Setting Performance Indicators for Coastal Marine Protected Areas: An Expert-Based Methodology

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Marine Protected Areas (MPAs) require effective indicators to assess their performance, in compliance with the goals of relevant national and international commitments. Achieving and prioritizing shortlists of multidisciplinary indicators demands a significant effort from specialists to depict the multiple conservation and socioeconomic interests, and the large complexity of natural systems. The present paper describes a structured expert-based methodology (process and outputs) to co-define a list of multidisciplinary MPA performance indicators. This work was promoted by the management authority of coastal MPAs in mainland Portugal to gather a consensual and feasible list of indicators that would guide the design of a future national monitoring program. Hence, Portuguese coastal MPAs served as a case study to develop such a process between 2019 and 2020. In the end, participants (1) agreed on a shortlist of prioritized indicators (*i.e.*, environmental, governance, and socioeconomic indicators) and (2) defined minimum monitoring frequencies for the indicators in this list, compatible with the potential replicability of the associated survey methods. The present approach recommends that management plans incorporate monitoring procedures and survey methods, with a validated list of indicators and associated monitoring periodicity, agreed among researchers, MPA managers and governance experts. The proposed methodology, and the lessons learned from it, can support future processes aiming to define and prioritize MPA performance indicators.

Keywords: marine protected area, MPA monitoring, marine and coastal management, performance indicators, marine conservation

INTRODUCTION

Global marine and coastal ecosystems continue to deteriorate due to resource overexploitation, release of pollutants, habitat degradation and the impacts of climate change (IUCN-WCPA, 2008; Secretariat of the Convention on Biological Diversity, 2020; O'Hara et al., 2021). Strongly protected and implemented Marine Protected Areas (MPAs) can achieve long-term marine conservation goals (Day et al., 2012; Grorud-Colvert et al., 2021). To this end, effective management and adequate monitoring planning, in light of MPA goals and objectives, are vital for MPA success (Kelleher, 1999; Greathead et al., 2020). Guidelines adopted by regional conventions and directives advise contracting parties to undertake regular assessments of the ecological quality status of the marine environment and management measures, including in MPAs, and to publish their results. This is done namely by the Convention for the Protection of the Marine Environment of the North-East Atlantic ('OSPAR Convention', Art. 6), the Convention on the Protection of the Marine Environment of the Baltic Sea Area ('HELCOM Convention', Art. 16), the European Marine Strategy Framework Directive (EU MSFD), and the EU Birds (Council Directive 79/409/EEC) and Habitats Directives (Council Directive 92/43/EEC).

MPA effectiveness depends on adequate and sufficient performance indicators to assess the impact of conservation measures and evaluate whether MPA objectives are being fulfilled. MPA performance indicators should inform about 1) effects on the environmental state, 2) uses' environmental impacts and socioeconomic conditions, and 3) management and governance response, to support adaptive management practices (IUCN-WCPA, 2008; Pelletier, 2011; Wu et al., 2017). Within the agreed commitments related to MPAs is also the promotion of ecological coherence, which is the scientific concept used to define synergy among various MPAs to achieve greater ecological benefits than those each MPA can individually provide (OSPAR Commission, 2007; Olsen et al., 2013). Hence, single MPAs' performance assessment must also address ecological coherence for the implementation of true networks (Olsen et al., 2013; Pendred et al., 2016). Identification of main pressures, MPA objectives, regulations, and enforcement strategies to reduce pressures and achieve MPA goals, and a monitoring program to evaluate performance, are key components of management plans. Despite the critical role of management plans for MPA success, many are ineffective and insufficient (Álvarez-Fernández et al., 2017; WWF & Sky Ocean Rescue, 2019). Moreover, experts recognize that creating a standardized list of indicators is one of the most challenging steps in the design of management plans (Borja et al., 2019). The prioritization of MPA performance indicators also demands a great effort due to the multiple conservation and socioeconomic interests and the intrinsic complexity of natural systems (e.g., Dale & Beyeler, 2001; Okey, 2018). Nevertheless, the assemblage of a core list of indicators needs to be prioritized for the effective monitoring and management of MPAs, the rational application of MPA funds, and the integrated evaluation of MPAs' performance (Pendred et al., 2016).

Given the multitude of dimensions potentially influenced by an MPA, it is reasonable to assume that a set of indicators that is built and agreed upon by different MPA stakeholders will ensure broader perspectives and a more integrated approach (e.g., Himes, 2007a; Pelletier, 2020) .

Different studies have performed collaborative work (expert-based or participatory processes) to co-design protected areas and evaluate their effectiveness, including co-defining lists of monitoring indicators (e.g., Heck et al., 2011; Izurieta et al., 2011; Garces et al., 2013; Day, 2017; Okey, 2018; Pelletier, 2020). Collaborative work is a widespread approach used by many entities seeking to attain the same goals and share responsibility for their fulfillment (Green & Johnson, 2015). Collaborative work promotes interaction between people from different circles, knowledge sharing and peer learning, thus contributing to the establishment of relationships and partnerships, and the development of innovative solutions (e.g., OECD, 2014; Green & Johnson, 2015). Thereby, defining consensual multidisciplinary lists of indicators is facilitated by this approach (e.g., Izurieta et al., 2011; Garces et al., 2013; Okey, 2018; Pelletier, 2020).

The composition of the stakeholder group participating in such processes, which depends on the purpose of the study and available resources, may affect results - for instance, the type of monitoring indicators selected and their number (e.g., Izurieta et al., 2011; Stacey et al., 2013; Pendred et al., 2016; Okey, 2018). The diversity in the stakeholder group will play an important role in the balance among monitoring themes (i.e., environmental, governance and socioeconomic) when developing and prioritizing lists of indicators (Himes, 2007a).

Several initiatives have been developed to create and implement methodologies for the selection and prioritization of viable and pragmatic sets of indicators, hoping to facilitate and enhance marine resources' monitoring and management (Himes, 2007b; Pendred et al., 2016; Okey, 2018). These initiatives are often survey-based (online or face-to-face), which, if not combined with more resourceful and interactive working group approaches, can cause fatigue to participants and consequent loss of interest (Okey, 2018). Moreover, various authors have argued that the typical duration of research projects (2-4 years, following Pelletier, 2020) may be insufficient to build up and sustain a broad multidisciplinary consortium, which depends on reaching understanding and consensus among peers with different backgrounds (e.g., Chapman et al., 2017; Pelletier, 2020). Nevertheless, the development of short to medium-term approaches, with adjusted goals, is of the utmost importance when long-term participatory processes are unlikely.

The main goal of this study was to develop, test, and validate a structured expert-based methodology to co-define a list of multidisciplinary MPA performance indicators within a year. This work was promoted by *Instituto da Conservação da Natureza e Florestas* (ICNF), the management authority of coastal MPAs in mainland Portugal. ICNF invited member scientists from MPA-related projects to gather a consensual, feasible, and prioritized list of indicators that would guide the design of a future national monitoring program. To this end, a multidisciplinary group of MPA researchers and practitioners

was engaged in face-to-face workshops and intersessional activities, organized and facilitated by the invited projects' members. They searched, listed, evaluated, and prioritized the best performance indicators, addressing environmental, governance and socioeconomic features (Pomeroy et al., 2004).
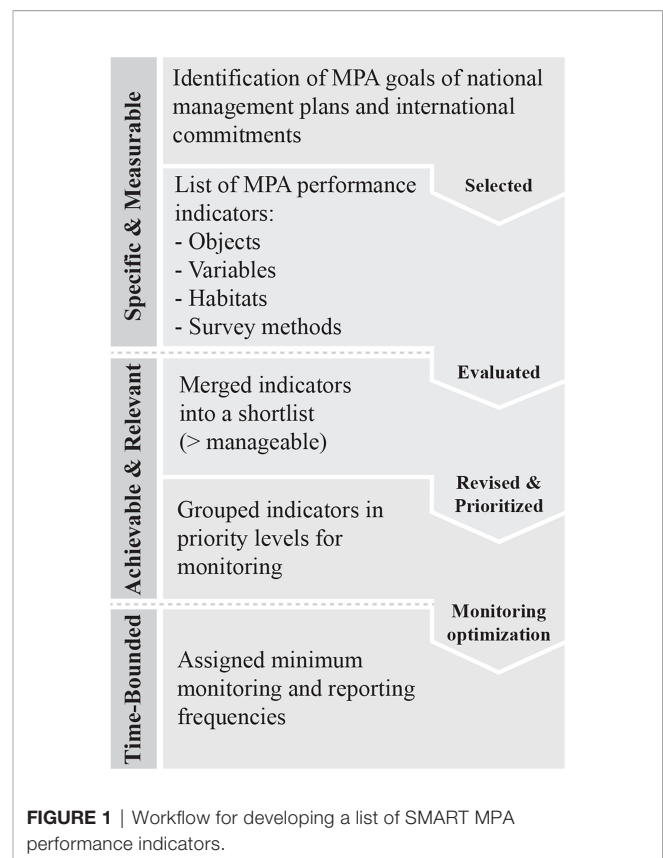
The proposed methodology (process and outputs) addressed monitoring efficiency and capacity by defining first, second and third priority indicators, and acknowledging the sets of indicators that could be potentially monitored simultaneously, depending on the survey methods and their monitoring frequency. The present work can serve as an example for future expert-based processes aiming to define and prioritize MPA performance indicators. The resulting shortlist of prioritized indicators – based on important marine conservation goals set by international instruments (*e.g.*, EU MSFD, Natura 2000 network, OSPAR Convention) – is prepared to be used in developing MPA monitoring programs, with specific adjustments on a case-by-case basis.

MATERIALS AND METHODS

Overview

Four groups of researchers from different scientific backgrounds (mainly within natural sciences) and MPA monitoring practitioners (29 people; henceforth the organizing team) in mainland Portugal organized and held three one-day workshops between February 2019 and February 2020, to agree on a list of performance indicators for coastal MPAs. Besides the organizing team, workshop participants (identified through expert judgment) were scientists, managers and governance experts with in-depth knowledge of the MPAs that served as case studies (Andrade et al. 2020). In total, 67 participants prepared and/or attended the face-to-face workshops and performed remote intersessional activities. Among the participants, 46 were researchers in natural sciences and monitoring practitioners of the marine environment and 21 had training and experience in social sciences, including the governance and management of MPAs. Managers were from the national management agency (ICNF). The number of participants and the representation of stakeholder groups varied through the different stages of the process. Participants at the workshops ranged from 28 to 44, and those who only participated remotely were 4 people. Some of the group representatives changed throughout the process, while others followed the entire process.

During the process, participants constructed and progressively refined a list of MPA performance indicators, to be regarded in a collaborative monitoring program for coastal MPAs (in Portuguese mainland territory) (**Figure 1**). To this end, MPA goals complying with national and international commitments (those of national MPA management plans and those agreed upon international conventions and directives) were considered in the selection and validation processes. As the success of indicators also relates to the survey methodologies (those widely used or those under experimentation), this study addressed methodology effectiveness and efficiency, considering the experts' experience and the environmental and socioeconomic context of three MPAs along the Portuguese coast – Litoral Norte Natural Park (PNLN),

FIGURE 1 | Workflow for developing a list of SMART MPA performance indicators.

Arrábida Natural Park (PNA), and Sudoeste Alentejano and Costa Vicentina Natural Park (PNSACV) - regarded as case studies. Natural Park is the predominant category of coastal MPAs in mainland Portugal, representing >80% of the total protected area in this context. The methodology addressed indicators' specificity, measurability, achievability, relevance and time-bound to develop SMART indicators (**Figure 1**). In a nutshell, participants agreed on a final list of MPA performance indicators, grouped them by priority level, and defined their desirable monitoring/reporting frequencies, creating bases for sustainable and effective long-term management plans (Pomeroy et al., 2004). See the complete workflow of this expert-based process in **Supplementary Figure 1**.

Preliminary Work

To prepare the workshops, the organizing team first selected a detailed preliminary list of performance indicators and a preliminary set of indicator performance criteria, based on a thorough literature review (*e.g.*, Dale & Beyeler, 2001; Ehler, 2003; Pomeroy et al., 2004; Heink & Kowarik, 2010; Beliaeff & Pelletier, 2011; Pelletier, 2011; Moffitt et al., 2013; Burrows et al., 2014; Roca et al., 2016; Bell et al., 2017) and expert knowledge.

The performance indicators responded to a set of collectively agreed objectives:

(1) report on the fulfillment of goals and objectives of each MPA, determined by national and international commitments;

(2) improve adaptive and integrated management among the Portuguese coastal MPA monitoring systems;

(3) contribute to an informed and adequate management and protection of marine ecosystems and resources;

(4) establish effective metrics for increased knowledge of protected species and habitats' distribution and conservation status, including those encompassed by the Natura 2000 Network and existing management plans.

The selected performance indicators fell into the following categories: environmental (E), social (S; *i.e.*, socioeconomic), and governance (G). Each indicator description included: object of measure (*e.g.*, commercial fish), variable (*e.g.*, abundance), habitat (*e.g.*, pelagic), and survey method (*e.g.*, acoustic sampling). Further information was added to the list about which indicators overlap with overarching goals adopted by the: (1) European Natura 2000 Network, (2) European Marine Strategy Framework Directive (EU MSFD), and (3) OSPAR Convention.

The selected set of indicator performance criteria would be used to score the list of performance indicators. It included criteria to assess the indicator's scientific attributes (*e.g.*, the existence of baseline monitoring/reference data, relevance to European Directives) and practical attributes (*e.g.*, feasibility/replicability, cost of the method) in the MPAs' context.

The preliminary list of performance indicators and the set of indicator performance criteria were sent to all participants for appreciation before the first face-to-face workshop.

Workshop I

The objectives of the first workshop were to discuss and validate (1) the matrix (structure and content) of the preliminary list of performance indicators and (2) the preliminary set of indicator performance criteria.

The event started with a brief explanation of the workshop's proceedings and a short round of presentations by the organizing team and participants on the monitoring methodologies applied in different MPAs.

Afterward, participants were split into five small (6 to 7 people) heterogeneous groups, including at least one representative of the organizing team in each group, and invited to validate a sample of 11 indicators selected from the preliminary list of performance indicators, representing the different categories (*i.e.*, environmental, socioeconomic and governance), and the preliminary set of indicator performance criteria. Participants were also asked to point out suggestions for improving these materials. In the closing plenary session, each group presented their observations and suggestions so that all participants could commit together to the best decisions. This discussion resulted in a set of guidelines for constructing a list of MPA performance indicators and defining their evaluation criteria, to be considered in this process and future ones.

Intersessional Activity

The intersessional activity that followed Workshop I had two purposes: (1) to score the list of 132 performance indicators and their survey methods validated in Workshop I (**Supplementary**

Table 1), and (2) to merge indicators into a shorter and more manageable list. Guidelines provided in Workshop I were followed to perform these activities.

Intersessional Activity I

Before the scoring exercise, the preliminary list of indicators and the preliminary set of performance criteria were revised to integrate participants' improvement suggestions resulting from Workshop I. The four groups that integrated the organizing team scored independently all 132 indicators and paired survey methods presented in the validated list (**Supplementary Table 1**): 93 environmental, 29 of governance, and 10 socioeconomic; using the validated indicator performance criteria (**Table 1**). Each variable was measured using a binary scale for the sake of simplicity. To assist the scoring process, the indicator performance criteria were divided into two groups: "indicator output criteria" and "survey methods criteria"; the first group to evaluate the indicator itself and the second to assess the associated survey method (**Table 1**).

One of the organizing team's four groups was responsible for analyzing the scoring data (henceforth the data analysis group). The final score of each performance indicator was calculated as follows: first, the binary scores assigned by each group to each indicator output criteria assessing each performance indicator were summed; secondly, for each indicator output criteria, the ratio between the computed scores and the number of groups that had scored them were calculated (Equation 1); finally, the average of the ratios divided by all the six criteria were computed (Equation 2).

The exact process was repeated to score the indicators' survey methods, using the five survey methods criteria (**Table 1**). The bottom third of all indicators and survey methods (with the lowest scores) were flagged for participants in Workshop II to decide whether to exclude or reintegrate them with the necessary adjustments.

Equation 1. Expression to determine the ratio of scores for the six criteria that assess each performance indicator.

$$z_j = \frac{1}{n}\sum_{k=1}^{n} x_k \star 100$$

Equation 2. Expression to determine the final score of each performance indicator.

$$y_i = \frac{1}{6}\sum_{j=1}^{6} z_j$$

Where:

x_k is the binary score of the kth group of experts scoring the indicator.

n is the number of groups scoring the indicator (minimum 1, maximum 4).

z_j is the score of the jth criterion.

y_i is the final score of the ith indicator.

Intersessional Activity II

After scoring the full list, the purpose was to achieve a shorter and more manageable list (as suggested during Workshop I) to

TABLE 1 | Validated indicator performance criteria and the scoring method (binary).

A) Indicator output criteria

Criteria	Requirements	Scoring method
1. Relevance	The indicator is relevant as it responds to European Directives (EU MSFD, Natura 2000 Network), OSPAR, or, at least, to one MPA objective.	0 = non-relevant 1 = relevant
2. Reliability	The indicator is reliable, as it is accurate and robust, *i.e.*, it is measured with a low error rate and is unambiguous in the interpretation of results.	0 = unreliable 1 = partly or fully reliable
3. Effectiveness	The indicator is effective in answering the monitoring question(s), *i.e.*, it reflects changing status.	0 = ineffective 1 = partly or fully effective
4. Baseline situation	The indicator has reference data (historical database).	0 = it has no reference data 1 = it has reference data
5. Comprehensiveness	The indicator contributes to one or more objectives or management requirements of the MPAs "network" (*i.e.*, common to the different MPAs).	0 = non comprehensive 1 = comprehensive
6. Uniqueness	The indicator is unique in its ability to respond to a particular monitoring objective of the MPA.	0 = it is comparable to other indicators 1 = it is unique

B) Survey methods criteria

Criteria	Requirements	Scoring method
7. Feasibility/ Scientific evidence	The survey method is feasible as it is replicable and accepted by the scientific community.	0 = non-replicable 1 = replicable
8. Capture	The survey method does not require capture or requires capture with replenishment (capture, tagging and recapture).	0 = requires capture 1 = does not require capture or requires capture with replenishment
9. Level of expertise	For the survey method, it is easy to hire specialized staff for taxonomic identification or the expected technical difficulty. It does not need long-term specialized training.	0 = difficult to hire specialized staff or needs long-term specialized training 1 = easy to hire specialized staff and/or it does not need long-term specialized training
10. Speed	The survey method has fast planning/preparation and fieldwork, and/or fast data processing/delivery of results.	0 = the process until the delivery of results is relatively slow 1 = the process until the delivery of results is relatively fast
11. Cost (per sampling) (adapted from Bell et al., 2017)	The survey method presents low to medium costs of inbound, logistic/consumption, and human resources.	0 = high total cost (*e.g.*, > 10,000 €) 1 = low to medium total cost (*e.g.*, 0 – 10,000 €)

The table is divided into two groups of criteria: A) Indicator output criteria and B) Survey methods criteria. The threshold used for the Cost criterion was provided as an example. Whether a method is high or low-cost is case-specific.

proceed with further classification and prioritization steps. For this purpose, the data analysis group merged indicators by (1) combining species/groups that are usually monitored simultaneously (*e.g.*, the average size of commercial fish and invertebrates); and (2) grouping complementary metrics (*e.g.*1, density and frequency of occurrence are complementary metrics of abundance; *e.g.*2, the annual number of surveillance activities and the annual number of fines per surveillance activity both assess the existence of an efficient and adequate MPA surveillance strategy).

The resulting shortlist would be the subject of further validation and evaluation in the following workshop.

The group also integrated into the shortlist the Pressure-State-Response (PSR) framework developed by OECD (2003). The PSR framework identifies the purpose of each indicator: a) pressure indicators measure direct or indirect impacts inflicted by anthropogenic activities on the environment; b) state indicators diagnose environmental states; and c) response indicators assess society's reaction to the changes exposed by state indicators, *i.e.*, if it is acting preventively, mitigating or reversing the adverse effects, and adopting strategies for the preservation and conservation of the environment and the

sustainable use of its natural resources (OECD, 2003; Pelletier, 2011). This approach would help in the next steps of the process by making the role of each indicator clear for all the members of the multidisciplinary group and highlighting the missing links between these three types of indicators (OECD, 2003).

Workshop II

The main goals of Workshop II were to (1) validate the proposed shortlist of indicators resulting from Intersessional activity II and (2) identify the indicators of higher relevance to establish priority levels. To allow for a more focused and optimized process (Okey, 2018), workshop participants were organized into groups and divided between two main monitoring themes: a) indicators of environmental state and pressure (researchers and MPA monitoring practitioners); b) indicators of governance response and socioeconomic pressure (researchers and managers). Each focus group assessed only the respective set of indicators.

The session included three exercises previously sent to all participants to get the contributions of the ones who were unable to attend the workshop. Each exercise was followed by a plenary session to discuss results and ensure a group conclusion. Survey methods were omitted from the shortlist to balance the influence

of the participants' working experience/familiarity with survey methods when they scored the indicators.

(1) The first exercise consisted of carefully reading the proposed shortlist of indicators (which incorporated the full list of evaluated indicators, merged according to the points explained above – Intersessional activity I). The low-scored indicators and survey methods from the previous scoring exercise (*i.e.*, from the extensive list and merged now in the shortlist), were also discussed in plenary in this part of the session to determine if they should be eliminated or redefined.

(2) In the second exercise, using the shortlist of indicators, the organizing team asked participants to take three actions to their group of indicators (*i.e.*, environmental or governance and socioeconomic) if necessary: a) to add if there were important omissions in the list, b) to edit when descriptions of indicators needed to be changed, c) to eliminate when indicators were found not to be relevant within the context of the shortlist. This represented the second round of review and allowed to validate and close the shortlist of performance indicators (**Supplementary Table 2**).

(3) The third exercise consisted of classifying the indicators from 1 (not relevant) to 5 (very relevant) to reach a final consensus between working groups of each indicator's relevance and, most importantly, to assign each a priority level. While the first performance criteria-based scoring exercise allowed a structured evaluation of each indicator and associated survey method, the second scoring exercise was to rank the validated performance indicators in priority groups, based on the experts' perceptions of each indicator's relevance (this time without considering the survey methods or specific criteria). The final score of each indicator was the weighted average of the scores given by the working groups that attended Workshop II (weight = 75%) and by the people who have participated remotely (weight = 25%). After computing the final scores, the following priority groups were defined: Priority 1 (5 points, maximum classification), Priority 2 (from 4.99 to 4 points), Priority 3 (from 3.99 to 1.75).

Workshop III

Workshop III was dedicated to: (1) validate the priority groups resulting from Workshop II; (2) define minimum monitoring frequencies for each prioritized indicator (each semester, annual, or multi-annual); and (3) review the adequacy of survey methodologies previously considered for the indicators by matching indicators' minimum monitoring frequencies with the survey methods' possible implementation frequencies (*i.e.*, using the existing resources).

This workshop's structure was the same as Workshop II, with three exercises. Groups were divided into environmental, and governance/socioeconomic monitoring themes and practical exercises were followed by plenary sessions to validate results.

(1) In the first exercise, the organizing team invited participants to check the proposed priority groups resulting from Workshop II, and to suggest changes in their classification if necessary.

(2) The second exercise took place during the first plenary session. Minimum monitoring frequencies were suggested, registered, and cross-checked by all.

(3) In the third exercise, a list of the survey methods previously considered (in the extensive list) was presented for each prioritized indicator and participants were asked to edit and complete the list (if necessary) with overlooked survey methods that should be integrated into the monitoring program (**Supplementary Table 3**). Considering that the survey methods could be exclusive of one indicator or shared by other indicators, participants checked which indicators could potentially be monitored together and if the survey methods selected would be compatible with the minimum frequencies previously assigned to each indicator (*i.e.*, participants verified the potential replicability of each method).

Validation of the List According to National and International Commitments

To validate the relevance of the final shortlist of prioritized indicators (**Supplementary Table 2**), the data analysis group overlapped it with the goals defined in:

(1) national law and MPA management plans - three mainland Portuguese coastal MPAs (**Supplementary Table 4**);

(2) international instruments and agreements relating to MPAs (**Table 4**):

- European Marine Strategy Framework Directive (EU MSFD),

- Natura 2000 Network,

- OSPAR Convention,

- Sustainable Development Goals (SDGs, 2030 Agenda),

- Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD).

Note that MPAs management plans of mainland Portugal share similar structure and objectives (Horta e Costa et al., 2019). Prioritized indicators should represent all the relevant goals of these environmental conservation instruments (**Table 2**) when adapted to the context of MPAs.

RESULTS

Guidelines for Lists of Indicators

In Workshop I, participants reached consensus on the following guidelines for constructing a list of MPA performance indicators and defining their evaluation criteria:

(1) Use clear, concise and consensual terms and sentences in the indicators' description, and of the indicator performance criteria, to avoid misinterpretations;

(2) Organize the list of indicators according to specific MPA goals (*e.g.*, restore and maintain fish biomass) and variables (*e.g.*, diversity, biomass), rather than having them dispersed and not associated to an overall and common goal. This would facilitate the detection and elimination of redundant indicators and also the identification of overlooked indicators;

TABLE 2 | General description of the goals of national MPAs and international commitments, adapted from their instruments.

Goals of national MPAs	Goals of international commitments
- Conserve and recover marine biodiversity (monitoring of species and habitats)	- Conserve and recover marine biodiversity (monitoring of species and habitats)
	- Prevent the introduction of non-indigenous species
	- Conserve and recover the marine food chain
- Implementation of an MPA network	- Implementation of MPA networks
- Sustainable fisheries	- Sustainable fisheries
- Sustainable management and use of marine resources	- Sustainable management and use of marine resources
- Sustainable development	- Sustainable development
- Prevent marine pollution	- Prevent eutrophication
	- Prevent marine pollution
	- Prevent and remove marine litter
- Promote, develop, and apply scientific research	- Promote, develop, and apply scientific research
- Community awareness and participation	- Community acceptance and participation
- Cooperation and participation of stakeholders	
- Knowledge dissemination for awareness	- Knowledge dissemination for community awareness
- Provide MPA management plans, enforcement, and foster compliance	- Provide MPA management plans, management capacity, enforcement, and foster compliance
	- Promote alteration of hydrographical conditions (including ocean acidification)
	- Maintain seafloor integrity
	- Control seafood security (human health)
	- Introduction of energy and noise without negatively impacting the marine environment

National goals adapted from national law - Decree-Law N.o 142/2008 (2008) and MPAs management plans: PNA - Regulatory Decree n.o 23/98 (1998); Resolution of the Council of Ministers n.o 141/2005 (2005); PNSACV - Resolution of the Council of Ministers n.o 11-B/2011 (2011); PNLN - Resolution of the Council of Ministers n.o 175/2008 (2008). International goals adapted from: EU MSFD descriptors[1]- Directive 2008/56/EC (2008); Natura 2000 Network, Habitats Directive - Council Directive 92/43/EEC (1992); Natura 2000 Network, Birds Directive - Directive 2009/147/EC (2009); Natura 2000 Network, Guidance document on the establishment of marine Natura 2000 site (European Commission, 2007); OSPAR Thematic strategies[2] and strategic objectives[3]; SDGs, 2030 Agenda[4] (UN General Assembly, 2015); and CBD – Aichi Biodiversity Targets[5].

(3) Simplify and reduce the list of indicators by eliminating undue unfolding of objects, variables, habitats and survey methods, and grouping them as suggested in (2);

(4) Choose quantifiable indicators as often as possible, including governance and socioeconomic ones. For instance, use indicators quantifying material and human resources allocated to MPA management (*e.g.*, number of surveillance events per year), rather than indicators with ambiguous descriptions (*e.g.*, comprehensive surveillance);

(5) Keep indicators measuring unique features in the list, even if low-scored after the criteria-based evaluation. They are measuring specific effects, and thus are needed in the list;

(6) Keep track of extractive methods to replace them with less destructive methods when possible;

(7) Use indicator performance criteria to assess whether the indicators can be tailored to the national context (*i.e.*, can serve the national MPA network rather than only single MPAs), and their relevance to the goals and objectives of European Directives and Conventions;

(8) Develop unambiguous and objective criteria to evaluate indicators' survey methods to allow coherence and comparison among assessments, *e.g.*, some of the raised questions during the workshop: "*The indicator performance criterion speed refers to fieldwork execution speed, data processing speed, or both?*", "*Which range of values defines a high or low cost to monitoring?*", "*The level of expertise required for the indicator's implementation is to be assessed in theoretical (taxonomy) or technical/operational aspects?*".

The Final Shortlist of Prioritized Indicators

After three workshops, with the selection, validation, and scoring of 132 MPA performance indicators, participants defined a shortlist of 37 indicators for coastal MPAs (**Supplementary Table 2**): 24 environmental indicators (E), 11 on governance and two socioeconomic indicators (GS). **Table 3** presents the final shortlist organized by priority groups, with the suggested minimum monitoring frequencies: the top priority group (Priority 1 group) with 13 environmental, three governance and two socioeconomic indicators (18 in total); Priority 2 group with eight environmental and eight governance indicators (16 indicators); and Priority 3 group with three environmental indicators. The socioeconomic indicators were considered top priority indicators, along with the indicators on governance measuring surveillance capacity (surveillance events and resources available) and legal framework adequacy. The remaining governance indicators, regarding articulation between MPA competent entities, scientific knowledge progress, sharing and application, and legitimacy of stakeholders, were included in the Priority 2 group.

Despite the environmental indicators (monitoring theme E) being in greater number compared to the governance and socioeconomic indicators (monitoring theme GS) – which is justified by the inherent complexity of natural systems and the greater number of participants with background in natural

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[1]https://mcc.jrc.ec.europa.eu/main/index.py
[2]https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/introduction/policy-context/
[3]https://www.ospar.org/documents?v=46337/
[4]https://unstats.un.org/sdgs/report/2020/goal-14/
[5]https://www.cbd.int/sp/targets/

TABLE 3 | Shortlist of performance indicators for Portuguese mainland MPAs grouped by priority level and their minimum monitoring frequencies or reporting frequencies for environmental, governance and socioeconomic indicators.

A) Priority 1 group

ID	Priority 1 indicator (P1)	Frequency
1E	Habitat distribution and coverage (Habitats Directive, OSPAR List, EUNIS).	Multi-year (*e.g.*, every 6 years)
2E*	Habitat vulnerability assessment (climate change and anthropogenic pressures).	Multi-year
3E	Diversity of fish, invertebrates, algae, and seagrass (species richness, diversity indices, trophic/functional diversity).	Multi-year** (*e.g.*, every 2 or 3 years)
4E	Abundance of birds, mammals, and marine reptiles in the Birds/Habitats Directive or OSPAR List.	Multi-year** (*e.g.*, every 2 or 3 years)
5E	Abundance of commercial fish, invertebrates, and algae (density/frequency of occurrence/coverage).	Multi-year** (*e.g.*, every 2 or 3 years)
6E	Abundance of fish, invertebrates, algae, and seagrass - communities, key-species, protected, functional/trophic groups (density/frequency of occurrence/coverage).	Multi-year** (*e.g.*, every 2 or 3 years)
7E	Biomass of commercial fish, invertebrates, and algae.	Multi-year** (*e.g.*, every 2 or 3 years)
8E	Biomass of fish, invertebrates, algae, and seagrass (key-species, protected, functional/trophic groups).	Multi-year** (*e.g.*, every 2 or 3 years)
9E	Early detection of non-indigenous species.	Annual**
10E	Average size of commercial fish, invertebrates, and algae.	Multi-year** (*e.g.*, every 2 or 3 years)
11E	Average size of fish, invertebrates (including corals and sponges), algae, and seagrass (key-species, protected, functional/trophic groups).	Multi-year** (*e.g.*, every 2 or 3 years)
12E*	Chemical pollution assessment.	Tune to EU MSFD/WFD cycles
13E*	Biological connectivity patterns of key-species (genetics, modeling and telemetry).	Multi-year
1GS	Existence of an efficient, comprehensive, and adequate surveillance of the MPA.	Annual for quantitative variables. Multi-year (*e.g.*, every 3 years) for qualitative variables.
2GS	Existence of adequate legislation for the MPA's management and its objectives.	Multi-year (*e.g.*, every 3 years)
3GS	Material and human resources capacity allocated to MPA's management.	Multi-year (*e.g.*, every 3 years)
4GS	Socioeconomic benefits and harms of MPAs for the fisheries sector.	Multi-year (*e.g.*, every 5 years)
5GS	Socioeconomic benefits and harms of MPAs for maritime and touristic activities (without resources extraction).	Multi-year (*e.g.*, every 5 years)

B) Priority 2 group

ID	Priority 2 indicator (P2)	Frequency
14E	Diversity of marine birds, mammals, and reptiles (species richness, diversity indices, trophic/functional diversity).	Multi-year** (*e.g.*, every 2 or 3 years)
15E	Distribution of marine birds (on the coast), mammals, and reptiles' populations.	Multi-year (*e.g.*, every 6 years)
16E	Distribution of commercial fish, and invertebrates.	Multi-year (*e.g.*, every 6 years)
17E	Distribution of key and protected species of fish, invertebrates, algae, and seagrass.	Multi-year (*e.g.*, every 6 years)
18E	Distribution of non-indigenous species of fish, invertebrates, and algae.	Multi-year (*e.g.*, every 6 years)
19E	Health and conservation status of engineering species (biotic habitat).	Multi-year (*e.g.*, every 2 or 3 years)
20E	Changes in environmental quality indices (CARLIT, RICQI, CFR, or similar).	Multi-year (*e.g.*, every 2 or 3 years)
21E	Environmental quality status assessment (DEVOTES NEAT: Nested Environmental Status Assessment Tool).	Multi-year
6GS	Performance of MPA management plans' implementation (including monitoring and enforcement plans).	Multi-year (*e.g.*, every 3 years)
7GS	Articulation of responsibilities, actions, and transparency between MPA's competent entities.	Multi-year (*e.g.*, every 5 years)
8GS	Communication efficiency (MPA's rules and regulations).	Multi-year (*e.g.*, every 3 years)
9GS	Communication efficiency (MPA's scientific support, reserve effects, and sustainable use).	Multi-year (*e.g.*, every 3 years)
10GS	Conflict level in the MPA.	Multi-year (*e.g.*, every 3 years)
11GS	Production of scientific knowledge that meets the needs detected by management.	Multi-year (*e.g.*, every 3 years)
12GS	Existence and thematic scope of monitoring campaigns for MPA's biological communities and habitats.	Multi-year (*e.g.*, every 3 years)
13GS	Integration of the local communities' knowledge and practices relevant to the conservation and sustainable use of biodiversity.	Multi-year (*e.g.*, every 3 years)

C) Priority 3 group

ID	Priority 3 indicator (P3)	Frequency
22E	Relative abundance of non-indigenous species of fish, invertebrates, and algae.	Multi-year
23E	Quantification of by-catch or accidental catch of marine birds, mammals, reptiles, fish, and invertebrates.	Multi-year
24E	Density of marine litter (by type).	Multi-year** (*e.g.*, every 2 or 3 years)

Priority levels: A) Priority 1 (i.e., higher/top priority), B) Priority 2, C) Priority 3 (i.e., lower priority). E – Environmental monitoring theme; GS – Governance and Socioeconomic monitoring theme. * - indicators added to the list during the 2nd workshop. ** - Monitored each semester. WFD – Water Framework Directive. See the indicators' complete description in the **Supplementary Table 2**.

sciences –, when scoring them independently (Workshop II), the group of participants considered both in the first priority group (**Table 3**). In Workshop III, participants widely accepted the priority groups (based on the relevance scores), with minor changes for both monitoring themes (in total, three out of 37 indicators changed the priority group).

Minimum monitoring frequencies were agreed for each indicator based on experts' knowledge and practical experience

(**Table 3**). Participants found it essential to coordinate monitoring cycles among indicators, as this allows for a better and more rationalized management of the resources allocated to monitoring activities. Indicators measuring abundance, diversity, biomass, and the average size of fish, invertebrates, algae, and seagrass should be monitored more frequently than others (monitored each semester every two or three years). Participants agreed that these indicators, which report on crucial variables of biological communities' response to protection measures (abundance, diversity, biomass, and average size) could be monitored simultaneously with indicator 24E "Density of marine litter (by type)" (Priority 3 group). Thus, minimum monitoring frequencies were harmonized among them.

On the other hand, indicators reporting the distribution of habitats and species (*i.e.*, mapping) require a much larger sampled area than the previous indicators. Therefore, the suggested minimum monitoring frequency is lower (every six years).

The ecosystem health status indicator 9E "Early detection of non-indigenous species", assessed in port areas and marinas in the vicinity of MPAs, was agreed to be monitored each semester or annually, or in case of imminent threat. The indicator 12E "Chemical pollution assessment" should be monitored according to the monitoring periodicity to be defined in the national monitoring programs for descriptors 5 and 8 (EU MSFD). Thus, potentially derived from the minimum monitoring frequencies defined by the Member State based on the requirements laid down in (1) the water policy framework for Community action (European Directive 2000/60/EC), according to the established environmental quality standards, and (2) the Common Fisheries Policy (European Regulation 1380/2013).

The governance indicator "Existence of an efficient, comprehensive, and adequate enforcement of the MPA" has two variables that should be reported annually: "Location and extension of the enforcement area", and "Number of events, or number of fines per surveillance event" (see the indicators' complete description in **Supplementary Table 2**). The remaining governance indicators should be reported every three years, while socioeconomic indicators can be reported every five years.

Validation of the List According to National and International Commitments

At the end of the process, the final shortlist of prioritized indicators was validated by matching the indicators with the goals of (1) national MPAs (**Supplementary Table 4**), and (2) international commitments (EU MSFD, Natura 2000 network, OSPAR Convention, SDGs, and CBD, **Table 4**).

MPA objectives oriented towards the goal "Conserve and recover marine biodiversity" were found to be the best represented by both the selected indicators and the international and national instruments.

Regarding the national goals (**Figure 2**), the shortlist of prioritized indicators serves all the 11 identified goals among the documents consulted (*i.e.*, management plans of three coastal

MPAs). Some of the indicators (*e.g.*, 3GS: "Material and human resources capacity allocated to MPA's management"), although not detailed in national MPA goals, were assumed as their enabling conditions. National MPA objectives were found to be mostly ambiguous and lack an operational dimension (*i.e.*, measurability). The group assessed which national goals would not be met if it was not possible to monitor all the priority groups of indicators. In case of impossibility to monitor the Priority 3 group, all national goals would still be met. If only the Priority 1 group can be monitored, 4 out of 11 MPA goals would be left unassessed: "Promote, develop, and apply scientific research"; "Community awareness and participation"; "Cooperation and participation of stakeholders"; and "Knowledge dissemination for awareness".

Regarding the international goals (**Figure 3** and **Table 4**), the shortlist of prioritized indicators serves 16 of the 18 goals identified in international instruments and agreements as compatible with the purposes of MPAs. The goals "Control seafood security" (related to human health), and "Introduction of energy and noise without negatively impacting the marine environment", were not represented in the shortlist because they were not considered priority issues for coastal MPAs by the participants. Moreover, 8 of the 16 goals served by the prioritized indicators are transversal to all international commitments considered in this study. All cross-cutting goals were covered by top priority indicators (Priority 1 group), except one: "Promote, develop, and apply scientific research"; which was covered exclusively by Priority 2 indicators.

The group also assessed which international goals (including those not covered by the Natura 2000) would not be met if it was not possible to monitor the three priority groups of indicators. In case it is only possible to monitor top priority indicators, 5 out of 18 MPA goals would be left unassessed: "Alteration of hydrographical conditions (including ocean acidification)"; "Prevent and remove marine litter"; "Promote, develop, and apply scientific research"; "Community acceptance and participation"; and "Knowledge dissemination for community awareness". If Priority 1 and 2 groups are monitored, only the goal "Prevent and remove marine litter" would not be assessed (**Table 4**).

Survey Methods Observations

The results of the scoring process for the survey methods (Intersessional activity I) revealed a set of low-scoring methods (*i.e.*, scored below the 33rd percentile) for several indicators (**Table 5**a). These methods obtained low scores for the following reasons: (1) high costs (multibeam/sonar scanning, ROV, remote sensing, dredges), (2) extractive methods (experimental fishing, dredges), (3) need to hire highly specialized staff, or to supply long-term specialized training (multibeam/sonar scanning, ROV, remote sensing, dredges), (4) slowness of the process (dredges). The method of by-catch analysis was also low-scored because it is associated with extractive methods. Nevertheless, these catches are not a direct consequence of the monitoring activity. This is an observational method of fishing activity. Hence, it was not flagged as a low-scoring survey method.

TABLE 4 | Correspondence between the prioritized MPA performance indicators and the goals of international instruments that are relevant for the MPAs context.

GOALS Description	EU MSFD Descriptors (D)[6]	CBD - Aichi Biodiversity Targets Strategic goal (Sg); Target (T)[7]	Strategic Development Goals (SDGs) Target (T) (UN General Assembly, 2015)	OSPAR Thematic strategies Strategic objectives (So)[8, 9]	Natura 2000 NetworkHabitats and Birds Directives (Council Directives 92/43/EEC, 1992 and 79/409/EEC, 1979)	PRIORITIZED INDICATORS Priority (P) 1, 2 and 3E – Environmental; GS – Governance/ Socioeconomic
Conserve and recover marine biodiversity (species and habitats)	D1	SgA; SgB: T5, T10; SgC: T12, T13; SgD: T14, T15	SDG14: T14.2	Biodiversity and Ecosystems (So5, So6)	Habitats Directive and Birds Directive	P1 (1E-4E, 6E, 8E, 11E), P2 (14E, 15E, 17E, 19E, 21E), P3 (23E)
Prevent the introduction of non-indigenous species	D2	SgB-T9	SDG14: T14.2	Human Activities (So7)	Habitats Directive (Art. 6.2); CEC, Document 52006DC0216, Policy Area 1, Priority Objective 5; European Commission (2007) - Ch. 5.9.1.	P1 (9E), P2 (18E), P3 (22E)
Implementation of MPA networks	DIRECTIVE 2008/56/EC, Article 13, 4.	SgC: T11	SDG14	Biodiversity and Ecosystems (So5)	European Commission (2007) - Ch. 2.5	P1 (1E, 2E, 13E), P2 (15E-17E, 21E)
Sustainable fisheries	D3	SgA: T3, T4; SgB-T6	SDG14: T14.4, T14.6	Human Activities (So7)	–	P1 (5E, 7E, 10E, 4GS), P2 (16E), P3 (23E)
Conserve and recover the marine food chain	D4	SgB-T6, SgD-T14	SDG14: T14.2	Biodiversity and Ecosystems (So5)	–	P1 (4E-8E, 10E, 11E), P2 (15E-17E, 21E)
Prevent eutrophication	D5	SgB-T8	SDG14: T14.1	Eutrophication (So1)	Habitats Directive (Art.6.2); CEC, Document 52006DC0216, Policy Area 1, Priority Obj. 3.	P1 (12E), P2 (20E)
Maintain sea floor integrity	D6	SgB-T6	SDG14: T14.2	Biodiversity and Ecosystems (So6), Human Activities (So9)	Habitats Directive	P1 (1E, 2E), P2 (19E, 20E)
Promote alteration of hydrographical conditions	D7	SgB-T8	SDG14: T14.3	Climate Change and Ocean acidification (So10)	–	P2 (20E)
Prevent marine pollution	D8	SgB-T8	SDG14: T14.1	Hazardous Substances and Radioactive Subst. (So2, So3)	Habitats Directive and Birds Directive	P1 (12E), P2 (20E)
Control seafood security (human health)	D9	–	SDG2	–	–	–
Prevent and remove marine litter	D10	SgB-T8	SDG14: T14.1	Biodiversity and Ecosystems (So4)	–	P3 (24E)
Introduction of energy and noise without negatively impacting the marine environment	D11	SgA-T2	–	Human Activities (So8)	Habitats Directive and Birds Directive	–
Sustainable management and use of marine resources	D3	SgA: T2, T3, T4	SDG14: T14.2. T14.b	Human Activities (So7, So9)	–	P1 (4GS, 5GS)
Sustainable development	D3	SgA: T2, T4, SgB-T7	SDG14: T14.4, T14.6	Human Activities (So7, So9)	–	P1 (4GS, 5GS), P2 (13GS)

(Continued)

TABLE 4 | Continued

GOALS Description	EU MSFD Descriptors (D)[6]	CBD - Aichi Biodiversity Targets Strategic goal (Sg); Target (T)[7]	Strategic Develop-ment Goals (SDGs) Target (T) (UN General Assembly, 2015)	OSPAR Thematic strategies Strategic objectives (So)[8], [9]	Natura 2000 NetworkHabitats and Birds Directives (Council Directives 92/43/EEC, 1992 and 79/409/EEC, 1979)	PRIORITIZED INDICATORS Priority (P) 1, 2 and 3E – Environmental; GS – Governance/ Socioeconomic
Promote, develop, and apply scientific research	DIRECTIVE 2008/56/EC, Article 24, 1.	SgA-T2, SgE-T19	SDG12: 12.a; SDG14: T14.a	Biodiversity and Ecosystems (So5, So6), Human Activities (So9); [10]NEAES 2030 - Ch. 3.1 and 3.4	Habitats Directive; European Commission (2007) (frequently mentioned)	P2 (11GS, 12GS)
Community acceptance and participation	DIRECTIVE 2008/56/EC, Annex VI, (8)	SgE-T18	SDG14: T14.b	Biodiversity and Ecosystems (So5), Human Activities (So7); [10] NEAES 2030 - Ch. 5.	–	P2 (10GS, 13GS)
Provide MPA management plans, management capacity, enforcement, and foster compliance	DIRECTIVE 2008/56/EC, Article 1, 3.	SgA-T2, SgC-T11, SgE-T17	SDG14: T14.4	Biodiversity and Ecosystems (So5); [10] NEAES 2030 - Ch. 5	Habitats Directive (Art.6.1); European Commission (2007) - Ch. 5	P1 (1GS, 2GS, 3GS), P2 (6GS, 7GS)
Knowledge dissemination for community awareness	DIRECTIVE 2008/56/EC -Annex VI,8	SgA-T1	SDG12: T12.8; SDG13: T13.3	[10] NEAES 2030 - Ch. 5	–	P2 (8GS, 9GS)

The low-scored survey methods were contrasted with the most comprehensive survey methods (*i.e.*, those allowing to obtain a greater number of prioritized indicators) listed in the final exercise of Workshop III (**Table 5B**). The most comprehensive survey methods were visual censuses (UVC and intertidal), image analysis collected by ROV and baited cameras (BRUV), surveys (*e.g.*, questionnaires), and experimental fishing (beam trawling or otter trawling). The most contested methods were some types of experimental fishing, namely beam trawling or otter trawling, due to their negative biophysical impact and ethical concerns, and acoustic sampling with multibeam/sonar scanning for pelagic species, as those species are less likely to benefit from conservation measures of small coastal MPAs as the ones in mainland Portugal.

As previously mentioned, the extensive list of performance indicators presented a complex pairing between objects, variables, habitats, and survey methodologies. Every time one indicator had more than one survey method that could be used, it was split and scored independently, *i.e.*, for the same indicator multiple scores were obtained during Intersessional activity I, based on the number of methods they were associated with. In this sense, it was expected that these indicators would obtain similar scores across the indicator output criteria, and only differ

by the last five criteria that evaluate the survey method. However, some indicators obtained different scorings for the indicator output criteria according to the different methods selected.

Participant groups decided unanimously that the monitoring protocol should tend to integrate modern non-invasive survey methods to replace traditional methods that require capture (*e.g.*, experimental fishing), typically more accurate in terms of taxonomic identification and biometric measuring (abundance, weight, length, sex, maturation, age, etc.). This replacement is complex, as it requires the calibration of modern methods to achieve equally accurate and efficient quantitative and qualitative results, and because it may preclude temporal comparisons with data already gathered *via* traditional methods. Thereof, methods that require capture were suggested to be used only sporadically, alternating with other non-invasive methods, which are improving with the new technological developments (*e.g.*, ROV, BRUV, AUV and UAV).

DISCUSSION

This study describes in detail both the process and the outputs of an expert-based methodology designed to achieve a prioritized list of performance indicators for coastal MPAs.

For one year, a total of 67 experts worked together face-to-face in three one-day workshops, and remotely, to achieve a final shortlist of 37 prioritized indicators, their adequate survey methods, and minimum monitoring frequencies. This shows that, in a feasible approach, management plans can incorporate monitoring programs with co-designed and validated lists of indicators.
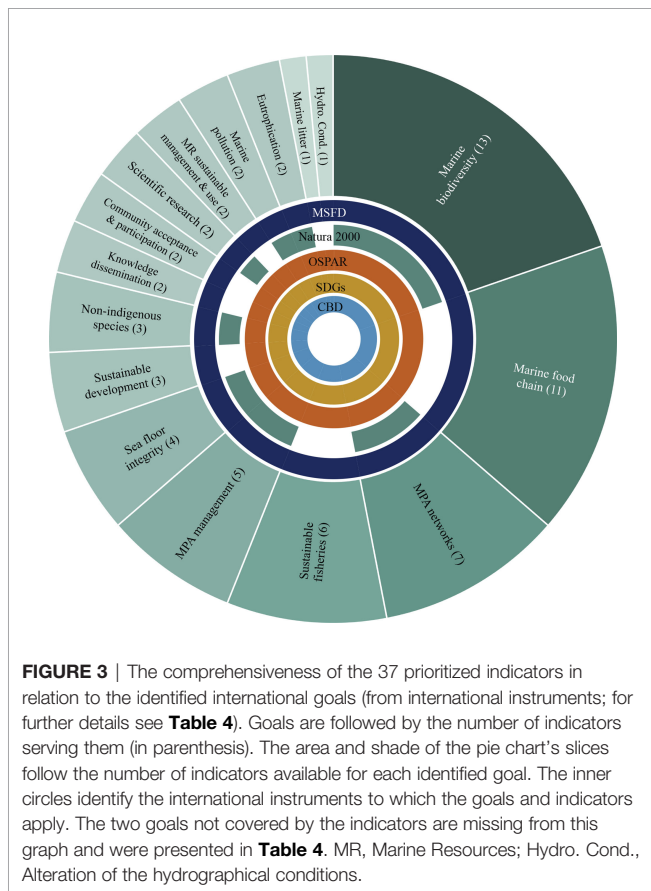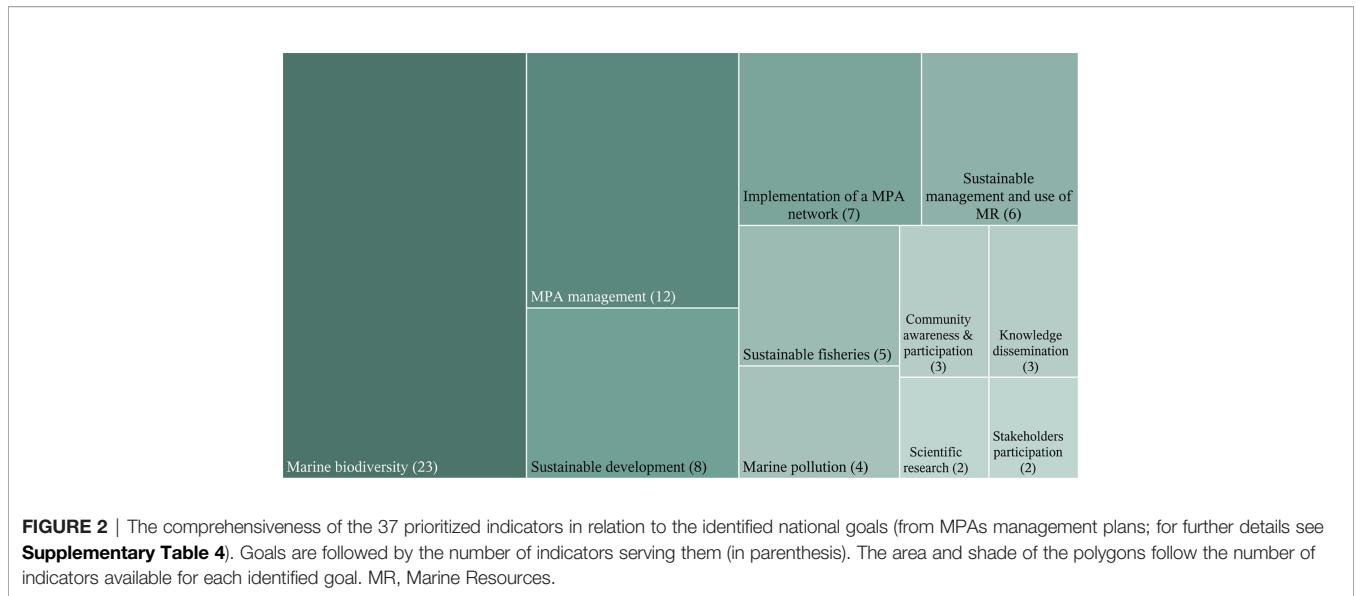
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[6] https://mcc.jrc.ec.europa.eu/main/index.py.

[7] https://www.cbd.int/sp/targets/.

[8] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/introduction/policy-context/.

[9] https://www.ospar.org/documents?v=46337.

[10] https://www.ospar.org/documents?v=46337.

FIGURE 2 | The comprehensiveness of the 37 prioritized indicators in relation to the identified national goals (from MPAs management plans; for further details see **Supplementary Table 4**). Goals are followed by the number of indicators serving them (in parenthesis). The area and shade of the polygons follow the number of indicators available for each identified goal. MR, Marine Resources.

FIGURE 3 | The comprehensiveness of the 37 prioritized indicators in relation to the identified international goals (from international instruments; for further details see **Table 4**). Goals are followed by the number of indicators serving them (in parenthesis). The area and shade of the pie chart's slices follow the number of indicators available for each identified goal. The inner circles identify the international instruments to which the goals and indicators apply. The two goals not covered by the indicators are missing from this graph and were presented in **Table 4**. MR, Marine Resources; Hydro. Cond., Alteration of the hydrographical conditions.

Among the 37 indicators selected, 18 are of top priority, 13 of which are environmental and 5 are governance and socioeconomic indicators. More than a decade of studies and reviews about MPA performance indicators show that the

biological response indicators attributed to this study's top priority group are the most frequently used in the assessment of MPA protection, as these respond directly to MPAs' main conservation goals (*i.e.*, protecting marine biodiversity, recovering of targeted species/groups) (Claudet et al., 2006; Lester et al., 2009; Grorud-Colvert et al., 2021). More recent studies, also highlight the role of resource capacity as one of the main predictors of MPA success (*e.g.*, Gill et al., 2017).

Indicators were prioritized to face the possibility of insufficient resources to monitoring. Top priority indicators were considered the most relevant and the ones that should be guaranteed. Further, by assigning methods and monitoring frequencies to indicators, it was evidenced that most environmental indicators within the top priority group could be monitored together. These are the ones requiring high expertise and resources to conduct work at sea. The remaining social and governance indicators rely on less expensive methods (*e.g.*, surveys, questionnaires), and some could be assessed in tandem as well. Monitoring programs are designed to guide efficient monitoring; these 18 concerted indicators are more likely to be achieved with monitoring programs than without these instruments. Here we recommend that future monitoring programs integrate the co-prioritization of selected indicators, thereby clarifying which monitoring components are considered the most relevant by experts and practitioners (and possibly by other stakeholders) for assessing MPAs' performance efficiently. Note that, if MPA success depends on diverse goals, the same diversity must be regarded by the indicators chosen to assess it. The composition of priority groups shows that participants assigned environmental, governance and socioeconomic indicators to the top priority group. Our results differ from Pendred et al. (2016)'s, who reported higher priority attributed to ecological indicators over socioeconomic and governance indicators in their case study. MPAs have been increasingly recognized as social-ecological systems whose success depends

TABLE 5 | Indicator's survey methods A) with low scoring – sorted according to their scores in ascending order (data from Workshop II) and B) the most comprehensive – sorted according to the number of indicators they serve in descending order (data from Workshop III).

A)	B)
Low-scored survey methods (Scores below the 33rd percentile)	Most comprehensive survey methods (Serve 10 indicators or more)
Dredges	UVC (e.g., transects and quadrats)
Remote sensing (orthophotos)	ROV image analysis
Multibeam/sonar scanning	Surveys (e.g., questionnaires)
Beam trawling (EF)	Intertidal visual censuses (e.g., transects and quadrats)
Pelagic trawling (EF)	Baited cameras (BRUVs)
Trammel net, longline, traps (EF)	Beam or otter trawling (EF)
ROV image analysis	

EF, Experimental Fishing; ROV, Remotely Operated Vehicle; UVC, Underwater Visual Censuses.

on effective management, engagement, compliance, and enforcement (e.g., Di Franco et al., 2016; Grorud-Colvert et al., 2021). Different studies reinforce this idea of a recent paradigm shift in MPA monitoring (e.g., Trimble & Plummer, 2018; Pelletier, 2020).

In this study, the number of governance and socioeconomic indicators may be found asymmetric when compared to the number of environmental indicators. Depending on the management context of MPAs (traditional or co-management) and evaluation approach used to assess management effectiveness (Trimble & Plummer, 2018), the type of indicators selected and prioritized will likely vary. In addition to the stakeholder group composition and process design, this asymmetry can be justified by the greater importance attributed to environmental conservation goals in some MPA management plans relatively to socioeconomic and governance goals (Heck et al., 2012; Pendred et al., 2016), and the great complexity of marine ecosystems (Dale & Beyeler, 2001; Dunham et al., 2020). MPAs are planned to achieve a diversity of ecological outcomes supporting human uses and ecosystem services (Gallacher et al., 2016; Grorud-Colvert et al., 2021). This study selected indicators according to an extensive literature review in MPA monitoring

and expert judgment, and attempted to accommodate a diverse and widely accepted set of MPA performance indicators.

In the present work, each workshop session was timely planned and consistently sought to solve pending issues and validate results from previous work. While developing and testing this methodological approach, some lessons were accrued and can be applied in the future (**Box 1**). This will allow starting the process at a more advanced and undemanding stage (e.g., merging indicators commonly monitored together before scoring them). A more straightforward and synthetic worktool (the shortlist) would avoid fatigue in criteria-based scoring exercises (e.g., Okey, 2018). The organizing team addressed this issue by splitting the list of indicators by heterogeneous groups and then revising and discussing each group sub-list of indicators at a plenary session (**Box 1**). Lessons learned also highlight the must-do steps contributing to the success of the process (e.g., a progressive approach, in which the outcomes of each exercise are validated in plenary sessions before moving forward to the following steps).

After determining adequate survey methods for each indicator, the group stressed that selecting and prioritizing the most cost-efficient monitoring methods for MPAs is still needed, and that non-intrusive forms should be privileged. Some indicators that could be measured with different survey methods obtained distinct scorings for the indicator output criteria (Intersessional activity I). This suggests that it was difficult to dissociate the indicators from the associated survey methodologies. One of the main factors that affects the quality of the indicator is the survey method used (Pomeroy et al., 2004), which, in turn, is dependent on the available resources (monetary, human and time resources; Pelletier, 2011), technical difficulty, the existence of comparable reference data, and even the knowledge or the experience that one has about its implementation in the context of MPA's monitoring. This study posits that indicators' relevance, in addition to varying according to different conservation goals, target species/groups or habitats, also varies with the assessors' perception about the effectiveness, complexity and affordability of different survey methods and designs for each indicator. An important future step is to select

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Box 1 Lessons learned through the process.

Efficiency lessons

✓ **Extensive lists of indicators.** To avoid overly extensive lists of indicators and possible redundancies from the start: a) The list should be organized by specific MPA goals to obtain the desired monitoring outcomes and avoid mutually redundant information; b) If reasonable, species or group of species that are usually monitored together, using similar variables and survey methods, should be merged into the same indicators.

✓ **Group dynamics.** The evaluation of lists of indicators is more efficient if the work is divided by small groups of experts and then discussed and consolidated in plenary sessions by all participants. Though, some redundancies between groups' indicators may be desirable to address experts' heterogeneous perceptions.

Effectiveness lessons

✓ **A progressive participatory methodology.** To review and validate each session's results consistently, with sequential exercises validated in plenary sessions. This progressive approach facilitates the reach of consensus among peers and consolidates decision-making.

✓ **A thoughtful partnership.** Similar participatory approaches are likely to succeed when institutions that share responsibility for MPAs' success (especially their management authority) are committed to the entire process.

✓ **A diverse working group.** Engaging a multidisciplinary group of experts (from academic institutions, public and administrative authorities, and environmental NGOs) to develop a list of prioritized MPA performance indicators, may not completely address the interests and values of non-experts in MPA management. Beyond the expert-based approach, a consultation with interest groups, such as local community representatives and other MPA users, or the development of a participatory process, could contribute to the diversity of indicators in the final list.

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and standardize the best methods for future national monitoring plans. This will avoid discrepancies in the survey methods used between monitoring teams within and between MPA networks (Pomeroy et al., 2004).

Participants also underlined the need to construct stable connectivity and climate change indicators to interpret cause-effect changes observed within MPAs (Zandvoort et al., 2017; Tittensor et al., 2019). Despite their recognized importance in this process (both were considered in the top priority group), participants struggled in defining complete indicators for them (**Supplementary Table 2**). The definition of connectivity indicators relies on overcoming important information gaps, some not easy to obtain at the MPA scale. These include marine species life history, large-scale spillover and larval dispersal, requiring clear indicators used at proper spatial scales, and the adequate transfer of this knowledge to managers (Olsen et al., 2013; Balbar & Metaxas, 2019). Moreover, MPA mitigation and adaptation strategies to climate change need to be informed by *in situ* empirical knowledge, *i.e.*, they must be supported by monitoring data trends of a given region, and thus they need proper indicators with suitable time scales (Kay & Butenschön, 2018; Wilson et al., 2020; O'Regan et al., 2021). Following a recent review by Wilson et al. (2020), "lack of scientific information" (*e.g.*, monitoring data at scales relevant to management) and "governance structure" (*e.g.*, lack of clear MPA objectives) are main limitations for adapting MPA planning to climate change. These shortcomings are commonly referenced for connectivity and habitat vulnerability assessment indicators (Balbar & Metaxas, 2019; Stratoudakis et al., 2019; Willaert et al., 2019; Lausche et al., 2021).

Halfway through this process, an independent process took place, in which the Portuguese government approved strategic guidelines and recommendations for the implementation of a National Network of MPAs (Resolution of the Council of Ministers n.o 143/2019, 2019). This study's shortlist of prioritized indicators is to report on single MPAs' performance and should be regarded as a complementary tool to this instrument when evaluating network success. Indeed, network success is dependent on single MPAs' success and their ecological coherence (Green et al., 2011).

The proposed shortlist of prioritized indicators is thematically comprehensive, addressing most of the EU MSFD GES Descriptors (except for the monitoring of food safety and underwater noise) and other important goals set out in relevant international commitments (*i.e.*, Natura 2000 network, OSPAR Convention, CBD Aichi Biodiversity Targets and the SDGs 2030 Agenda). Thus, it can serve as a tool to carry out useful comparisons with other lists developed for MPA monitoring programs of different countries and regions. As the instruments supporting effective implementation and management of MPAs and their networks are being developed and refined, lists of indicators should guide national agencies on their pursue to fulfilling these international MPA-related commitments. Furthermore, by overlapping the shortlist of prioritized indicators with the goals set out in the management plans of the national coastal MPAs, we found that the proposed indicators are more detailed than the objectives, which are mostly ambiguous and non-operational. The report by WWF & Sky Ocean Rescue (2019) stated that numerous MPA management plans failed to define clear and measurable objectives. In this regard, several authors stressed the importance of clearly defining MPA objectives and quantifiable indicators and thresholds (O'Regan et al., 2021). In this sense, future management plans for national MPAs or the review of existing ones should address comprehensively the goals of national and international commitments. This requires defining clear objectives accompanied by measurable indicators, and thresholds, that allow assessing whether MPA and MPA network objectives are being achieved.

Further work is necessary to develop a complete MPA evaluation process. MPA monitoring programs benefit from more inclusive approaches, such as participatory processes, as recommended by several authors (*e.g.*, Pomeroy et al., 2004; Trimble & Plummer, 2018), aiming at better representing the values and interests of non-experts. For instance, a consultation with local community representatives and other MPA users could add to the selection of socioeconomic indicators. This study also suggests the recognition of expert-based and participatory processes as complementary approaches, in order to build increasingly effective and feasible management tools.

The expert-based approach adopted in this work provides an example of how to define and prioritize a mutually agreed list of MPA performance indicators through structured collaborative work. The level of interaction promoted through group exercises followed by face-to-face discussions of their results, allowed effective communication, as it provided several opportunities for optimized debates. Groups of experts from different disciplines (from the natural and social sciences), and in MPA monitoring, management, and governance worked together to meet the goals of this process, *i.e.*, to create a valuable MPA monitoring tool. Most importantly, this expert-based methodology can guide MPA managers, monitoring teams and policymakers on how to design multidisciplinary lists of MPA performance indicators for effective monitoring programs. It also synthesizes the lessons learned, allowing fruitful future adaptations of the proposed approach.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

MC-A, BH, and JG conceived and designed the study. MC-A wrote the manuscript with BH, JG, and HQ. All authors participated in all stages of the participatory process and contributed to the discussion of results and manuscript review. All authors approved the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.848039/full#supplementary-material

Supplementary Data Sheet 1 | Process workflow.

Supplementary Table 1 | Extensive list of indicators.

Supplementary Table 2 | Shortlist of prioritized indicators.

Supplementary Table 3 | Indicators' survey methods.

Supplementary Table 4 | Correspondence between the prioritized indicators and national goals.

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