low, medium and high) associated to threat values corresponding to the fully protected zones, partially protected zones and the outside areas of the marine protected areas.

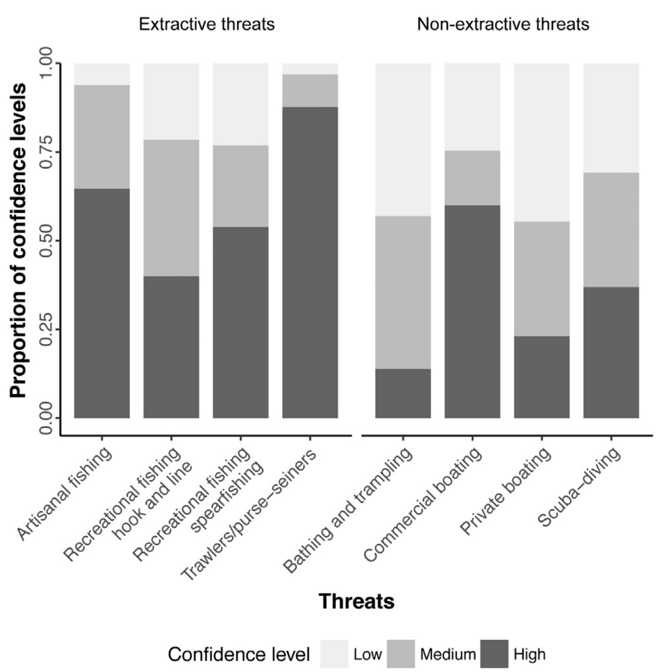

Fig. 6. Confidence levels (low, medium and high) associated to threat values for each threat.

et al., 2013) our approach uses data specific to each zone of the MPA, where strong heterogeneity among threats intensity can occur, and accounts for manageable threats at manageable scales relevant for MPA managers. We therefore believe this work has general and wide applications, especially for managers and planners who need to assess the success of MPAs at achieving marine spatial planning goals (Partelow et al., 2015).

4.1. Management implications

By providing the ability to easily compare threat intensities and the capacity of a given MPA to reduce threats, our proposed framework can help prioritize management actions. Management actions should first be directed towards reducing threats that would prevent achieving the MPA objectives. Besides, the threat assessment framework can help identify unexpected indirect effects of MPA creation, such as increased non-extractive threat due to increase attendance.

By providing the ability to easily compare threat reduction score among zones, in the case of multiple-use MPAs, our proposed framework can help guide local spatial planning. Assigning different uses in different zones can have trade-offs in terms of biodiversity conservation and ecosystem services delivery and threat assessment is a first step towards the identification of acceptable thresholds of uses. When scaled-up regionally, the threat assessment framework can help guide regional spatial planning.

The threat assessment framework could be incorporated into monitoring programs. First, monitoring threat evolution over time helps identify the management actions able to reduce threats. Second, this would necessarily imply to monitor and collect data, which is a condition of proper MPA effectiveness assessments.

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