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Research article

Priorities for Mediterranean marine turtle conservation and management in the face of climate change

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ABSTRACT

As climate-related impacts threaten marine biodiversity globally, it is important to adjust conservation efforts to mitigate the effects of climate change. Translating scientific knowledge into practical management, however, is often complicated due to resource, economic and policy constraints, generating a knowledge-action gap. To develop potential solutions for marine turtle conservation, we explored the perceptions of key actors across 18 countries in the Mediterranean. These actors evaluated their perceived relative importance of 19 adaptation and mitigation measures that could safeguard marine turtles from climate change. Of importance, despite differences in expertise, experience and focal country, the perceptions of researchers and management practitioners largely converged with respect to prioritizing adaptation and mitigation measures. Climate change was considered to have the greatest impacts on offspring sex ratios and suitable nesting sites. The most viable adaptation/mitigation measures were considered to be reducing other pressures that act in parallel to climate change. Ecological effectiveness represented a key determinant for implementing proposed measures, followed by practical applicability, financial cost, and societal cost. This convergence in opinions across actors likely reflects long-standing initiatives in the Mediterranean region towards supporting knowledge exchange in marine turtle conservation. Our results provide important guidance on how to prioritize measures that incorporate climate change in decision-making processes related to the current and future management and protection of marine turtles at the ocean-basin scale, and could be used to guide decisions in other regions globally. Importantly, this study demonstrates a successful example of how interactive processes can be used to fill the knowledge-action gap between research and management.

1. Introduction

Scientific research provides an evidence-base for managing the world's ecosystems; however, a fundamental gap persists in translating this knowledge to practical management outcomes (Gibbons et al., 2011; Knight et al., 2008). Undoubtedly, climate change should be incorporated into decision-making processes related to current and future management and protection of marine areas (Bates et al., 2019; Katsanevakis et al., 2020); however, climate change adaptation and mitigation strategies are often left to conservation practitioners rather than included in the decision-making process (e.g. O'Regan et al., 2021; Raaphorst et al., 2020). For instance, over the last decade, fewer than half of the management plans for Marine Protected Areas (MPAs) globally included at least one climate change-related term (O'Regan et al., 2021).

Despite the need for environmental protection being highlighted in all climate change relevant policies, specific, quantified and operational targets are rarely adopted and monitoring targets are seldom met (Tittensor et al., 2019). As the pace of research on climate change and associated outputs is accelerating (Doxa et al., 2022; García Molinos et al., 2016), many findings are contradictory due to regional differences in environmental characteristics and anthropogenic pressures (Fuentes et al., 2013). This issue often challenges conservation practitioners to set targets that are guaranteed to remain relevant over the long term, with regular reassessments and adjustments being key. Thus, it is essential to gauge the perceptions of both researchers and conservation practitioners on how climate change is impacting threatened wildlife, how to mitigate such impacts, and to identify gaps between conservation science and practitioners to formulate ways to bridge those gaps.

The Mediterranean region is an ideal setting for exploring the science-policy interface, as it is a biodiversity hotspot (Coll et al., 2010) that has been historically impacted by human activities and, more recently, climate change (Aurelle et al., 2022; Lionello and Scarascia, 2018). Within the Mediterranean Sea, marine megafauna has received considerable focus by scientists and policy makers as indicators of ocean health under a changing climate (Maffucci et al., 2016; Schofield et al., 2010). Indeed, marine turtles make an excellent indicator because they require both terrestrial (beaches) and marine habitats to survive, and are widely dispersed throughout the oceanic and coastal habitats of the Mediterranean, for development, breeding, feeding and migration (Schofield et al., 2013). Three species of marine turtles frequent the Mediterranean; however, only green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles breed, whereas the leatherback turtle (*Dermochelys coriacea*) only feeds in this region (Casale et al., 2018). Thus, marine turtles represent a key model species for exploring potential gaps and challenges in translating scientific knowledge into practical management.

The seven extant marine turtle species have been extensively studied with respect to their life history, population status, human pressures, and various environmental impacts. They have been used as flagship species by various MPAs informing ocean monitoring and conservation actions (Donnelly et al., 2020; Eckert and Hemphill, 2005; Miyazawa et al., 2019). However, the survival of marine turtles under climate change is threatened, with all life stages being at risk (Fuentes et al., 2013; Maurer et al., 2021; Patrício et al., 2021). For instance, increased temperatures are already affecting the offspring sex ratios of populations, with a high risk of feminization (Hays et al., 2014; Jensen et al., 2018; Tanner et al., 2019), triggering changes to nesting activity (Camiñas et al., 2020; Cardona et al., 2022; Hochscheid et al., 2022) and potentially altering the distributions and food availability in foraging and wintering habitats (Chatzimentor et al., 2021; Jančič et al., 2022; Monsinjon et al., 2019; Poloczanska et al., 2009). Other direct and indirect impacts of climate change include reducing nesting and hatching success, changing the microbial community/abundance (Candan and Candan, 2020), altering the morphology and performance of hatchlings, altering movement and distribution at sea of all life stages, and altering breeding patterns, phenology, and the availability of nesting areas (Patrício et al., 2021 and references therein, Poloczanska et al., 2009; Patino-Martinez et al., 2014; Dimitriadis et al., 2022; Hochscheid et al., 2022; Martins et al., 2022). Nevertheless, strategies to help improve the resilience of marine turtles populations to climate change are still not being adequately incorporated in MPA management plans (Fuentes et al., 2012; O'Regan et al., 2021), reaffirming the need to find ways to apply scientific evidence more efficiently and timely (Casale et al., 2018).

Here, we explored the knowledge-action gap between researchers and conservation management practitioners (i.e. MPA managers) with respect to marine turtle conservation under a changing climate in the Mediterranean. Based on the perceptions of the actors involved in the conservation of green and loggerhead marine turtles in the Mediterranean, we aimed to: (1) evaluate the importance of potential climate change impacts on the critical habitats, life history stages and biological characteristics of marine turtles, and (2) identify and prioritize adaptation/mitigation measures to safeguard marine turtles from climate change. To accomplish this, we took advantage of a regional experience-sharing workshop with managers and researchers. Participants were also asked to rate possible mitigation and adaptation measures/strategies (defined as measures/practices aimed at directly reducing the impacts of climate change, complementing management actions focused on assessing and addressing climate change-related risks) to alleviate these effects based on the combined evaluation of their effectiveness, practical applicability, and financial and societal costs. Our results are expected to prioritize of possible mitigation and adaptation measures to tackle climate change impacts on marine turtles, setting priorities for decision and policy-making, thereby enhancing the effectiveness of management actions in the Mediterranean region, with potential global applicability in other ocean basins.

2. Methods

In 2017, following the strategy and the initiatives of the Network of Marine Protected Area's managers in the Mediterranean (MedPAN), the Mediterranean Marine Turtle Working Group was established, bringing together MPA managers, conservation practitioners, and researchers working on marine turtle conservation from 10 Mediterranean countries. Under the umbrella of a regional experience-sharing workshop entitled ('Management of highly mobile species across Mediterranean Marine Protected Areas') that was held on 12–14 November 2019 in Akyaka, Türkiye, the Mediterranean marine turtle working group was invited to participate in an online survey aiming to explore the main conservation priorities and challenges for marine turtles under a changing climate. By 2019, the Marine Turtle Working Group consisted of diverse representatives in marine turtle conservation: managers (e.g. representatives of MPAs that implement activities focusing on marine turtle conservation), researchers (e.g. personnel of academic or research centers) and both (this latter group being involved in both, e.g., scientific staff of management agencies that also produce scientific articles and contribute to research projects).

A three-step process was implemented to create the online survey. First, the preliminary structure of the questionnaire was developed (A.D. Mazaris), and two representatives from the three groups reviewed it and provided feedback (Researchers: G. Schofield, A. Chatzimentor; Managers: M. Xanthakis, L. Sourbes; serving as both Researcher and Manager: C. Dimitriadis, D. Koutsoubas). Second, three conservation biologists, not involved in the first stage of the preliminary structure, with long-term experience in conservation but not marine turtles, were consulted to ensure that the questionnaire was balanced regarding climate change impacts on biodiversity (A. Doxa, S. Katsanevakis, P.G. Dimitrakopoulos). These specialists were only involved in the questionnaire design and did not participate in the survey to avoid any possible bias. In the third step, 32 marine turtle working group members responded to the questionnaire. To ensure broad spatial representation of participants, invitations to complete the survey were sent to additional actors who were not members of the marine turtle working group but had been working on marine turtles as researchers and/or managers in the Mediterranean region; 55 additional response surveys were collected. These actors were initially identified from scientific publications, reports, and available attendance lists of related conferences and meetings. Thus, a total 87 questionnaires was completed in 2021.

2.1. Survey sampling methods and design

The online survey was conducted using a structured questionnaire (based on a Likert scale response, 1–5). A broad set of questions was developed and divided into three sections: (1) expertise of participants, country and number of years working on marine turtles; (2) perceptions on climate change impacts with respect to critical habitats, life history stage, and biological characteristics of marine turtles (Table 1); and (3) perceptions on 19 mitigation and adaptation measures to tackle climate change impacts on marine turtles (Table 2). In the third section of the questionnaire, mitigation and adaptation measures were explored in relation to their effectiveness, practical applicability, financial cost and societal cost. Adaptation and mitigation measures were classified according to different thematic areas: (i) protection of MPAs and important marine turtle areas; (ii) direct protection of marine turtle populations; (iii) species monitoring and status assessments; and (iv) legislative actions and the collaboration of different actors.

2.2. Data analysis

Before analyzing the surveys, the dataset was treated to address missing values (NAs), which accounted for 9.8% of total responses. Correction for NAs was implemented to avoid discarding questionnaires in score computation (listwise deletion). We employed multiple imputation methods for multivariate missing data (van Buuren, 2007),

Table 1
List of variables used to score the perceptions of survey participants regarding the impacts of climate change on critical habitats, life history stage, and biological characteristics of marine turtles in the Mediterranean (scale 1–5).

Impacts of climate change on:
Sex ratio of hatchlings
Reproductive output (namely, the number of viable hatchlings entering the sea)
Breeding habitat availability/quality
Location of nesting sites (i.e. the risk of current sites becoming unviable in the future)
Foraging areas (extent)
Foraging areas (quality)
Migratory corridors
Wintering sites
Impacts could jeopardize population viability of:
Hatchlings
Juveniles
Adults

Table 2
List of composite variables used to score the perceptions of survey participants regarding the 19 mitigation and adaptation measures (expressed as the average score of their ecological effectiveness, practical applicability, financial cost and societal cost), to tackle climate change impacts on marine turtles in the Mediterranean (scale 1–5). The thematic area of adaptation and mitigation measures is also shown.

Thematic area	Code	Adaptation and mitigation measures
A. Protection of MPAs and important marine turtle areas	A1	Increase the extent of existing MPAs
	A2	Design new MPAs that fall in areas of predicted use over the next 20–50 years
	A3	Protect current movement corridors
	A4	Protect climatic refugia
	A5	Manage and restore ecosystem function rather than focusing on specific components (e.g. nest location)
	A6	Improve restoration of existing MPAs to facilitate resilience to climate change
B. Direct protection of marine turtle populations	B1	Reduce pressure on species from sources other than climate change
	B2	Increase the number of artificially incubated eggs
	B3	Identify and protect nesting beaches more resilient to climate change
	B4	Protect existing or create new male producing sites (e.g. artificial shading of nests)
C. Species monitoring and status assessment	C1	Evaluate and enhance existing monitoring programs
	C2	Update monitoring programs to incorporate changes in phenology, distribution and reproductive capacity
	C3	Identify tipping points, indicators and thresholds for assessing species conservation status and changes
	C4	Monitor and assess the efficacy of existing management strategies
	C5	Incorporate predicted climate-change impacts into management plans and systematic conservation planning
D. Legislative actions and different actors' collaboration	D1	Fitness check (i.e. evaluate efficacy and potential overlaps) and review of existing Laws, Regulations and Policies
	D2	Reform or revision of legislative pieces and agreements to tackle emerging pressures and activities
	D3	Establish or increase communication across policy makers-managers-researchers
	D4	Enhance cooperation (exchange of experience/practices) among managers

substituting five plausible random values for each missing value, and created five plausible complete versions of the incomplete dataset. The multiple imputation method was based on a chain of regression equations, adding error terms, chosen randomly from the observed residuals, to the regression estimates. Then, each complete dataset was analyzed, and the outcomes were pooled as one final outcome (van Ginkel and Kroonenberg, 2014). Once NAs had been inputted for each variable related to a mitigation and adaptation measure, we merged the perception scores of the four components (i.e. effectiveness, practical applicability, financial cost, and societal cost) to create a composite score (i.e. average) for each measure (Bennett et al., 2020). These composite scores allowed us to treat the original categorical values of the Likert scale as continuous values.

We employed univariate analysis of variance (one-way ANOVA) of multiple imputed data (van Ginkel and Kroonenberg, 2014) to detect significant differences between (1) the scores of questions linked to potential climate change impacts on critical habitats, life history stage, and biological characteristics of marine turtles, and (2) the composite scores of mitigation and adaptation measures to tackle climate change impacts on marine turtles. We used pairwise comparisons based on the least significant difference criterion (LSD) to assign impacts and mitigation/adaptation measures of top, medium and low-ranking importance based on participants' perceptions. ANOVAs were also used to check for differences in participants' perceptions among the four components (i.e. effectiveness, practical applicability, financial cost and societal cost) and among the different thematic areas of the measures (see Table 2).

We examined statistical differences in the perceptions of participants based on (1) their background (researcher, manager, both), (2) the subregion of the Mediterranean where they work (North: Portugal, Spain, France, Italy, Malta, Slovenia, Croatia, Montenegro, Albania, Greece, and Türkiye versus South: Morocco, Algeria, Tunisia, Libya, Egypt, Cyprus and Lebanon), and (3) number of years of experience in working with marine turtles (<5, 6–10, 11–20, >20 years). We fitted generalized linear models (GLMs) for our continuous response variables (related to mitigation and adaptation measures) and generalized multinomial logistic models (with a cumulative logit as the link function) for our ordinal response variables (related to climate change impacts on marine turtles). All predictors were treated as fixed factors.

3. Results

3.1. Characteristics of survey sample

Eighty-seven people working in marine turtle conservation across 18 Mediterranean countries completed the survey; these included 51 researchers, 20 MPA managers and 16 persons involved in both research and management. Of the respondents, 73.6% and 26.4% were located in the north and the south Mediterranean, respectively (Fig. 1). Two-thirds of respondents had worked 10–20 or ≥20 years with marine turtles (64.4% of respondents in total; 32.2% and 32.2%, respectively). In comparison, 17.2% and 18.4% of respondents had <5 years and 6–10 years of experience, respectively.

3.2. Impacts of climate change on marine turtles

Impacts that received the highest scores (significantly higher than the rest) included: (1) risk to the sex ratios of hatchlings and (2) risk of current nesting sites becoming unviable in the future (i.e. location of nesting sites) (Table 3, Fig. 2). The impacts that received intermediate scores included: (1) quality of foraging areas, (2) availability/quality of breeding grounds, and (3) reproductive output (i.e. number of viable hatchlings entering the sea). The impacts that received the lowest scores included: (1) impacts on wintering sites, (2) extent of foraging areas and (3) migratory corridors. Hatchlings were considered to be more prone to climate change impacts than adults and juveniles (ANOVA results, Table 3, Fig. 3). When comparing the perception of the participants on the different impacts of climate change on marine turtles, we found no effect of 'background', 'number of years working', and 'sub-region' factors (generalized multinomial logistic models, $p > 0.05$ in all cases).

3.3. Adaptation and mitigation measures to climate change

When comparing mean scores on the importance of adaptation/mitigation measures, as rated by all participants, we identified significant differences ($F = 7.016$, $df = 18$, $p < 0.01$; Table 3). Based on pairwise comparisons, we delineated three main categories (high, intermediate, low) of importance for adaptation/mitigation measures. The adaptation/mitigation measures that received the highest scores include the following, sorted in descending order: (1) reducing pressure on species from sources other than climate change, (2) managing and restoring ecosystem functions (rather than focusing on specific components), (3) evaluating and enhancing existing monitoring programs, (4) designing new MPAs that fall in areas of predicted use over the next 20–50 years, (5) identifying and protecting nesting beaches more resilient to climate change, and (6) incorporating predicted climate change impacts in management plans and systematic conservation planning

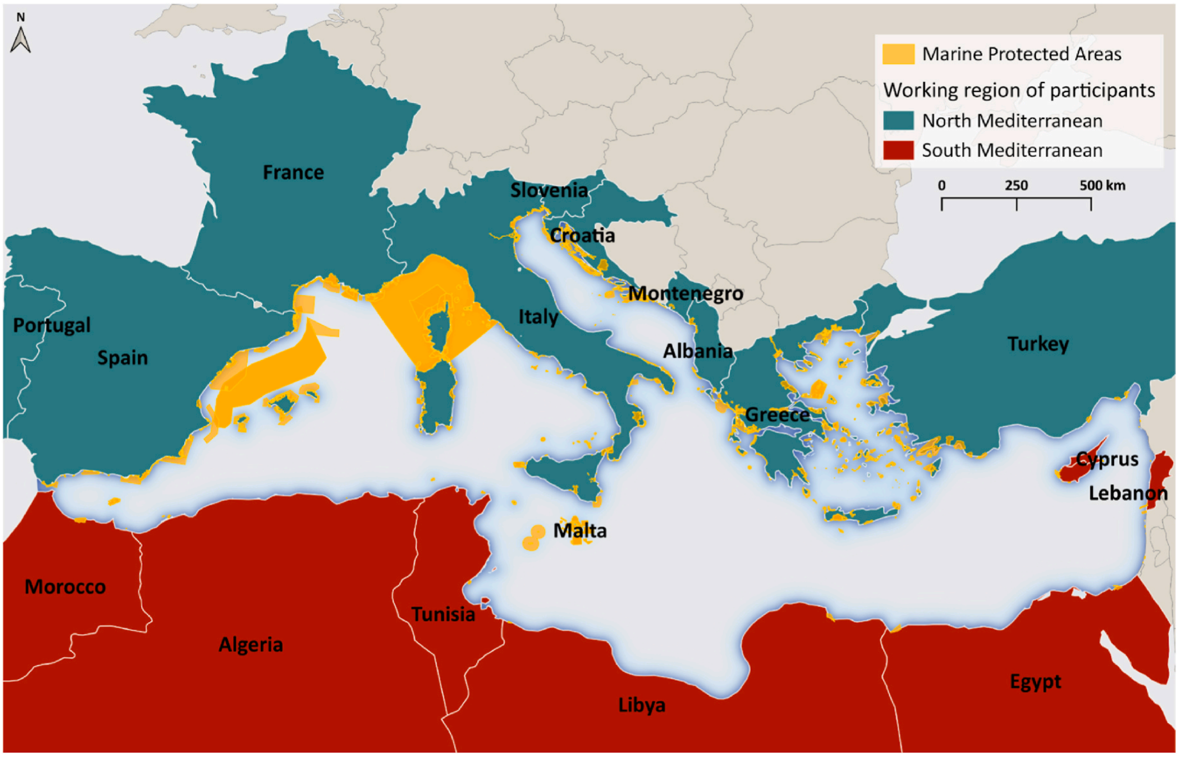

Fig. 1. A map of the Mediterranean Sea, depicting all countries (n = 18) from which responses were received. The MPA network in the Mediterranean Sea is also illustrated.

Table 3
ANOVA results for the ranking of variables related to: i) climate change impacts importance on marine turtles habitats and biological attributes, ii) climate change impacts importance on different life history stages for marine turtles and iii) measures to tackle climate change impacts on marine turtles. Pairwise comparisons indicate significant different groups of variables according to their mean score.

	df	F	P	Significant Pair-wise differences (LSD)
Ranking of climate change impacts importance on marine turtles habitats and biological attributes	7	10.087	0.0001*	Sex ratio and location of nesting sites > all other ($p < 0.05$); Migratory corridors < reproductive output, breeding habitat, foraging areas (quality), location of nesting sites, sex ratio ($p < 0.05$)
Ranking of climate change impacts importance on different life history stages for marine turtles	2	17.03	0.0001*	Hatchlings > Juveniles and adults ($p < 0.05$)
Ranking of measures to tackle climate change impacts on marine turtles	18	7.016	0.0001*	B1,A5,C1,A2,B3,C5>D4, C2,A1,D3,C4,A3,C3,A6, A4>D2,D1,B4, B2 ($p < 0.05$)

(Fig. 4). The adaptation/mitigation measures that received intermediate scores include measures on (1) protection of MPAs and important marine turtle areas (four measures), (2) species monitoring and status assessment (three measures), and (3) legislative actions and collaboration of different actors (two measures) (Fig. 4). The adaptation/mitigation measures that received the lowest scores included (1) direct protection of marine turtle populations (two measures) and (2) legislative actions and the collaboration of different actors (two measures).

The perception of adaptation/mitigation measures was not affected by the 'background', 'number of years working' and 'sub-region' of the participant (GLM results) except in a few cases (Fig. 6). For instance, compared to participants working in the North Mediterranean, those from the South Mediterranean gave higher scores on (1) evaluation and enhancement of existing monitoring programs and (2) protection of current movement corridors. The importance of enhancing cooperation (exchange of experience/practices) scored higher for managers than for researchers and those involved in both research and management. Of note, the importance attributed to designing new MPAs that fall in areas of predicted use over the next 20–50 years was inversely proportional to the years of experience in marine turtle research and conservation. Measures associated with the geographical extension of existing MPAs received higher scores from respondents from southern countries, persons involved both on research and management, and those with less experience.

Respondent scores were significantly different when comparing ecological effectiveness, practical applicability, financial cost, and societal cost ($F = 313.03$, $df = 3$ $p < 0.01$). The highest score was obtained for the ecological effectiveness of measures, followed by practical applicability, financial cost, and societal cost ($p < 0.05$ in all cases; Fig. 5a). Categories of measures identified for prioritization included the protection of MPAs, important areas for marine turtles, and species monitoring and status assessment. Measures identified as of lower importance included those linked to direct protection of marine turtle populations and legislative actions and collaboration among actors ($F = 6.84$, $df = 3$, $p < 0.01$; $p < 0.05$ for reported pairwise comparisons; Fig. 5b).

4. Discussion

It is important to gauge and communicate potential differences in the priorities of researchers and conservation management practitioners to decrease knowledge-action gaps that currently impede the implementation of climate adaptation/mitigation strategies in conservation planning. Our study demonstrated that the opinions of key actors in

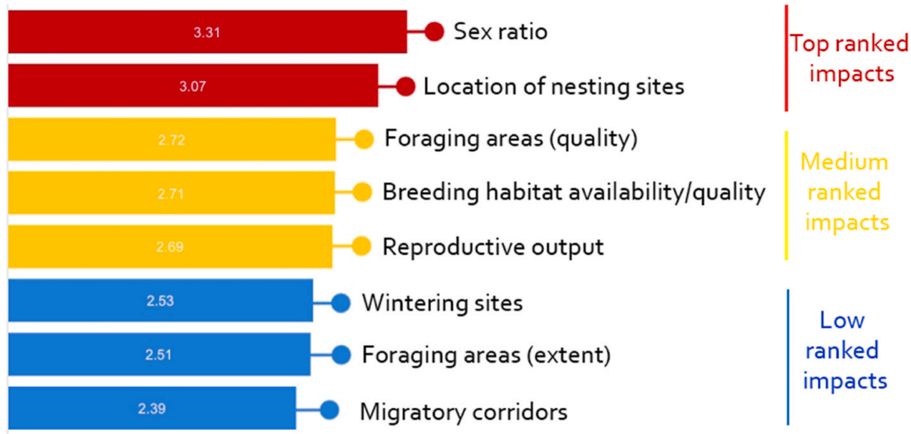

Fig. 2. Average score and ranking (top – red, medium-yellow, low – blue color) of the perception of 87 responders on the importance of climate change impacts on critical habitats, life history stage, and biological characteristics for marine turtles in the Mediterranean region. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

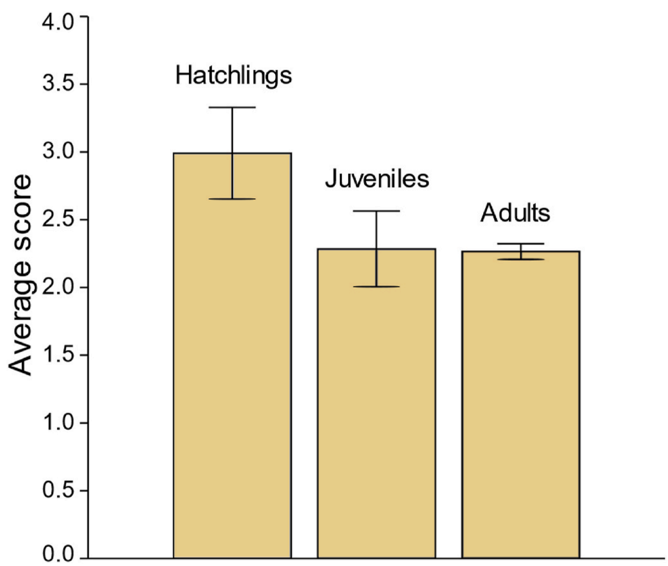

Fig. 3. The mean (±95% CI) score of the perception of 87 responders on the importance of climate change impacts on different life stages of marine turtle life history.

conserving all aspects of marine turtle life history in the Mediterranean converged regarding climate change, despite different levels of expertise, experience and geographical region. However, the level of importance that participants placed on measures aimed at enhancing adaptation or mitigation of climate change impacts partly depended on specific parameters. For instance, while participants working in countries of the south and the north Mediterranean generally agreed on most of the listed measures, participants from the south Mediterranean placed higher importance on evaluating and consolidating existing monitoring programs and improving the protection of current movement corridors. These two measures could be critical to the southern part of the Mediterranean Sea, as there are fewer MPAs in this region, despite supporting many coastal nesting and foraging areas (Casale et al., 2018). Thus, conservation and management initiatives should consider and adjust to conditions and needs applied at finer scales, with this insight likely being relevant to other species and regions globally.

Worldwide, most MPA management plans strongly advocate the use of more ecological adaptation actions (e.g., enhance connectivity), rather than actions that can safeguard socio-economic viability (e.g., develop alternative livelihoods) (O'Regan et al., 2021). This priority was also confirmed by our study, as possible mitigation and adaptation measures were mostly ranked based on criteria of effectiveness and practical applicability, rather than financial and societal cost. Climate change will not uniformly impact social groups and economic activities, with some suffering greater loss of resources and well-being than others (Abbass et al., 2022; Otto et al., 2017; Thomas et al., 2019). Thus, it is necessary to consider climate-related impacts on mitigation and adaptation planning, including potential conflicts and, even, opportunities for more sustainable livelihoods (Lam et al., 2016). For example, most nations with coastlines support communities with fisheries-dependent livelihoods (Allison et al., 2009), which are highly vulnerable to climate change (Bell et al., 2013; Sainsbury et al., 2018). In countries where marine turtles nest or forage, ecotourism activities could provide an alternative source of income, if implemented using good environmental practices (Papafitsoros et al., 2020). Climate-related impacts on small- and large-scale fisheries (Hilmi et al., 2021) could also result in the redistribution of the fishing effort (Cheung et al., 2010), potentially exacerbating adverse interactions with marine turtle populations and other human uses. Similarly, the loss of sandy shores due to sea level rise could also be translated as reduced space for tourism activity, inevitably leading to increased conflicts for beach use (Dimitriadis et al., 2022; Katselidis et al., 2013).

Management (action) plans often do not consider climate change impacts, due to a lack of financial resources and a short-term political focus (Barr et al., 2021; Lemieux et al., 2011). Yet, the recovery of marine megafauna, including marine turtles, is being recorded and attributed to long-term management actions, often spanning over 50 years (Mazaris et al., 2017). The protection of marine turtle nesting beaches and facilitating increased production of offspring contributed to the recorded recoveries, along with the regulation of fishing activities (Balazs and Chaloupka, 2004; Mazaris et al., 2017). The current study clearly showed that both managers and researchers involved in marine turtle conservation were strongly aware of the importance of hatchling production in safeguarding the resilience of marine turtles, and further highlighted its fragility due to climate change. Towards ensuring a standardized flow of information that could support predictive tools and early warning systems, the selection and consistent monitoring of indicator sites, covering latitudinal, longitudinal and environmental gradients should be prioritized. Yet, other ecosystem wide stressors related to climate change, such as invasive species, should not be disregarded since they can remarkably modify the structure and function of ecosystems through time, therefore challenging conservation outcomes (Simberloff et al., 2013).

Top-ranked adaptation/mitigation measures indicated that participants advocated for ecosystem-based approaches. Specifically,

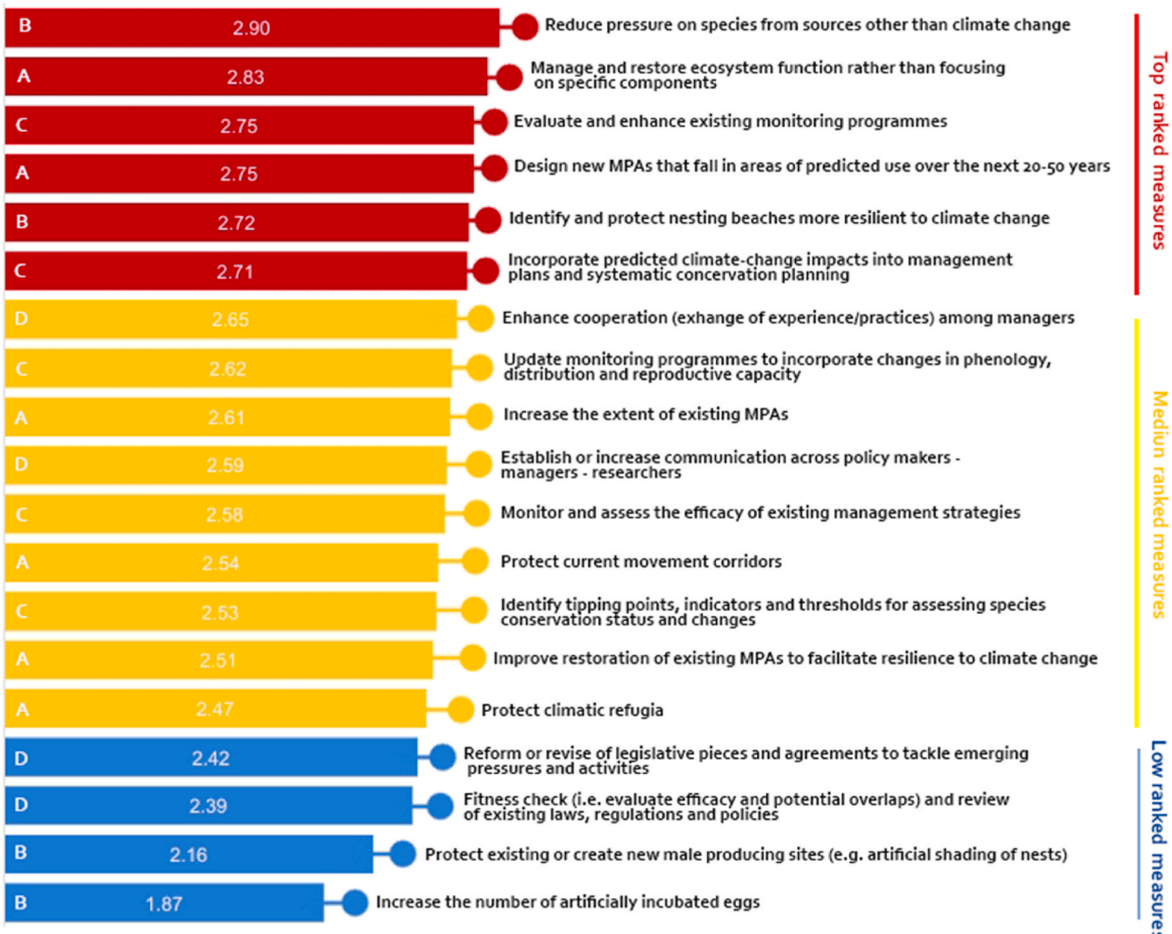

Fig. 4. Average score and ranking (top – red, medium-yellow, low – blue color) of measures that could be used to mitigate climate change impacts on marine turtles. Thematic areas of adaptation/mitigation measures are also shown (A: Protection of MPAs and important marine turtle areas, B: Direct protection of marine turtle populations C: Species monitoring and status assessment, D: Legislative actions and different actor collaborations). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

participants selected measures focusing on the status of and interactions within the entire landscape, both natural and anthropogenic. A climate-robust management plan would first require the most vulnerable species and ecosystem functions in the face of climate change to be identified, shifting towards climate smart management for MPAs (Doxa et al., 2022; Tittensor et al., 2019). Initiatives such as Natura 2000 network of European protected areas (92/43/EEC directive) should, thus, adjust their fixed list of protected species and habitats in relation to rapidly changing conditions under climate change (Ibisch et al., 2012). Similarly, the the newly formed network of experts and Non-Governmental Organizations in North Africa (NASTNet) could support the incorporation of climate change dimensions into conservation. Climate smart management plans should consider both current and future hotspots of risk for marine turtles in the Mediterranean region, taking into account multiple human induced threats, and aligning actions with current or planned conservation plans and regulatory efforts implemented by national and international organizations throughout the Mediterranean region (e.g. Barcelona Convention-regional action plan for marine turtles, FAO-General Fisheries Commission for the Mediterranean and the Black Sea, International Commission for the Conservation of Atlantic Tuna).

In terms of alternative adaptation and mitigation measures, an interesting finding of our study was the low score by managers and researchers for the category "legislative actions and collaboration strategies of different actors". These results indicate distrust in the slow pace of institutional change (Lonsdale et al., 2017). In many cases, the legislative tools are already in place (Dickson et al., 2022; Girard et al., 2022), but enforcement and monitoring of the efficiency of measures are lacking, while the spatial coverage by MPAs remains rather limited in the region (Gomei et al., 2019). In other words, while MPAs can shield wildlife and habitats from many pressures, actual practice is needed. Still, participants appeared to be aware that different pressures might act synergistically or cumulatively with climate change, thus posing further conservation and management challenges. Taking into account the concerns on the practical applicability and financial cost towards enhancing conservation efficiency, the adoption of a dynamic spatial management framework for Mediterranean MPAs could be considered a viable option. Under such a framework, the boundaries of MPAs and the zoning of controlled activities could be flexible and adopted to a number of factors such as seasonality, intensity of activities, available resources.

The financial costs for meeting the targets of conservation and management are often high, and in many cases, represent a key obstacle for implementing measures (McCarthy et al., 2012). Interestingly, in our study region, financial cost was ranked below ecological effectiveness and practical applicability of potential measures for management and adaptation. This might be explained by the diverse, or even unstable, economic status of some countries in the region, which could result in limited support for conservation. Where conservation actors are aware about financial limitations, limited resources are usually allocated in a way to ensure the maximum ecological efficiency, being practical in use and application (O'Connor et al., 2003). Yet, even when financial resources are available, the efficiency of conservation and management actions depends on local or regional conditions (e.g. tourism,

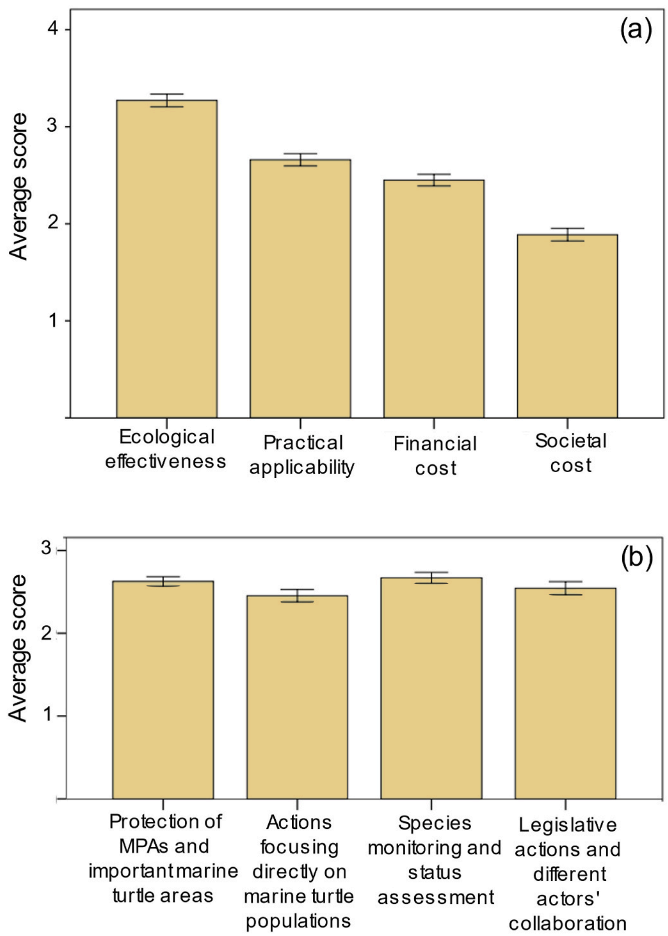

Fig. 5. Mean (±95% CI) score of the perception of 87 responders on the importance of adaptation and mitigation measures regarding (a) their ecological effectiveness, practical applicability, financial cost and societal cost, and (b) according to four, broad thematic areas.

governance, support of local community) which could act as obstacles for the practical applicability of the measures (McCreless et al., 2013; Smith et al., 2003). Although different groups of actors involved in conservation potentially prioritize management and mitigation alternatives differently, we found remarkable similarities in the priorities of managers and researchers (including those involved in both). This convergence might have been driven by various international initiatives in the Mediterranean to improve marine turtle conservation efforts over the last two decades (Mazaris et al., 2018) (see also Supplementary Materia S1).

The need to delineate and monitor the marine habitats of marine turtles holistically throughout the region has been raised as a key research priority (Chatzimentor et al., 2021). Various studies have demonstrated low rates of survival rates of both juveniles and adults in the Mediterranean during foraging (Casale et al., 2015; Omeyer et al., 2019; Schofield et al., 2020). Potential spatial shifts in foraging ground (Chatzimentor et al., 2021) and likely energetic changes in migration patterns due to climate change (Petsas et al., 2023) further support the need for accelerating research on the marine habitats of marine turtles, particularly in areas with high human use (e.g. fisheries, marine traffic) (Dickson et al., 2022). Changes to foraging habitat distribution and/or prey species presence could have a direct effect on the energetic budget of marine turtles, negatively impacting fitness, somatic growth, time to reach sexual maturity and breeding frequency (remigration intervals, typically 1 year for males and 2–3 for females in the Mediterranean; Hays et al., 2014). Nonetheless, the importance of the quality of foraging areas ranked "intermediate" by respondents. Yet, as the foraging habitat of marine turtles is widespread throughout the Mediterranean, practical difficulties exist in monitoring and evaluating climate change effects at appropriate scales (Dickson et al., 2022).

For species with temperature-dependent sex determination (i.e. the surrounding environment determines whether male or female offspring are produced, sand temperature for marine turtles), populations are under threat as existing incubation temperatures are leading to predominantly female-skewed hatchling sex ratios (Patrício et al., 2021). Indeed, like other regions globally, data in the Mediterranean region show a significant bias towards female production (e.g., Hays et al., 2014). As climate is warming and sea level rise potentially threatens nesting beaches (Dimitriadis et al., 2022; Sönmez et al., 2021), marine turtles might have to shift to alternative (potentially new) nesting sites to maintain favorable environmental conditions (Marbà et al., 2015; Poloczanska et al., 2013). For example, the expansion of marine turtle nesting activity is being documented throughout the Mediterranean Sea, with sporadic nesting events (Cardona et al., 2022; Hochscheid et al., 2022), potentially demonstrating the onset of shifts by turtles to maintain favorable thermal niches under a changing climate. Consequently, both researchers and managers were strongly aware of the potential climate change impact on the sex ratio of marine turtles and possible degradation of current nesting grounds, which could reduce the resilience and persistence of current marine turtle populations in the long term. Thus, mitigating these effects was given higher importance over climate change impacts on foraging areas or migratory routes.

This study demonstrated the strong similarities in the opinions of different conservation actors on how to tackle the conservation of large, long-lived marine vertebrates under climate change, regardless of their background (experience/expertise). While researchers have the capacity to explore the potential effects of climate change at different spatial and temporal scales, it is managers who must transfer knowledge into practice, selecting the best solution. The Mediterranean is small, it captures the full life-history needs of marine turtles and wide economic backgrounds of multiple countries; given these features, it could be used as a baseline to guide similar initiatives elsewhere globally. In conclusion, our study highlighted a clear preference towards more holistic protection of threatened wildlife against climate change.

Credit author statement

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	Sub-region	Expertise	Years
B1. Reduce pressure on species from sources other than climate change			
A.5. Manage and restore ecosystem function rather than focusing on specific components			
C1. Evaluate and enhance existing monitoring programs	SMED > NMED		
A2.Design new (Marine) Protected Areas that fall in areas of predicted use over the next 20-50 years		Researcher > Manager > Both	6-10 > < 5 > 11-20 > >20
B3.Identify and protect nesting beaches more resilient to climate change			
C5.Incorporate predicted climate-change impacts into management plans and systematic conservation planning			
D4.Enhance cooperation (exchange of experience/practices) among managers		Manager > Researcher > Both	
C2.Update monitoring programmes to incorporate changes in phenology, distribution and reproductive capacity			
A1.Increase the extent of existing Marine Protected areas	SMED > NMED	Both > Researcher > Manager	6-10 > 11-20 > < 5> >20
D3.Establish or increase communication across policy makers-managers-researchers			
C4.Monitor and assess the efficacy of existing management strategies			
A3.Protect current movement corridors	SMED > NMED		
C3.Identify tipping points, indicators and thresholds for assessing species conservation status and changes			
A6.Improve restoration of existing MPAs to facilitate resilience to climate change			
A4.Protect climatic refugia			
D2.Reform or revision of legislative pieces and agreements to tackle emerging pressures and activities			
D1.Fitness check (i.e. evaluate efficacy and potential overlaps) and review of existing Laws, Regulations and Policies			
B4.Protect existing or create new male producing sites (e.g. artificial shading of nests)			
B2.Increase the number of artificially incubated eggs			

Fig. 6. Results of analyses (i.e. generalized linear and multinomial models) on the perceptions of marine turtle conservation actors in the Mediterranean, on the importance of alternative mitigation and adaptation measures related to climate change impacts on marine turtles. The green cells highlight significant effects of the following three predictors i) Mediterranean sub-region: North (NMED) vs South (SMED), ii) expertise (researcher, manager, both) and iii) number of years of experience in working with marine turtles (Years); non-significant effects are highlighted in orange. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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