ENHANCING BIODIVERSITY MONITORING IN MEDITERRANEAN MPAs: eDNA AND STRATEGIC SOLUTIONS

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Abstract: Marine Protected Areas (MPAs) are essential for conserving marine biodiversity and ensuring the sustainability of marine ecosystems. This study examines the current management and monitoring practices within the Mediterranean Sea. Utilizing a questionnaire distributed to 93 MPA managers, we received 29 complete responses, providing insights into the governance, management plans, and monitoring strategies employed across the region. Our findings reveal significant variability in the implementation of management plans, with 48 % of respondents reporting full implementation and 41 % employing ad hoc monitoring strategies. Traditional monitoring methods, such as visual censuses, remain prevalent, while 28 % of respondents reported using eDNA metabarcoding as an additional tool. The integration of eDNA metabarcoding has shown substantial potential in enhancing the accuracy and efficiency of biodiversity monitoring, particularly in detecting species diversity and invasive species. Despite these advancements, challenges persist, including funding constraints, lack of human resources, and inadequate data-sharing practices. To address these issues, we recommend increasing funding, standardizing monitoring protocols, enhancing regional cooperation, and promoting adaptive management informed by robust monitoring data. This study underscores the transformative potential of eDNA metabarcoding in MPA management and highlights the need for strategic improvements to ensure the sustainability and ecological health of Mediterranean MPAs.

Keywords: Marine Protected Areas (MPAs), eDNA metabarcoding, Mediterranean, Biodiversity monitoring, Management strategies

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Introduction

Marine Protected Areas (MPAs) play a critical role in conserving marine biodiversity, safeguarding habitats, and ensuring the sustainability of marine resources [1]. The MedPAN network, encompassing over 100 organizations across 21 Mediterranean countries, is dedicated to enhancing the effectiveness and connectivity of MPAs in the region. Despite significant efforts, MPAs face numerous challenges, including inconsistent management practices, limited resources, and fragmented monitoring strategies [1]

Effective monitoring is fundamental to the success of MPAs, providing the data needed to inform management decisions, assess the health of marine ecosystems, and adaptively manage conservation efforts. Traditional monitoring methods, such as visual censuses, have been widely used but often fall short in capturing the full spectrum of marine biodiversity, especially for elusive or rare species [2].

Emerging technologies, such as environmental DNA (eDNA) metabarcoding, offer promising advancements in biodiversity monitoring. eDNA involves collecting and analyzing genetic material from environmental samples, providing a non-invasive, efficient, and comprehensive approach to detecting species presence and abundance [3]. This study builds on the findings of Capurso et al. [4], which assessed the utility of eDNA metabarcoding for MPAs. The research aims to evaluate the current management and monitoring status of Mediterranean MPAs, assess the application and potential of eDNA, and identify gaps and opportunities for enhancing MPA monitoring frameworks within the MedPAN network.

Materials and methods

This research builds upon that of Capurso et al. [4], which systematically reviewed the literature and conducted a SWOT analysis to evaluate the effectiveness of eDNA metabarcoding as a monitoring tool for MPAs, highlighting its benefits and limitations in marine ecosystems.

To assess the current management and monitoring status of MPAs in the Mediterranean, the extent of eDNA usage, and the requirements for developing an improved monitoring framework and regional network, we designed and disseminated a comprehensive questionnaire.

The target respondents comprised MPA managers within the MedPAN network, which supports a sustainable, ecologically representative, and well-defined network of MPAs in the Mediterranean. MedPAN includes 127 organizations from 21 Mediterranean countries, but for this study, only members from EU nations were contacted: Croatia, Cyprus, France, Greece, Italy, Slovenia, Spain, and Malta. These individuals are referred to as MPA managers throughout this research.

The anonymous questionnaire was crafted using Qualtrics (www.qualtrics.com) and administered between May and June 2022. It drew inspiration from existing methodologies for evaluating MPA management effectiveness [5, 6]. The questionnaire was structured into four sections, incorporating both multiple-choice and open-ended questions:

i. Details about the organization, including the country of origin, organizational category, geographical scale of operation, and the type of designation of the MPAs managed;
ii. Information regarding the existence, implementation status, and scope of management plans within the MPAs;
iii. Insights into the adopted monitoring strategies, primary tools used, inclusion of eDNA metabarcoding, perceived efficiency of these strategies, and identified limitations;
iv. Assessment of the Mediterranean MPA network's functionality, including the comparability of monitoring strategies, data sharing practices, collaboration among MPA managers, and network gaps and limitations.

The questionnaire was distributed to 93 MPA managers affiliated with the MedPAN network between May and June 2022. Responses were collected and analyzed to determine the current state of MPA management and monitoring, the utilization of eDNA metabarcoding, and to identify areas for improvement in the regional monitoring framework and network collaboration.

By systematically gathering and analyzing this data, the study aimed to provide actionable insights for enhancing the management and monitoring of MPAs in the Mediterranean, leveraging innovative tools like eDNA metabarcoding to address existing challenges and improve overall efficacy.

Results

Overview of Marine Protected Areas part of the MedPAN network

From the 93 organizations contacted, we received 56 responses to our questionnaire resulting in a response rate of 60 %. After excluding incomplete and duplicate responses, the final dataset comprised 29 analysed responses.

The majority of the organizations (52 %) were from the national government administration, including public institutions, agencies and specific MPA managers. This group was mainly represented by Italy, Croatia, and Greece, followed by Cyprus and Spain. The second largest group, representing 24 % of respondents, included organizations from Italy, Croatia, France, and Spain that operated at regional or municipal levels. Non-governmental organizations (NGOs) made up 17 % of the respondents, with representation from France, Italy, and Slovenia. The least represented group, comprising 7 % of respondents, consisted of research and scientific organizations from Greece and Cyprus. Concerning the geographical scale of operations, most organizations (59 %) operated primarily at the local level. A smaller proportion (20 %) operated at the national level, with fewer organizations operating at supra-national levels, such as sub-regional seas networks, Mediterranean, and European scales.

Regarding the type of designation of MPAs, 43 % of organizations operated in MPAs with multiple designations, combining Natura 2000 sites and nationally designated areas. Another 21 % worked in MPAs with only national designations, mostly in Italy, France, and Spain. Additionally, 25 % are involved with MPAs that

are part of the Natura 2000 network, primarily in Croatia, France, Greece, and Spain. A minority of 11 % of organizations did not operate with specific designations.

Management of Marine Protected Areas part of the MedPAN network

A minority of respondents (11 %) reported the absence of management plans in their areas of competence, while 17 % had plans that were not implemented. Among the remaining respondents, 24 % indicated partial implementation of management plans, and 48 % reported full implementation. Full or partial implementation was mainly seen in organizations managing MPAs with either national or combined designations. Notably, all organizations in France reported full implementation, followed by Slovenia and Spain, where implementation was partial. In contrast, Croatia and Greece are more frequently characterized by a lack of management plans or their implementation. See Figure 1.
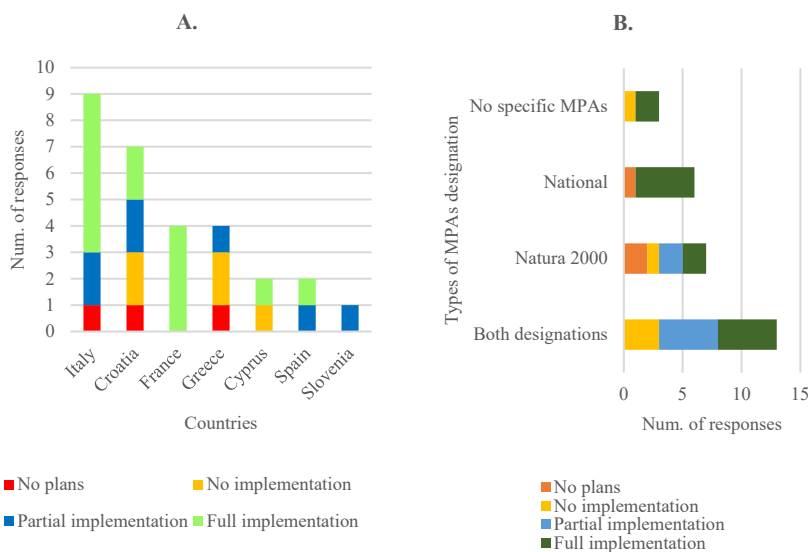

Figure 1 – Management plans of MPAs per country (A.) and Management plans of MPAs classified per type of designation (B.) (n=29).

Monitoring of Marine Protected Areas part of the MedPAN network

Most of respondents reported that there was monitoring in the MPAs of their competence, with only two respondents, from Croatia and Greece, declaring that no monitoring activity was taking place. While 41 % did not have an overarching strategy or systematic collection of results and instead conducted ad hoc monitoring and evaluation, 38 % reported having a well-implemented monitoring and evaluation system used in adaptive management. These structured monitoring strategies were predominantly reported by organizations operating MPAs with

national or combined designations. Adaptive management based on monitoring was notably absent in Greece and Slovenia.

In terms of monitoring tools, 69 % of respondents reported using visual census as the primary monitoring tool. Additionally, 28 % used eDNA metabarcoding, primarily for monitoring species diversity and detecting protected or invasive species. All managers using eDNA approaches (28 %) considered their monitoring strategy efficient, though they acknowledge room for improvement. Conversely, more significant limitations in the monitoring efforts were reported by those not using eDNA methods (14 %). Respondents using eDNA generally report better performance, with the majority (5 out of 8 respondents) indicating full implementation of management plans and robust monitoring and evaluation systems.

Gaps and limitations identified by MPAs managers part of the MedPAN network

The monitoring strategy and the Mediterranean MPAs network were evaluated based on respondents' perceptions concerning the comparability of monitoring methods, cooperation, and data-sharing among MPA managers. Most respondents reported that monitoring methods were either partially (59 %) or fully comparable (30 %), with some (38 %) or substantial (45 %) cooperation among managers. However, only 27 % had implemented data-sharing procedures, while 24 % do not implement them, and 21 % lacked available procedures.

Comparing the answers of respondents that used eDNA as monitoring tool to those that did not, some significant differences were observed. Firstly, 1 of MedPAN survey responders that do not use eDNA methods, there was a significantly higher proportion ($z=-2.27$, $df=13$, $p=0.023$) that also report no data sharing within the network ($n=10$) to those that do ($n=4$), regardless of whether available procedures are in place (see Table 1). Moreover, of respondents that did not use eDNA methods and also shared no data (or don't know if they share data) ($n=13$ of 17), the proportion is even more significant ($z=-3.087$, $df=16$, $p=0.002$). Conversely, there was no significant difference for responders that did use eDNA methods for biomonitoring in their data sharing approach ($n=3$ data share, $n=3$ no data share).

Table 1 – Comparison of answers received from MPAs managers that use eDNA and those that do not on data-sharing practices ($n=24$).

	eDNA users	Non-eDNA users
Procedures & sharing	3	4
Procedure & no sharing	2	5
No procedure & no sharing	1	5
Don't know	1	3

Secondly, diving deeper into the level of cooperation among MPAs managers, the proportion of those respondents that did not use eDNA methods self-reported significantly less cooperation among the MedPAN MPA network (z=1.7889, df=23, p=0.073; one-tailed test). Combining the respondents that reported "some cooperation" and "little to no cooperation" together, the comparison between eDNA users to non-eDNA users demonstrated a significantly higher proportion of non-eDNA users that reported some to little cooperation among MPAs (z= 1.62, df=23, p=0.053; one-tailed test). See Table 2.

Table 2 – Comparison of answers received from MPAs managers that use eDNA and those that do not on cooperation practices (n=24).

	eDNA users	Non-eDNA users
Substantial cooperation	4	7
Some cooperation	4	6
No/little cooperation	0	3

The most common limitation identified by MPA managers regarding monitoring strategies concerned funding constraints (11 out of 29 respondents). These were followed by a lack of human resources (6 out of 29) challenges in data gathering (6 out of 29), including the need to gather data that are still unknown, such as the life cycle of exploited species and the socio-economic impacts of MPAs. Additional concerns included a lack of time and continuity in monitoring (4 out of 29), insufficient expertise (4 out of 29) and technology/equipment (4 out of 29), and gaps in the management and administrative framework (4 out of 29), such as the absence of comprehensive management plans. Some respondents also noted that the size of the monitoring area posed significant challenges (3 out of 29), and better collaboration and knowledge sharing among managers could improve the monitoring strategy (4 out of 29), mirroring patterns found with eDNA methods specifically.

Regarding the gaps and limitations of the MPA network itself, many respondents highlighted the need for improved collaboration (14 out of 29). They suggested that conducting twinning programs and organizing more regular meetings and cooperation forums to exchange expertise and best practices, as well as to share data, would significantly enhance the network. Other frequently mentioned limitations include management and administrative issues (7 out of 29), such as the lack of binding guidelines and targets and inadequate coordination by national and supranational institutions. Funding constraints and the diversity and lack of inclusiveness within the network were also noted (respectively by 6 and 4 out of 29). Respondents emphasized that it is not always possible to apply the same models across different regions or countries, and not all member states have the same level of environmental awareness and management capacity, which affects the quality of MPA management and monitoring.

Discussion

The analysis of the MedPAN network reveals a diverse and multi-level governance landscape of MPA governance, with significant representation from national government administrations. The dominance of local-level operations suggests a strong focus on addressing specific, localized environmental and conservation issues.

The mixed results regarding the implementation of management plans reflect varying levels of management effectiveness across the network. The fact that some of the respondents reported no management plans or unimplemented plans highlights areas where MPAs are potentially vulnerable due to inadequate governance frameworks, as already underlined by the European Commission [7]. This issue is particularly pronounced in Croatia and Greece, where the lack of management plans is more prevalent.

Conversely, the high rate of full implementation in France and partial implementation in Slovenia and Spain suggests successful governance models that could serve as best practices for other regions. The correlation between management plan implementation and the type of MPA designation (national or combined with Natura 2000 sites) suggests that legal frameworks and funding mechanisms associated with national designations may provide better support for effective management.

The widespread practice of monitoring within MPAs is encouraging, yet the significant proportion of ad hoc monitoring points to a need for more structured and systematic approaches [8]. The presence of well-implemented monitoring and evaluation systems in some MPAs indicates that effective frameworks do exist and can be adopted more widely. The absence of adaptive management based on monitoring in Greece and Slovenia is a critical gap that needs to be addressed to enhance the effectiveness of conservation efforts in these countries.

The prevalent use of visual census as a monitoring tool aligns with traditional methods, but the emerging use of eDNA metabarcoding is noteworthy. The positive perception of eDNA metabarcoding by its users highlights its potential as a valuable tool for biodiversity monitoring [9]. The reported efficiency of eDNA methods, despite acknowledged areas for improvement, suggests that expanding its use could enhance monitoring capabilities across the network. Furthermore, the better performance reported by respondents using eDNA approaches indicates that integrating innovative technologies can potentially lead to more effective MPA management.

Notably eDNA metabarcoding offers several advantages over traditional monitoring methods such as its ability to detect a broader range of species, including those that are elusive or present at low densities [4]. This capability is particularly valuable for monitoring biodiversity in MPAs where e.g. understanding protected and invasive species presence is critical for effective management. Additionally, eDNA methods are less invasive and can provide quicker results, making them suitable for large-scale and frequent monitoring efforts [10].

The positive feedback from managers using eDNA methods further underscores its utility in providing reliable data for adaptive management. These managers reported better implementation of management plans and more effective monitoring

systems, highlighting eDNA's potential role in enhancing the overall management framework of MPAs. As such, promoting the use of eDNA metabarcoding across the MedPAN network could address several current limitations and improve the robustness of MPA monitoring and management. Moreover, those MPAs managers who did not use eDNA also reported a significantly lower level of data-sharing and cooperation among MPAs managers within the MedPAN network, suggesting a possible gap between the two groups. The MedPAN network, through enhanced and fostered cooperation and data sharing, could provide the opportunity to fill this gap and eventually help to facilitate a better uptake of eDNA approaches and data sharing for biodiversity monitoring. Enhancing data-sharing protocols and fostering regular communication and cooperation forums could significantly improve the effectiveness of MPA management by facilitating the exchange of knowledge and best practices.

Recommendations

To address the identified gaps and limitations, several key recommendations can be made:

i.   Enhance Funding and Resources: Increasing financial support and investing in capacity-building initiatives are crucial to overcoming the primary constraints of funding and human resources. This could involve seeking additional funding from international organizations, government budgets, and private sector partnerships.

ii. Standardize Monitoring and Data-Sharing Practices: Developing standardized protocols for monitoring and data-sharing can enhance comparability and collaboration across the network. This could include the adoption of eDNA metabarcoding as a complementary monitoring tool and the establishment of centralized data repositories accessible to all MPA managers.

iii. Strengthen Regional Cooperation: Promoting regular meetings, workshops, and twinning programs can facilitate the exchange of expertise and best practices. Establishing regional cooperation frameworks can also help address transboundary ecological challenges and improve overall network coherence. The results suggested some difference in performance between countries, that could benefit from a systematised network to share expertise and know-how.

iv. Promote Adaptive Management: Encouraging the adoption of adaptive management practices based on robust monitoring and evaluation systems can enhance the responsiveness and effectiveness of MPA management. This involves regularly reviewing and adjusting management strategies based on monitoring results and emerging scientific knowledge.

Conclusion

The management and monitoring of Marine Protected Areas (MPAs) within the MedPAN network exhibit both strengths and areas needing improvement. The diverse governance structures and varying levels of management plan

implementation highlight the complexity and challenges faced by MPA managers across the Mediterranean. While traditional monitoring methods remain prevalent, the integration of eDNA metabarcoding presents a significant opportunity to enhance biodiversity monitoring and adaptive management practices.

eDNA metabarcoding has demonstrated considerable potential in providing comprehensive, efficient, and non-invasive monitoring solutions. Its ability to detect a wide range of species, including those difficult to observe through traditional methods, makes it a valuable tool for improving the accuracy and scope of biodiversity assessments. The positive outcomes reported by managers utilizing eDNA methods underscore its effectiveness and the necessity for broader adoption across the network.

To address the identified gaps and limitations, the following key actions are recommended: enhancing funding and resources, standardizing monitoring and data-sharing practices, strengthening regional cooperation, developing comprehensive management guidelines, and promoting adaptive management based on robust monitoring data. By implementing these strategies, the MedPAN network can significantly improve its management and monitoring frameworks, ensuring the sustainability and ecological health of Mediterranean MPAs.

In conclusion, the adoption of innovative technologies like eDNA metabarcoding, coupled with strategic improvements in governance and resource allocation, holds the promise of transforming MPA management in the Mediterranean. This holistic approach will enable more effective conservation efforts, better protection of marine biodiversity, and greater resilience of marine ecosystems in the face of ongoing environmental challenges.

Supplementary material

The questionnaire can be found on Figshare doi: 10.6084/m9.figshare.27060172

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