



## Artificial night lighting in the Mediterranean: Management priorities and constraints for sea turtle conservation

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### ABSTRACT

Artificial light at night (ALAN) is an escalating anthropogenic threat that disrupts coastal and marine ecosystems worldwide, yet its impacts on Mediterranean sea turtles remain poorly quantified. We surveyed 27 experts across 16 Mediterranean countries to evaluate perceived ALAN effects on sea turtle nesting sites and nearshore habitats, identify research gaps, assess monitoring limitations, and prioritize mitigation strategies. Respondents consistently highlighted hatchlings as the most vulnerable life stage, particularly during sea-finding and early dispersal, with ALAN causing disorientation, increased predation risk, and reduced recruitment. Standardized monitoring of ALAN impacts is largely absent, with financial constraints representing the main barrier, alongside gaps in communication, education, and policy. Experts ranked the highest-priority mitigation measures as updating monitoring programs to incorporate ALAN, reducing light exposure on nesting beaches through shielding,

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downward-directed and long-wavelength lighting, shaded corridors, and nature-based solutions, and integrating advanced technologies into conservation planning. Measures such as policy reform, public awareness campaigns, and scenario-based coastal planning were considered of moderate priority, emphasizing that practical, site-specific interventions may yield the most immediate benefits. Limited expert consensus on the prioritization of mitigation strategies indicates persistent uncertainties and critical regional knowledge gaps that hinder effective conservation planning. ALAN is an established but under-addressed threat to Mediterranean sea turtles. Effective conservation will require integrating evidence-based research, standardized monitoring, and targeted mitigation measures at nesting and nearshore habitats. Implementing such strategies will not only safeguard sea turtle populations in the Mediterranean but also provide a globally relevant framework for managing ALAN in other coastal ecosystems.

## 1. Introduction

Artificial Light at Night (ALAN) has emerged as a rapidly expanding and pervasive form of pollution threatening global biodiversity and challenging conservation efforts (Falchi et al., 2016; Gaston et al., 2021). ALAN is detectable along a significant portion of the world's coastline (more than 22% in 2010, Davies et al., 2016) further extending across the sea surface, subsurface, and seafloor, altering the natural photic zones of the oceans (Davies et al., 2020; Smyth et al., 2021; Davies and Smyth, 2025) and impacting coastal and marine ecosystems (Gaston et al., 2014). This form of pollution represents a major ecological concern, as it introduces artificial illumination characterized by temporal patterns, spectral range, and intensities that are absent under natural conditions. Yet, its influence extends beyond the directly illuminated areas, as scattered and reflected light can alter the natural nocturnal environment over large spatial scales, disrupting many ecologically relevant processes in a wide range of wildlife species (Longcore et al., 2018; Tidau et al., 2021; Hirt et al., 2023). The progressive erosion of natural nocturnal darkness imposes profound consequences for ecological systems and a wide spectrum of taxa, including invertebrates, fish, amphibians, reptiles, birds and, mammals, whose life-history strategies are fundamentally contingent upon ambient light regimes (Hölker et al., 2010; Gaston et al., 2013; Karan et al., 2023). In this context, the loss of natural darkness triggers pervasive disruptions to essential ecological processes across species, encompassing foraging dynamics, reproductive success, recruitment patterns, orientation and navigational capacity, dispersal mechanisms, consumer-resource interactions, migratory behaviour and overall fitness (Sanders et al., 2021; Marangoni et al., 2022; Burt et al., 2023 and references therein).

Sea turtles are among the species most acutely impacted by ALAN, as their ontogenetic transitions and reliance on multiple coastal and marine habitat types make them highly susceptible to light-induced disturbance (Limpus and Kamrowski, 2013; Fuentes et al., 2023). Exposure of sea turtles to ALAN is particularly pronounced at nesting sites and nearshore coastal areas situated in proximity to urban, touristic or industrial developments (Kamrowski et al., 2014; Pendoley and Kamrowski, 2015; Dimitriadis et al., 2018; Colman et al., 2020). Although the magnitude and extent of ALAN impacts may vary across different spatial and temporal scales, substantial evidence indicates they are predominantly associated with on-beach nesting behaviour and site selection by adult females, hatchling orientation during sea-finding, and offshore dispersal capacity (Salmon, 2003; Thums et al., 2016; Silva et al., 2017; Shimada et al., 2023; Attum and Nagy, 2024). These disruptions can ultimately reduce reproductive success, population resilience, and recruitment (Lorne and Salmon, 2007; Dimitriadis et al., 2018; Wilson et al., 2019).

On a global scale, the Mediterranean region is among the areas most exposed to ALAN, primarily as a result of concentrated human population and activities along its coastal and nearshore zones, including urbanization, coastal development, tourism, industrial operations, shipping and transport networks (Piante and Ody, 2015; Marangoni et al., 2022; Polinov, 2023). The region sustains significant populations of two sea turtle species the loggerhead turtle (*Caretta caretta*) and the green turtle (*Chelonia mydas*) which currently rely on approximately 52

and 13 major nesting sites, respectively, in addition to numerous minor nesting sites distributed around the Mediterranean basin (Casale et al., 2018). The overlap of coastal areas of intense ALAN exposure with these critical nesting and nearshore hatchling dispersal areas renders the Mediterranean a hotspot for potential light-induced ecological disruptions (Biddiscombe et al., 2020). Notwithstanding, knowledge of the threat posed by ALAN and its associated ecological impacts on sea turtles in the Mediterranean remains limited, being largely confined to a small number of sites and timeframes (e.g. Mazor et al., 2013; Dimitriadis et al., 2018; Leader et al., 2024; Simantiris et al., 2025; Jribi, 2025).

While natural dark skies become less common, important limitations and knowledge gaps persist in evaluating the ecological footprint of ALAN on sea turtles and in adopting the best management practices at nesting sites and nearshore areas (Rivas et al., 2015; Rees et al., 2016; Gomez Isaza et al., 2025). From a management perspective, the considerable heterogeneity in ALAN properties and sources across coastal and nearshore marine environments complicates not only the design and implementation of standardized monitoring protocols, but also the establishment of effective conservation measures. Nevertheless, identifying and prioritizing suitable strategies and measures toward the mitigation of ALAN effects on sea turtles is critical for enhancing the conservation effectiveness of their populations, recognizing current knowledge gaps and strengthening evidence-based management (Schofield et al., 2013; Fuentes et al., 2023).

Based on the perceptions of the experts involved in the monitoring and conservation of marine turtles in the Mediterranean, we aimed to: (a) evaluate the perceived impacts of ALAN on sea turtle nesting sites and nearshore marine habitats; (b) identify the principal research gaps; (c) determine critical limitations; and (d) establish priorities for strategies and mitigation measures to alleviate ALAN effects. By integrating research and practice, this study highlights critical ALAN-related knowledge gaps and management priorities for sea turtles, offering guidance and insights with broad applicability to marine conservation globally.

## 2. Material and methods

In February 2024, members of the Marine Turtle Specialist Group (MTSG) (<https://www.iucn-mtsg.org>) with a focus on the Mediterranean Regional Management Units of *Caretta caretta* and *Chelonia mydas* (Wallace et al., 2023), together with additional experts in sea turtle monitoring and conservation, were invited to participate in an online survey. The objective of this survey was to assess and prioritize existing knowledge gaps, management priorities, and constraints, as well as to evaluate the perceived ecological impacts of artificial light at night (ALAN) on sea turtles across the Mediterranean region. Experts invited to participate in the online survey (Supplementary File 1) were professionals involved in marine turtle monitoring and conservation across Mediterranean coastlines and were selected to initially meet two eligibility criteria: (a) active involvement at nesting sites and adjacent waters (thereby excluding experts whose primary focus was fisheries bycatch or in-water studies), and (b) demonstrated experience in ALAN monitoring and management. Participants were: (1) researchers, comprising personnel from academic or research institutions and regional experts

contributing to MTSG assessments and related scientific research, and implementing conservation / management measures; (2) managers, representing Marine Protected Areas (MPAs) implementing sea turtle conservation actions and contributing to relevant scientific publications and research projects.

A two-step process was followed to develop and disseminate the online survey. In the first step, the structure of the questionnaire was designed by the core team (S. Hochscheid, F. Maffucci, A.D. Mazaris, C. Dimitriadis). These experts were exclusively involved in the design phase and did not participate in the survey itself, thereby minimizing any potential bias. In the second step, the questionnaire was disseminated to 27 members of the MTSG who met the predefined selection criteria (out of a total of 31 members comprising the Mediterranean MTSG). These included 24 members affiliated with the Mediterranean MTSG and 3 members formally associated with other MTSG regions but possessing substantial expertise and long-term experience in the Mediterranean region. After excluding two Mediterranean MTSG members who did not intentionally participate in the survey (S. Hochscheid and F. Maffucci), as identified on the previous step, a total of 22 completed questionnaires were obtained, corresponding to a response rate of 81.5% among eligible MTSG regional experts. To ensure broad spatial and institutional representation, the survey was additionally disseminated to seven stakeholders beyond the MTSG. These included researchers and/or managers engaged in sea turtle conservation in the Mediterranean region, as well as members of other relevant initiatives (e.g., the Mediterranean Marine Protected Area Turtle Working Group -<https://medpan.org/en/projects/conservation-marine-turtles-mediterranean-region>), identified through peer-reviewed scientific publications, technical reports, and participant lists from relevant conferences and professional meetings. This process yielded 5 further responses. In total, 27 completed questionnaires were collected in 2024. Of 27 questionnaire responses, 25 were from researchers engaged in monitoring, management and conservation measures, and 2 from participants focused primarily on nesting site management and conservation. The majority of survey participants were male (90%), and all had more than 10 years of professional experience across multiple nesting and nearshore sites in the Mediterranean region. Participants were based in 15 Mediterranean countries: Greece ( $n = 4$ ), Türkiye ( $n = 3$ ), Italy ( $n = 2$ ), Israel ( $n = 2$ ), Cyprus ( $n = 2$ ), France ( $n = 2$ ), Libya ( $n = 2$ ), Spain ( $n = 2$ ), and one participant each from Algeria, Tunisia, Lebanon, Albania, Morocco, Syria, Egypt, and Croatia. All survey participants and core team members were asked to confirm authorship, resulting in a total of 24 co-authors.

### 2.1. Survey sampling methods and design

The online survey was implemented through a structured questionnaire (in English) employing a five-point Likert scale (1–5). The questionnaire consisted of four sections: (1) participants' expertise and country of work on sea turtles; (2) general perceptions of ALAN monitoring at critical nesting sites and nearshore marine areas; (3) perceptions of ALAN impacts on sea turtle nesting sites and nearshore areas across different life stages, including identification of research gaps and limitations in monitoring and impact assessment; and (4) perceptions of 11 strategies and mitigation measures aimed at reducing the effects of ALAN on sea turtles in nesting and nearshore habitats. The proposed strategies and mitigation measures were grouped into two thematic categories: (a) species monitoring, assessment, and conservation planning, and (b) law and policy. Within Sections 3 and 4, both impacts and mitigation measures were assessed in terms of adequacy (i.e., completeness, suitability, and operational fitness of existing frameworks and protocols), practical applicability (i.e., ease of use during implementation), financial cost (i.e., affordable to implement and maintain over time), and societal cost (i.e., the extent of negative impacts on communities, lifestyles, or social acceptance). Similarly, questions addressing the limitations of implementing monitoring protocols were

evaluated against multiple criteria, including effectiveness, carrying capacity (i.e., expertise and equipment constraints), practical applicability, and financial cost.

### 2.2. Data analysis

For the questions related to strategies and mitigation measures (Section 4), we merged the perception scores of the four components (i.e. adequacy, practical applicability, financial cost, and societal cost) to create a composite score (i.e. average) for each question (Bennett et al., 2020). These composite scores allowed us to treat the original ordinal values of the Likert scale as continuous values. Ranking of importance of strategies and mitigation measures was determined using quartile analysis. Responses were categorized into three groups based on their distribution. Items falling within the upper quartile ( $\geq 75$ th percentile) were classified as of high importance, those within the lower quartile ( $\leq 25$ th percentile) as of lower importance, and the remaining items were designated as of moderate importance. Kendall's tau correlation coefficient was employed to evaluate the degree of consensus among experts in their ranking assessments on the importance of strategies and mitigation measures counteracting ALAN effects. This nonparametric statistic quantifies the strength and direction of agreement among multiple raters by providing the pair-wise level of probability of concordance minus discordance. Values approaching 1 and  $-1$  denote a perfect direct agreement or disagreement, respectively while values close to 0 suggest no agreement.

## 3. Results

### 3.1. Characteristics of survey sample

Twenty-seven people working on sea turtle conservation across 16 Mediterranean countries (Albania, Algeria, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Morocco, Spain, Syria, Tunisia, and Türkiye) participated in the online – survey. Among the respondents, 92% identified their expertise as encompassing both nesting beach monitoring and the conservation -management of sea turtles, of whom 48% reported expertise in marine protected area management.

### 3.2. Base line information for ALAN and sea turtles

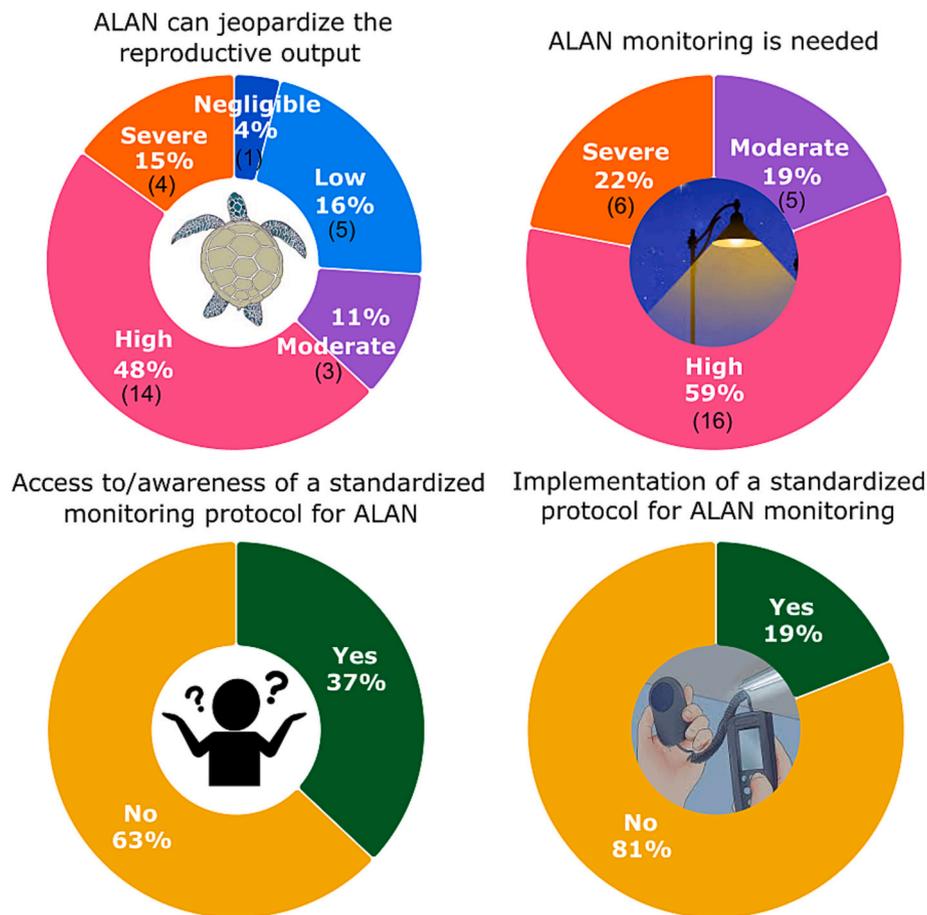
The majority of the respondents concur that ALAN could jeopardize the reproductive output of sea turtles (with severe and high level of impact evaluation collectively representing 63% of responses), and that monitoring of its effects is necessary (81% of responses). Nonetheless, over 60% of respondents reported lacking access to, or awareness of, a standardized monitoring protocol for ALAN effects at sea and nesting beaches, while more than 80% indicated that they had never applied such a protocol either at sea or on nesting beaches (Fig. 1).

### 3.3. Impacts of ALAN on sea turtle nesting sites and nearshore marine areas

Overall, based on their experience, researchers reported that the greatest perceived impact of ALAN occurs on hatchling orientation during the sea-finding transit from the nest to the sea, whereas the lowest impact is observed in adult females returning to the sea after emerging onto the beach to nest (Fig. 2a). This indicates that respondents consider hatchlings to be the life stage most affected by ALAN while participants evaluated all the other life stages with very similar score (around 3 – moderate).

### 3.4. Research gaps

Considering the impacts of ALAN on different sea turtle reproductive



**Fig. 1.** Responses ( $n = 27$ ) of the survey participants regarding the perceived impact of ALAN on the reproductive output, the necessity for monitoring ALAN at sea and nesting beaches, the availability of monitoring protocols and their use in the field (donut size represents % of responses; numbers in brackets show response counts when more than three categories are present; categories with zero responses were omitted from the graphs).

stages, the most critical knowledge gap appeared to concern the offshore dispersal of hatchlings, followed by the return of adult females to the sea and their search of suitable nesting sites (Fig. 2b).

### 3.5. Limitations in applying ALAN monitoring protocols

The primary limitation in implementing a standardized methodology and monitoring protocol for ALAN across spatial scales (all life stages and nesting sites) and temporal coverage (throughout and across nesting seasons) was financial cost (mean score around 4 – High), rather than practical applicability (mean score around 3.5), carrying capacity, or effectiveness (both mean score around 3; Fig. 3a). By contrast, limitations related to communication, education, updating protocols to include ALAN, and policy constraints were primarily linked to adequacy (mean score around 4 – High), while other factors (practical applicability, social cost, and financial cost) were consistently rated moderate (Figs. 3b, 4a, b).

### 3.6. Priorities for strategies and mitigation measures to alleviate ALAN effects

Based on the ranking of strategies and mitigation measures for ALAN effects on sea turtles above the 75th percentile, the three highest-ranked measures were related to species monitoring, assessment, and conservation planning. These included: (1) updating monitoring programs to incorporate ALAN measurements; (2) implementing measures to reduce ALAN exposure on nesting beaches, such as creating shaded corridors for hatchlings, eliminating direct light sources, minimizing remote light

visible from the beach through the use of light-blocking fences or vegetation, use of motion-activated lights, and redirecting public and private lighting downward, as well as reducing sky glow from nearby human settlements, tourism facilities, and industries; and (3) updating conservation measures to integrate state-of-the-art interventions, new technologies, and nature-based solutions aimed at mitigating the impacts of ALAN (Fig. 5). Measures and strategies of moderate importance included the: 1) identification of tipping points of abrupt change, indicators and alarm threshold for ALAN effects on sea turtles, 2) Enhancement of cooperation (exchange of experience and good practices) among managers and conservation practitioners, 3) establishment or increase of communication across policy makers-managers-researchers, 4) monitoring and assessment of the efficacy of existing management strategies for mitigating ALAN effects.

Measures below the 25th percentile, which were ranked to have lower importance, were linked to: 1) fitness check (i.e. evaluate efficacy and potential overlaps) and review of existing Laws, Regulations, and Policies, 2) enhance public awareness on ALAN impacts on sea turtle nesting habitat and wildlife in general, 3) adapt scenario-based planning (i.e. identify management actions that would be justified under proper ALAN impact assessment) and 4) reform or revision of legislative pieces and agreements to tackle emerging pressures and activities.

With respect to the ranking of the relative importance of strategies and mitigation measures, no significant convergence was observed among most expert responses. Specifically, 88% of the pairwise comparisons (286 out of 325) yielded non-significant Kendall's tau coefficients ( $p > 0.05$ ). Among the remaining 12% that showed statistically significant results, a strong negative association predominated,

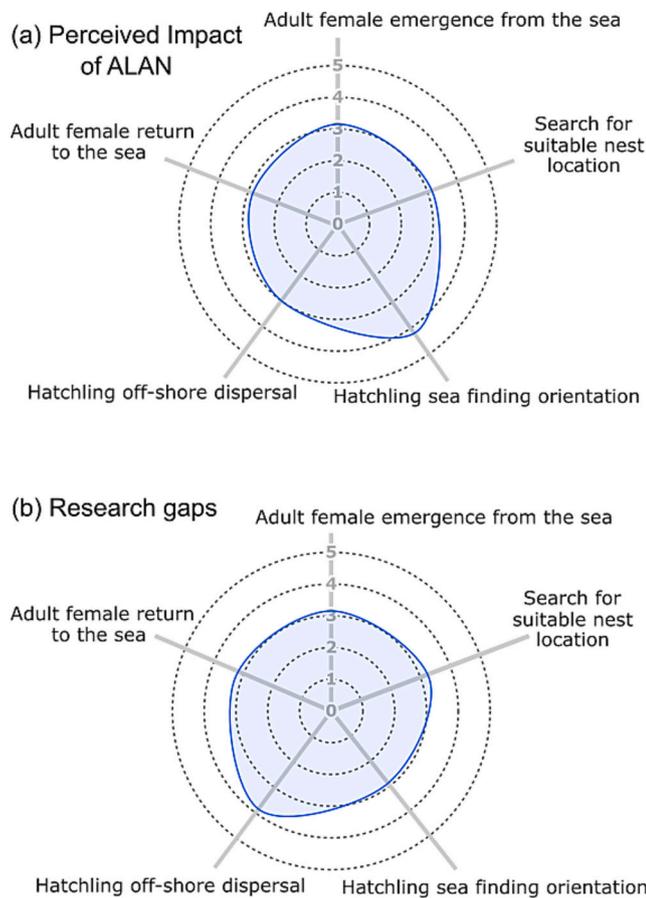


Fig. 2. Evaluation of the (a) perceived impacts of ALAN and (b) associated research gaps on sea turtle nesting sites and nearby marine environment (1 = negligible and 5 = severe).

indicating substantial disagreement among experts.

## 4. Discussion

### 4.1. Baseline information for ALAN and sea turtles

Artificial light at night (ALAN) has emerged as a pervasive anthropogenic driver of ecological change in coastal ecosystems (Gaston et al., 2021; Tidau et al., 2021; Stanton and Cowart, 2024). However, its effects on Mediterranean Sea turtles remain insufficiently characterized and have been circumstantially translated into management, systematic monitoring, or conservation practices. (Peters and Verhoeven, 1994; Turkozian, 2000; Rees, 2005; Margaritoulis et al., 2025). Our expert survey across 16 Mediterranean countries confirmed broad recognition of ALAN as a threat, with most respondents rating impacts on reproductive output as high or severe and emphasizing the urgent need for standardized monitoring protocols. More than 80% indicated that they had never applied a standardized monitoring protocol, either at sea or on nesting beaches, regarding ALAN effects on sea turtles. Recent reviews of research trends and conservation priorities indicate that ALAN is understudied compared to other threats (Robinson et al., 2023), despite being ranked as a high conservation priority in some regions (Rees et al., 2016; Fuentes et al., 2023). In the Mediterranean, ALAN has been previously identified as a significant threat requiring conservation focus (Casale et al., 2018; Peregrym et al., 2020a), but only a moderate amount of knowledge is currently available (Marsili et al., 2025). Globally, knowledge on ALAN impacts remains concentrated on *Caretta caretta* and *Chelonia mydas*, the two species that nest widely in the Mediterranean, and is heavily biased toward regions such as North

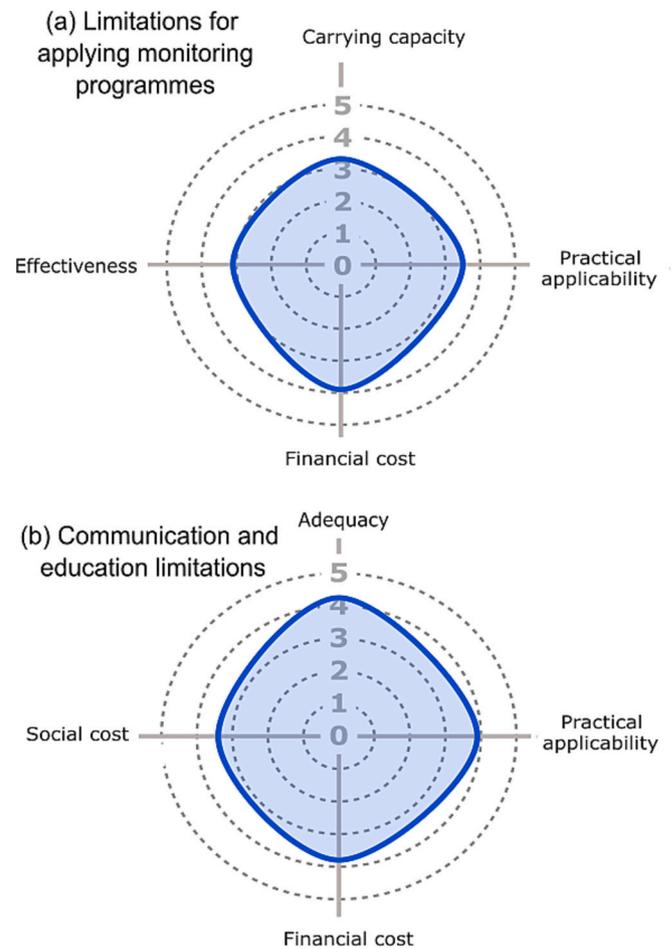
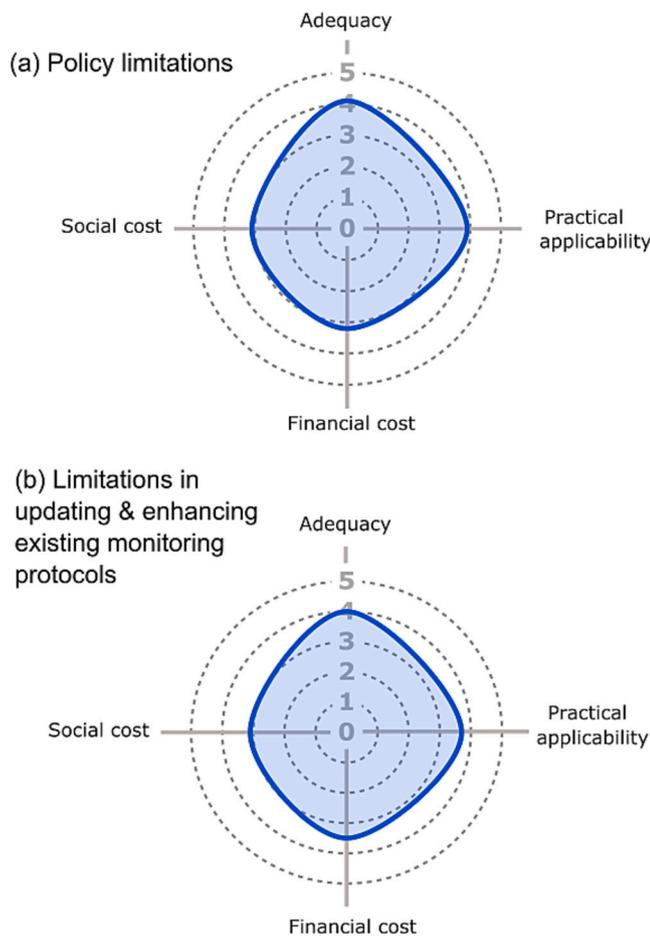


Fig. 3. Evaluation of perceived limitations related to ALAN issues focusing in applying (a) monitoring, (b) communications and education programmes on sea turtle nesting sites and nearby marine environment (1 = negligible and 5 = severe) (e.g. adequacy: completeness, suitability, and operational fitness of existing frameworks; carrying capacity: expertise and equipment constraints; practical applicability: ease of use during implementation; financial cost: affordable to implement and maintain over time; Social cost: the extent of negative impacts on communities, lifestyles, or social acceptance).

America and Australia (Robinson et al., 2023; Gomez Isaza et al., 2025). This geographic and taxonomic imbalance underscores the importance of synthesizing Mediterranean perspectives, given the basin's dense overlap of nesting habitats with some of the world's most intensively developed and illuminated coastlines (Piante and Ody, 2015; Falchi et al., 2016; Polinov, 2023).

### 4.2. Life-stage-specific impacts at nesting and nearshore habitats

Our findings indicate that hatchlings are perceived to be the life stage most vulnerable to ALAN, particularly during the sea-finding phase on the beach and, to a lesser extent, during the frenzy period of nearshore dispersal to open ocean waters. Exposure to artificial light during these critical windows results in high rates of disorientation, exhaustion and prolonged residence in predator-rich coastal waters (Lorne and Salmon, 2007; Thums et al., 2016). Such outcomes compromise recruitment, population resilience and may have population-level consequences when compounded across nesting cohorts (Dimitriadis et al., 2018). Adults were evaluated as less sensitive but not immune to ALAN, as illumination can deter nesting on bright beaches, modify nest site selection, and reduce reproductive output (Silva et al., 2017; Hu et al., 2018). Despite their importance, the effects of ALAN on nesting site selection and offshore dispersal remain underexplored (Price et al.,



**Fig. 4.** Evaluation of perceived limitations to ALAN issues focusing to (a) policy and (b) the update and enhancement of existing monitoring protocols for sea turtle nesting sites and nearby marine environment (1 = negligible and 5 = severe) (e.g. adequacy: completeness, suitability, and operational fitness of existing frameworks; practical applicability: ease of use during implementation; financial cost: affordable to implement and maintain over time; Social cost: the extent of negative impacts on communities, lifestyles, or social acceptance).

2018). Our findings align with previous studies documenting life-stage-specific vulnerabilities to artificial lighting (Salmon, 2003; Thums et al., 2016; Silva et al., 2017), emphasizing the need for management strategies tailored to ontogenetic sensitivities.

Despite the substantial knowledge gaps regarding the impacts of ALAN across different life stages and nesting process phases identified in this study, the Mediterranean represents a high-risk scenario. Coastal development, tourism, industrial activities, and urban lighting collectively intensify ALAN pressures in nearshore zones, rendering the region a potential hotspot for light-induced ecological disruption (Biddiscombe et al., 2020). Expansion of ALAN could increase the proportion of illuminated beaches, including within protected areas, eroding the effectiveness of conservation designations or plans for MPA expansion (Kamrowski et al., 2014; Davies et al., 2016). While estimates of exposure to ALAN in regions such as Brazil and the United States range from 60% to 98% of nesting sites (Fuentes et al., 2016; Colman et al., 2020), comparable data for the Mediterranean are limited to the main *Chelonia mydas* nesting areas, where approximately 65% of nests occur on beaches influenced by ALAN (Leader et al., 2024). However, in the Mediterranean context, major nesting rookeries are situated near densely populated and tourism-developed coastlines (Casale et al., 2018), suggesting that even modest increases in lighting could affect a disproportionately large share of regional nesting populations.

#### 4.3. Knowledge gaps and monitoring limitations

Despite significant advances in sea turtle research over recent decades (Mazaris et al., 2017) and evidence of population rebounds worldwide (Hays et al., 2025), several uncertainties limit the translation of scientific knowledge into conservation practice. One of the most striking gaps identified herein is that ALAN assessments are rarely integrated into monitoring plans, and standardized protocols are consistently absent, particularly across wide spatial scales encompassing all life stages and nesting locations and across temporal coverage throughout the nesting period and across nesting seasons. Salmon and Witherington (1995) proposed a standardized protocol—the fan mapping method—along with threshold criteria to systematically evaluate disrupted hatchling sea-finding orientation using directional data (Kamrowski et al., 2015). To date, only a single study has been published that applied this protocol in the Mediterranean to quantify ALAN effects on hatchlings (Dimitriadis et al., 2018). This limited application highlights the urgent need for broader adoption of standardized monitoring protocols to generate comparable data across sites and seasons, a necessary approach for monitoring all anthropogenic threats (Casale et al., 2025).

Financial constraints were identified as the primary barrier to implementing ALAN monitoring programs, limiting both spatial and temporal coverage. Additional challenges, related to communication, education, updating protocols, and policy uptake, stemmed from inadequate resources, knowledge, tools, and institutional frameworks, followed by practical applicability issues. Funding constraints primarily affect the operational level of sea turtle monitoring and conservation programs across Mediterranean countries, where financial support is often inconsistent and fragmented. Core activities are frequently carried out by NGOs, research institutions, and local conservation groups that rely on short-term project grants, intermittent EU funding instruments, and limited private foundation support, rather than stable national budget allocations (Casale et al., 2018). The extent of funding gaps varies geographically, with generally stronger institutional backing in several EU Member States and more limited, less structured, and non-targeted mechanisms in a number of non-EU Mediterranean countries (Mazaris et al., 2023). Legislative and policy frameworks likewise differ substantially between EU and non-EU jurisdictions, including African and Asian countries, reflecting a heterogeneous regional governance landscape rather than a uniform regulatory framework. Yet, at a policy level, laws, standards, and codes regulating ALAN in marine environments are rare globally, with uptake in Mediterranean conservation programs being particularly limited (Rees et al., 2016). Further research gaps include the impacts of skyglow on hatchlings, physiological consequences of misorientation, and the identification of light mitigation measures effectiveness (Tidau et al., 2021; Gomez Isaza et al., 2025). Taken together, all these limitations reduce the effectiveness of mitigation efforts and hinder the generation of standardized, decision-relevant data.

#### 4.4. Conservation priorities and mitigation strategies

Maintaining naturally dark coastal habitats remains the most effective safeguard against the impacts of artificial light at night (ALAN) (Rivas et al., 2015; Peregrym et al., 2020a). Experts have emphasized the need to update monitoring programs to incorporate ALAN parameters and to minimize light exposure on nesting beaches. This objective can be achieved through the implementation of targeted management measures, including the installation of shielding structures, the use of downward-directed and long-wavelength lighting, the elimination of superfluous light sources, the regulation of illumination intensity to essential levels, and the establishment of shaded transit corridors for hatchlings (Salmon, 2003; Di Bari et al., 2023). The integration of advanced technologies and nature-based solutions into conservation interventions was also identified as a priority. Such measures may



**Fig. 5.** Ranking and grouping of the importance of strategies and mitigation measures for ALAN effects on sea turtles with color differentiation based on the 25th (lower than 25th colored yellow) and 75th (higher than 75th colored red) percentile (1 = negligible and 5 = severe). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

involve the use of automated lighting systems triggered by the movement of vehicles or people at night, as well as the restoration of sand dune systems and coastal vegetation to reduce light dispersion (Pendoley and Kamrowski, 2015; Simantiris et al., 2025). Policy reform, public awareness campaigns, and scenario-based coastal planning were considered relevant but of moderate priority, indicating that practical, site-based interventions may provide the most immediate conservation benefits (Kamrowski et al., 2014). Integrating ALAN considerations into marine protected area (MPA) management and coastal spatial planning is equally critical, particularly given that nearly one-third of MPAs globally already experience nighttime illumination (Davies et al., 2016). Recent advances in remote sensing and real-time light mapping offer promising opportunities to monitor illumination dynamics and to assess the effectiveness of mitigation measures (Falchi et al., 2016; Stare and Kyba, 2019; Caruana et al., 2020). Another important finding highlighted in our study was the considerable lack of convergence among experts regarding the scoring of light impact mitigation measures. This divergence in expert opinions likely reflects broader uncertainties within the scientific and management communities. In particular, it may be attributed to the limited understanding of the actual ecological impacts of light pollution across the Mediterranean region and the scarcity of empirical assessments evaluating the effectiveness of mitigation strategies on nesting beaches and adjacent nearshore habitats. These gaps, as identified in our study, underscore the need for region-specific, evidence-based research to inform adaptive management frameworks and guide the prioritization of effective ALAN mitigation actions.

Several limitations of the study must be acknowledged. First, a

potential source of bias may originate from the disproportionate representation of researchers compared to managers among the expert respondents. As a result, expert perceptions may have been skewed toward issues related to research, knowledge gaps, and inconsistencies in translating scientific findings into management practices. Yet, the relatively modest sample size, although spanning 16 Mediterranean countries, may limit the generalizability of rankings for specific strategies and mitigation measures, reflecting fine-scale variability in perceptions or local context. Future research should prioritize empirical quantification of ALAN impacts across multiple life stages, map vulnerable to ALAN areas, standardize monitoring protocols and ALAN intensity measurements, rigorously assess the effectiveness of mitigation interventions under field conditions, and investigate skyglow impacts and the physiological consequences of disorientation (Gomez Isaza et al., 2025).

#### 4.5. Synthesis and implications

Taken together, our results emphasize that ALAN is an established (Leader et al., 2024) but under-addressed threat to Mediterranean sea turtles, with disproportionate impacts on hatchling survival and recruitment. Conservation efforts are currently hampered by gaps in monitoring, methodological limitations, and limited policy uptake. Addressing these challenges requires a dual approach: a) advancing empirical research to resolve gaps and limitations, and b) scaling up evidence-based mitigation at nesting and nearshore habitats. Switching off, dimming, or shielding lights, preserving naturally dark landscapes,

and limiting ecologically harmful spectra have been suggested as practical measures to reduce artificial light exposure (Gaston et al., 2013; Davies et al., 2014; Peregrym et al., 2020b). Implementing these strategies will not only safeguard regional sea turtle populations but also confer broader ecological benefits for a wide range of species and habitats (Marangoni et al., 2022), while simultaneously providing a globally relevant framework for managing ALAN in other coastal ecosystems.

### CRediT authorship contribution statement

**Charalampos Dimitriadis:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nikolaos Simantiris:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Fulvio Maffucci:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Mustapha Aksissou:** Writing – review & editing, Investigation. **Moulood Benabdi:** Writing – review & editing, Investigation. **Piero Carlino:** Writing – review & editing, Investigation. **Paolo Casale:** Writing – review & editing, Investigation. **Simon Demetropoulos:** Writing – review & editing, Investigation. **Wayne J. Fuller:** Writing – review & editing, Investigation. **Marc Girondot:** Writing – review & editing, Investigation. **Brendan J. Godley:** Writing – review & editing, Investigation. **Abdulmaula Hamza:** Writing – review & editing, Investigation. **Imed Jribi:** Writing – review & editing, Investigation. **Yakup Kaska:** Writing – review & editing, Investigation. **Yaniv Levy:** Writing – review & editing, Investigation. **Jonathan R. Monsinjon:** Writing – review & editing, Investigation. **Ayse Oruc:** Writing – review & editing, Investigation. **Aliki Panagopoulou:** Writing – review & editing, Investigation. **Vilma Pirolì:** Writing – review & editing, Investigation. **Alan F. Rees:** Writing – review & editing, Investigation. **Jesús Tomás:** Writing – review & editing, Investigation. **Oguz Turkozan:** Writing – review & editing, Investigation. **Sandra Hochscheid:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonios D. Mazaris:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

### 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.

### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2026.119476>.

### Data availability

Data will be made available on request.

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