Journal of Coastal Conservation (2025) 29:31
https://doi.org/10.1007/s11852-025-01117-x

# Monitoring the conservation status of sea turtle nesting sites: expert knowledge and quantitative indicators

Paolo Casale[1,2] · Thomas Arapis[3] · Simona A. Ceriani[4] · Erdal Elginoz[5] · Wayne Fuller[6] · Yakup Kaska[7,8] · Tonya M. Long[9] · Maria A. Marcovaldi[10] · Dimitris Margaritoulis[3] · Ayşe Oruç[11] · Alexsandro Santos[10] · Doğan Sözbilen[8,12] · Panagiota Theodorou[3]

Received: 18 August 2023 / Revised: 3 February 2025 / Accepted: 8 June 2025


## Abstract

Coastal habitats are key for many species of conservation concern, but they face increasing anthropogenic threats. Sea turtles rely on sandy beaches for egg incubation, which are increasingly degraded, leading to growing conservation issues. Disagreements on the conservation status and the required conservation actions can arise between conservationists and stakeholders due to the lack of objective evaluations. The first objective of this study is to provide a formal analysis of the potential and limitations of the most common indicators, such as anthropogenic threats and conservation measures, that are human-related. Thirty-six variables describing threats and conservation measures were scored and analyzed for 37 turtle nesting sites in five countries (Brazil, Cyprus, Greece, Türkiye and USA). Results show that monitoring the conservation status of a nesting site is challenging, especially if based only on human-related indicators or on the number of egg clutches deposited (the most common turtle-related indicator). Results highlight the importance of local community attitude and legal protection, that may interact in very different ways, as shown by examples from the five countries considered in this study. Ultimately, only turtle-related indicators can provide information on the impact of anthropogenic threats on the number and sex of hatchlings entering the sea. Therefore, the second objective of this study is to provide, in a single document, the necessary information for an effective monitoring of hatching production in relation to anthropogenic threats. To this aim, we review and propose a set of the 12 most feasible quantitative indicators of six biological variables.

**Keywords** Anthropogenic threats · Coastal development · Enforcement · Local community · Legal protection · Stakeholder engagement

✉ Paolo Casale
paolo.casale@unipi.it

[1] Department of Biology, University of Pisa, Via A. Volta 6, Pisa 56126, Italy

[2] Marine Vertebrate Research Institute, Via A. Calderara 29, Roma 00125, Italy

[3] ARCHELON, the Sea Turtle Protection Society of Greece, Solonos 113, Athens GR- 10678, Greece

[4] Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue Southeast, St. Petersburg, FL 33701, USA

[5] Ulupinar Environmental Protection, Development and Management Cooperative, 07980 Çıralı, Kemer, Antalya, Türkiye, Turkey

[6] Faculty of Veterinary Medicine, Near East University, Nicosia, Cyprus

[7] Department of Biology, Faculty of Science, Pamukkale University, Denizli, Türkiye, Turkey

[8] Sea Turtle Research, Rescue and Rehabilitation Center (DEKAMER), Pamukkale University, Denizli, Türkiye, Turkey

[9] Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 19100 SE Federal Hwy, Tequesta, FL 33469, USA

[10] Fundação Projeto Tamar, Rua Rubens Guelli, 134, sala 307, Salvador CEP 41815-135, Bahia, Brazil

[11] WWF-Türkiye (Doğal Hayatı Koruma Vakfı, 136 Kat 4 Beyoğlu, İstanbul, Türkiye, Turkey

[12] Department of Veterinary, Acıpayam Vocational School, Pamukkale University, Denizli, Türkiye, Turkey

Published online: 16 June 2025

## Introduction

Coasts are impacted by development due to increasing human utilization (increasing human population and/or wealth) (Seto et al. 2012) and are threatened by predicted sea level rise due to climate change (Noss 2011; Mills et al. 2016; Silva et al. 2020). They represent unique ecosystems and host key habitats for species of conservation concern like sea turtles, that depend on sandy beaches for egg incubation (Miller 1997). Sea turtle nesting beaches are becoming increasingly degraded due to direct exploitation (e.g. sand mining, harbours) or by human utilization for leisure, leading to growing conservation issues (Lutcavage et al. 1997; Chan et al. 2007; Lopez et al. 2015; Casale et al. 2018; Nelson Sella and Fuentes 2019; Van De Geer et al. 2022).

At several major sea turtle nesting beaches, specific long-term conservation programs have been established to counteract anthropogenic threats such as habitat degradation, disturbance, light pollution and anthropophilic predators (Yerli 1996; Marcovaldi and dei Marcovaldi 1999; Rees 2005; Kaska et al. 2010; Ehrhart et al. 2014; Ergene et al. 2016; Chattopadhyay et al. 2018; Colman et al. 2020; Sönmez et al. 2021; de Castilhos et al. 2022). Great attention is given by individuals, NGOs, and governmental bodies to the conservation status of sea turtle nesting sites. In some cases, conservationists and other stakeholders may disagree on the conservation status and the required conservation actions (Sloan et al. 1994), and the intervention of authorities (local, national, supranational) is solicited. For instance, the Bern Convention (Convention on the conservation of European wildlife and natural habitats; Council of Europe) has a mechanism to monitor conservation issues which have arisen through complaints and to provide recommendations to the Contracting Parties (national authorities). This mechanism has been successful in initiating conservation action by the national authorities in various instances (e.g., Zakynthos, Greece; Dimopoulos 2001). However, four out of the five case files currently active in three Mediterranean countries (Cyprus, Greece and Türkiye), have remained open for more than 10 years (since 1986–2012; https://www.coe.int/en/web/bern-convention/active-cases) and this suggests that finding solutions to close these case files is difficult and protracted. The annual reports by complainants and governments show that the conservation status of sea turtle nesting sites is perceived differently by these two parties, with complainants claiming a worse conservation status than governments, also because of the lack of objective evaluations.

Therefore, objectively assessing the conservation status of a sea turtle nesting beach is pivotal for proper discussions among interested parties and for authorities to monitor the situation. However, the status of a sea turtle nesting site is difficult to assess. How to evaluate the effects of anthropogenic factors on sea turtle habitats (including nesting sites) was listed among the research priorities for sea turtle conservation but remains the least investigated topic (Rees et al. 2016). The most common indicators used for this purpose can be classified into two categories: human-related indicators (i.e., resulting from human activities: level of anthropogenic threats and of conservation measures) and turtle-related indicators (i.e., resulting from turtle biological processes, often limited to the number of clutches laid). Quantitative measures (Bell et al. 2007) are difficult to obtain and arbitrary scores are more common in such assessments (Varela-Acevedo et al. 2009; McLachlan et al. 2013; Flores-Monter et al. 2015; Garcin et al. 2022). If the human impact on a sea turtle population is of interest, then the effect of anthropogenic threats on the value of a nesting site for the wider population– in terms of reproductive success of nesters - should be considered (Dutton and Squires 2011). Nesting sites have a very specific role in sea turtle biology and hence in sea turtle conservation: they are the only habitat where new individuals can develop. Moreover, the beach environment (incubation temperature) determines the sex of the hatchlings (Ackerman 1997). In other words, the role of one nesting site is to contribute– with other nesting sites– to the production of individuals of both sexes recruiting to the population at sea. While the presence of potential threats is a reason for concern, how much they impact a sea turtle population cannot be known without assessing the biological output of a nesting site in terms of production of new individuals of both sexes. The same applies to the effects of conservation measures.

While the concepts outlined above are widely recognized as important for effective sea turtle conservation, they are not necessarily implemented in practice at every sea turtle nesting site around the world that receive conservation attention. Additionally, these concepts have not yet been synthesized in a single document. This study aims to fill this gap by providing conservationists and decision-makers with a comprehensive synthesis of sea turtle conservation at nesting sites through two specific objectives and approaches. In the first objective (#1) we use expert elicitation to investigate potential relationships between conservation status descriptors and conservation measures. Through this investigation, we will gain valuable insights into the value of using such an approach in terms of monitoring indicators. This objective is pursued through an analytical formalization of basic indicators and expert knowledge. The second objective (#2) aims to provide a monitoring scheme that focuses on measured biological indicators to track interannual changes in the impacts of anthropogenic threats and conservation measures at a sea turtle nesting site. This objective is based on available knowledge and methods. Overall, our study contributes to an important aspect of sea turtle conservation by providing a practical synthesis of key concepts and offering recommendations for effective monitoring and management of sea turtle nesting sites.

## Materials and methods

Only the methods based on expert knowledge (Objective #1) are described in this section. The theoretical development of a monitoring scheme based on scientific information (Objective #2) is presented in the Discussion section.

To provide indications about the conservation measures that contribute more to the perceived conservation status of a nesting site two groups of variables were set up, totalling 36 variables (Fig. 1, supplementary Table S1). A group of 12 response variables define the current conservation status in terms of threats and a group of 23 explanatory variables explain the current conservation status in terms of conservation measures, including 12 variables about legislation (and its enforcement) specifically targeting the 12 threats. One additional variable (trend in clutch numbers) was also included in the last group because it is commonly used as a proxy for the conservation status. This is the only variable that is specific for a sea turtle species. The 12 threat variables were also grouped into three higher level variables (Overall conservation status, Habitat degradation, Habitat use), for a total of 15 response variables (Fig. 1). The 24 explanatory variables were also grouped into six higher level variables (Economic interest in development, Economic interest in turtles, Protection through general or other local legislation, Protection through legislation focused on habitat degradation, Protection through legislation focused on habitat use, Protection by field conservation projects), for a total of 30 explanatory variables (Fig. 1).

These variables were scored for each of 37 nesting sites in Brazil, Cyprus, Greece, Türkiye and USA (supplementary Table S2)), selected to cover a wide range of conservation status ("good" and "bad") and different socio-economic contexts. However, they cannot possibly cover the entire spectrum of the variety of local contexts occurring worldwide and therefore this exercise does not aim to be representative of all contexts. Scores were given to each variable based on 12 authors' expert knowledge, an approach used in many cases where quantitative measures are not available or feasible (e.g., Wallace et al. 2011; McLachlan et al. 2013; Nelson Sella et al. 2019). All these nesting sites are frequented by loggerhead turtles (exclusively or with other species) and only this species was considered for the variable describing trend in clutch numbers. Independently of how the variable was named/described, higher score values always meant a condition beneficial for conservation (for instance, high and low "Habitat destruction" were scored as 1 and 3, respectively). Variables of the "Anthropogenic threats" group were scored from 1 (high) to 4 (none). Variables of the "Protection through legislation" group (that included enforcement in their definition) were scored from 0 (no legislation) to 3 (high). Variables of the "Protection by field conservation projects" group were scored from 0 (not applicable) to 3 (high). All the other variables were scored from 1 to 3. In a few cases where information was not available, a score 2 was given as a neutral value.

The relation between anthropogenic threats (response variables, defining the conservation status) and conservation measures (explanatory variables, explaining the conservation status) was investigated through a Bayesian ordinal mixed-effects model fitted using brms function (package brms) in R (R Development Core Team 2022) incorporating monotonic effects for ordinal predictors and with the country/territory as a random factor accounting for possible legislative or cultural differences among countries. Three sets of models were run, with different levels of aggregation of the fundamental variables (Fig. 1), for a total of 15 models. The first set included 12 models, one for each of the 12 fundamental response variables ($RV_i$, with $i = 1$ to 12) (anthropogenic threats), where the explanatory variables (EV) (conservation measures) included one explanatory variable about legislation ($EVL_i$, targeting the same threat $i$ of the response variable) and the other 11 explanatory variables (not legislation): $RV_i \sim EVL_i + EV_1 + \ldots + EV_{11}$. The second set included two models, one for each of the two aggregated response variables (Habitat degradation, Habitat use), with the corresponding explanatory variable related to legislation (Legislation on Habitat degradation or on Habitat use) and the other six explanatory variables (Trends in clutch numbers, Remoteness, Economic interest in development, Economic interest in turtles, Protection by field conservation projects, Local community supportive attitude): $RV \sim EVL + EV_1 + \ldots + EV_6$. The third set included one model, with one aggregated response variable (Overall conservation status) and seven aggregated explanatory variables (Trends in clutch numbers, Remoteness, Economic interest in development, Economic interest in turtles, Protection through general or other local legislation, Protection by field conservation projects, Local community supportive attitude): $RV \sim EV_1 + \ldots + EV_7$.

## Results

Only the results of the expert knowledge exercise (Objective #1) are provided in this section. The monitoring scheme based on scientific information and developed as part of Objective #2 is presented in the Discussion section.

| Explanatory variables / Response variables | **Overall conservation status** | **Habitat degradation** | Habitat destruction | Obstacles to sea level rise adaptation | Constructions on or close to the beach | Constructions in the adjacent marine area | **Habitat use** | Vehicles on the beach | Beach use daylight | Beach use night | Light pollution | Pollution | Recreational boats & water sports | Fishing close to shore | Predation by anthropophilic species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trend in clutch numbers** | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| **CONSERVATION FACTORS** | | | | | | | | | | | | | | | |
| Remoteness | + | + | + | ns | + | + | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| **Economic interest in development** | ns | ns | | | | | ns | | | | | | | | |
| Tourism (recreational acitivities) | | | - | - | - | ns | | ns | - | - | ns | ns | ns | ns | + |
| Other (not tourism) | | | ns | ns | ns | ns | | ns | ns | ns | ns | ns | ns | ns | ns |
| **Economic interest in turtles** | ns | ns | | | | | ns | | | | | | | | |
| on the beach | | | ns | ns | ns | ns | | ns | ns | ns | - | ns | ns | ns | ns |
| in water | | | ns | ns | ns | ns | | ns | ns | ns | ns | ns | ns | ns | ns |
| **Protection through general or other local legislation** | ns | | | | | | | | | | | | | | |
| **Legislation on Habitat degradation** | | ns | | | | | | | | | | | | | |
| Habitat destruction | | | ns | | | | | | | | | | | | |
| Obstacles to sea level rise adaptation | | | | ns | | | | | | | | | | | |
| Constructions on or close to the beach | | | | | ns | | | | | | | | | | |
| Constructions in the adjacent marine area | | | | | | ns | | | | | | | | | |
| **Legislation on Habitat use** | | | | | | | ns | | | | | | | | |
| Vehicles on the beach | | | | | | | | + | | | | | | | |
| Beach use daylight | | | | | | | | | ns | | | | | | |
| Beach use night | | | | | | | | | | + | | | | | |
| Light pollution | | | | | | | | | | | ns | | | | |
| Pollution | | | | | | | | | | | | + | | | |
| Speed boats & water sports | | | | | | | | | | | | | ns | | |
| Fishing close to shore | | | | | | | | | | | | | | + | |
| Predation by anthropophilic species | | | | | | | | | | | | | | | + |
| **Protection by field conservation projects** | ns | ns | | | | | ns | | | | | | | | |
| Public awareness | | | ns | ns | ns | ns | | + | ns | ns | ns | + | ns | ns | ns |
| Nest protection by structures | | | ns | ns | ns | ns | | ns | ns | ns | ns | ns | ns | ns | ns |
| Nest protection by presence | | | ns | ns | ns | ns | | - | ns | ns | ns | - | ns | ns | + |
| Management of the hatching phase | | | ns | ns | ns | ns | | ns | - | ns | ns | ns | ns | ns | ns |
| Promotion of light pollution minimization | | | + | - | - | ns | | ns | ns | ns | ns | ns | ns | ns | ns |
| **Local community supportive attitude** | + | ns | + | + | + | ns | + | ns | ns | + | + | ns | ns | ns | ns |

**Fig. 1** Results of 15 Bayesian ordinal mixed-effects models investigating the relationship between 12 anthropogenic threats (response variables) and 24 conservation factors (explanatory variables) at 37 nesting sites in Cyprus, Greece, Türkiye, Brazil and Florida (USA). More description of the variables is provided in supplementary Table S1. Non-significant relationships (where Bayesian 95% CIs did not include 0) are indicated by "ns". Significant relationships are indicated by "+" or "-" if explanatory variables showed a positive or negative effect, respectively, in terms of conservation (i.e. they are higher/lower at sites with lower/higher levels of threats). To this aim, the sign of "Economic interest" variables is here reversed from the real model outputs to be more intuitive

The relationship among potential conservation measures and descriptors of conservation status about 37 sea turtle nesting sites is provided in Fig. 1. Local community attitude and remoteness were the explanatory variables with a positive significant effect on the highest number of response variables. Remoteness had a positive relationship with three individual variables in the Habitat degradation group (habitat destruction and construction on the beach and on the adjacent marine area) (Fig. 1), i.e. these threats occurred less at remote sites. Local community supportive attitude had a positive relationship with five individual variables, three in the Habitat degradation group (Habitat destruction, Obstacles to sea level rise adaptation, Construction on the beaches) and two in the Habitat use group (beach use at night, light pollution) (Fig. 1), i.e. these threats occurred less at sites with a local community with a supportive attitude. Individual variables belonging to the group "Protection by field conservation projects" showed both positive and negative relationships with some individual response variables (Fig. 1). Economic interest in touristic development showed a negative effect, in terms of conservation status, on several variables (Habitat destruction, Obstacles to sea level rise adaptation, Construction on the beaches, and Beach use in daylight and night) while a positive effect on Predation (i.e. predation is lower with interest in development). No effects were detected for economic interest in development other than tourism Trends in clutch numbers were not significantly related to any conservation status descriptors.

## Discussion

### Indicators based on expert knowledge (Objective #1)

The results of the approach based on expert knowledge show that the relationship between conservation measures and general or specific descriptors of conservation status in terms of anthropogenic threats occurring at a sea turtle nesting site is not obvious. Therefore, monitoring the evolution of the conservation status of a nesting site may be difficult if based only on such information. This could lead to different interpretations among different stakeholders, general misunderstandings and ultimately hinder a prompt reaction to a deterioration or improvement in conservation status.

Of the explanatory factors considered, the presence of human aggregations near the nesting area (explanatory variable Remoteness) and their attitude towards sea turtles (explanatory variable Local community supportive attitude) showed important general and specific relations with threats. The positive effect of remoteness is rather obvious and the pivotal role of local communities in sea turtle conservation is a well-known topic (Campbell 2003; Witherington 2003; Ferraro and Gjertsen 2009; Senko et al. 2011; Liu 2017; Tognin et al. 2019; Elginoz et al. 2022). Such strong results from these two explanatory variables also represent a sort of validation of the formalization adopted.

As also expected, the level of legal protection and its enforcement appear to affect the level of impact of anthropogenic threats, at least for some threats related to habitat use. Economic interest in development related to tourism shows a negative effect in terms of a few specific threats (Habitat destruction, Obstacles to sea level rise adaptation, Constructions on or close to the beach, Beach use), while no effects are observed for the economic interest in sea turtles. Results about field conservation projects are less clear and even counterintuitive in some cases. A possible interpretation is that more field activities are undertaken as the anthropogenic impact increases, resulting in the observed negative relationship. (Fig. 1; Table 1). In other words, field conservation projects would be the effect, and not the cause, of the threat level.

The most common variable mentioned in sea turtle nesting site assessments (trend of clutch counts) showed no relation with anthropogenic threats.

In conclusion, although a few explanatory variables show a relationship with threats that suggests an intuitive cause-effect relationship, other relationships are less intuitive, and no single variable seems to be a reliable indicator to monitor interannual changes of the impact of anthropogenic threats. This applies also to clutch counts, the main (if not the only in many areas) biological indicator used.

### Interaction among conservation measures, legislation and local community attitude in different contexts

The above results support the importance of remoteness, local communities and legal protection for the conservation of nesting sites. While the way remoteness can favour conservation is rather intuitive, legal protection and local community attitude may interact in complex and subtle ways that may change with the specific context. Examples of how the interaction among conservation measures, legislation and local community attitude can vary according to different contexts are summarized below for the five countries considered in this study (see Supplementals for more details).

Brazil hosts major sea turtle nesting sites that were historically overexploited for meat, eggs, and cultural practices (Marcovaldi and dei Marcovaldi 1999). With the prohibition of turtle meat/egg harvesting and decades of conservation by Projeto Tamar, populations have rebounded (e.g., Marcovaldi and Chaloupka 2007; de Castilhos et al. 2022). A key factor in Projeto Tamar's success is the creation of

**Table 1** Summary of the relationship among anthropogenic threats and biological variables at sea turtle nesting sites and their possible indicators. Quantitative indicators of effects of anthropogenic threats: HD (human density), BW (beach width), SC (sand color), BP (beach profile), OD (obstacle density), LP (light pollution). Indicators of turtle variables (see text for details): C (number of clutches), NS (nesting success), HS (hatching success), ES (emergence success), PC (predation rate on clutches), PH (predation rate on hatchlings), E (entrapment), OI (orientation index), T (incubation temperature), ID (incubation duration), G (gonad inspection), H (hormone level of hatchlings). *Useful only in particular cases, see text. References, 1: Dugan and Hubbard (2006); 2: miller (2003); Karavas et al. (2005); mazaris et al. (2006); serafini et al. (2009); Kelly et al. (2017); Fujisaki et al. (2018); halls and Randall (2018); Siqueira-Silva et al. (2020); 3: mazaris et al. (2009); 4: Tuttle and rostal (2010); Rizkalla and Savage (2011); Limpus et al. (2020); 5: Foley et al. (2000); Oz et al. (2004); Foley et al. (2006); Martins et al. (2022); 6: fish et al. (2008); Lyons et al. (2020); 7: Peters et al. (1994); 8: McGehee (1990); ackerman (1997); Speakman et al. (1998); 9: Witherington (1992); Kaska et al. (2010); price et al. (2018); 10: Silva et al. (2017); 11: Witherington and Martin (2000); salmon (2006); Lorne and salmon (2007); Erb and Wyneken (2019); 12: Witherington et al. (2011); Fujisaki and lamont (2016) margaritoulis (2005); González et al. (2020); ware and Fuentes (2020); 13: margaritoulis (2005); Kaska et al. (2010); 14: Kaska (2000); Oz et al. (2004); 15: Triessnig et al. (2012); Van de Merwe et al. (2012); 16: Jensen et al. (2018); 17: Lyons et al. (2020)

| Anthropogenic threats | | | Biological variables and indicators | | | | |
|---|---|---|---|---|---|---|---|
| Type | Possible effects | Quantitative indicators of effects | Nesting Success or Clutch number* | Incubation Success | Surfacing Success | Beach Survival | Sex Ratio |
| Habitat degradation | | | | | | | |
| Habitat destruction (e.g. sand mining, flattening of dunes, building on dunes, erosion, heavy machinery)<br>Obstacles (e.g. walls) to sea level rise adaptation (landwards beach shift)<br>Constructions on or close to the beach (e.g. buildings, roads, seasonal facilities, parking areas) | Reduction of nesting area, also for the effect of hard constructions (1), alteration of beach profile and sand composition: Different nest distribution (2). Reduced reproductive success (3). Increased risk of washing over (4). Potential effect on in-nest mortality and sex ratio (5). Impediment to sea level rise adaptation (6). Reduced in-nest survival (7). Altered incubation environment (8) | HD, BW, SC, BP | NS (C) | HS | ES | | T, G,H, ID |
| Constructions in the adjacent marine area (e.g. harbours, breakwaters) | Potential effects on currents or factors affecting nesting site selection by females | | NS (C) | | | | |
| Climate change (warming, sea level rise) | Reduction of nesting area (17). Feminization (16). | BW, BP | | | | | T, G,H, ID |
| **Habitat use** | | | | | | | |
| Vehicles on the beach | Sand compaction may affect incubation | | | HS | ES | | |
| Beach use daylight (furniture, human presence) | Sand compaction and shadow may affect incubation and sex ratio. Furniture left in place at night may affect nesting activity (12) | HD, OD | NS (C) | HS | ES | | T, G,H, ID |
| Beach use night (human presence, noise, campfires, beach parties) | Disturbance of the nesting phase (13). Damage of eggs. | HD | NS (C) | | | | |
| Light pollution | Different nest distribution (9). Disturbance of the nesting phase and increase of predation on hatchlings (10). Mis- and disorientation increase hatchling mortality (11). | LP | NS (C) | | | OI | |
| Pollution (e.g. oil, litter, trash) | Effects on incubation and entrapment on the beach. | | NS (C) | HS | ES | E | T, G,H, ID |
| Recreational boats | Disturbance of adult females. | | NS (C) | | | | |
| Fishing close to shore | Adult female mortality | | C | | | | |
| Predation by anthropophilic species (e.g. canids, rats) | Predation on eggs and hatchlings. Differential predation of nests with different sex ratio and alteration of sex ratio of predated nests (14) | | | PC, HS | PC, ES | PH | PC, T,G, H, ID |

alternative livelihoods for coastal communities, such as T-shirt manufacturing groups (da Silva et al. 2015; Tognin et al. 2019). Outside legally protected areas, awareness campaigns focus on reducing light pollution by awarding symbolic certificates to property owners who adopt turtle-friendly lighting measures, greatly reducing hatchling disorientation (da Silva et al. 2015).

Along the northern coast of Cyprus, over 30 years of cooperation between the Environmental Protection Department (EPD) and the Society for the Protection of Turtles (SPOT) have fostered strong local support for sea turtle conservation along the northern coast of Cyprus. Collaborations with businesses, notably a beach restaurant at Alagadi, show how community members help clear beaches at night to protect nesting turtles. Extensive stakeholder consultations led to the establishment of Special Environmental Protected Areas (SEPAs), resulting in positive trends in clutch numbers (Fuller et al. 2010, 2011; Omeyer et al. 2021). SPOT's long-term work with fishers has also reduced bycatch and prompted fisher engagement in research (Snape et al. 2013).

Florida is home to one of the world's largest loggerhead nesting aggregations (Ceriani et al. 2019) yet faces challenges from intensive coastal development and tourism. Conservation is guided by federal, state, and local regulations, with the Florida Fish and Wildlife Conservation Commission (FWC) overseeing sea turtle programs. Model lighting ordinances address light pollution, while the Coastal Construction Control Line regulates development near nesting beaches. Ordinance enforcement varies by municipality, but education and outreach have encouraged residents and tourists to comply. Around 3,000 FWC-authorized individuals collect turtle data annually, making Florida a prominent example of large-scale citizen science.

Greece supports the most significant share of Mediterranean loggerhead clutches (Casale et al. 2018), yet economic interests have sometimes led to local resistance against centrally imposed policies. The NGO ARCHELON has implemented long-term nesting protection and public awareness efforts, collaborating with tourism businesses, fishers and authorities since the 1980s. Early initiatives reduced intentional turtle killings (Margaritoulis et al. 1992), and management plans crafted with stakeholders have been voluntarily adopted (Irvine et al. 1998); Panagopoulou and Dimopoulos 2003). Memoranda of Understanding with fisher associations (Margaritoulis et al. 2007) further strengthened cooperation, while recent programs encourage local communities and citizens to monitor and protect sporadic nesting.

Türkiye is a key Mediterranean region for both loggerhead and green turtles, with 22 nesting beaches covered by international conventions and national legislation. Dalyan beach demonstrates successful long-term conservation, involving nighttime beach closures and active monitoring (Türkozan and Kaska 2010). Initiatives such as the "Turtle Friendly Stakeholder" certification enhance collaboration between hotels and NGOs (Kaska, Y. Pers. Com.). In areas like Fethiye, rapid development and beach furniture pose challenges, though local NGOs work to mitigate impacts (Başkale et al. 2016, 2018). By contrast, sites like Çıralı benefit from strong partnerships among local authorities, WWF-Türkiye, and community cooperatives (Sönmez et al. 2021).

## Measured indicators to improve assessment and monitoring of the conservation status of a sea turtle nesting site (Objective #2)

The results of the approach based on expert knowledge show the challenges of assessing and monitoring the conservation status of a sea turtle nesting site. Such a task is challenging or may even provide misleading results if based purely on anthropogenic factors (threats or conservation measures). If the ultimate interest is assessing the impact of anthropogenic threats on sea turtles, biological sea turtle indicators directly affected by the specific threats would represent a clearer picture. Unfortunately, the most common sea turtle indicator (number of clutches) is not useful in this respect, as shown by the present results and by previous studies (Bell et al. 2007). The number of clutches laid at a nesting site (C) is primarily due to factors occurring at sea (e.g. food availability in feeding areas, mortality at sea) or to the number of hatchlings born decades ago (i.e. a period equal to the age of turtle sexual maturity) that return as adults to their natal beach to reproduce. It may also be affected by factors acting at the nesting site, if they induce the female to lay all or part of her clutches elsewhere. However, with moderate disturbing factors, the female might still lay the clutch in another part of the same nesting site, with no effect on the total number of clutches laid in the overall nesting site. Such a situation can be detected through monitoring the nesting success (NS, proportion of number of clutches on the total number of emergences), although even this variable may not be affected by coastal development (Bell et al. 2007). Both C and NS require classification of emergences as with or without a clutch, either from the visual examination of the track or by assessing the presence of eggs (Demetropoulos and Hadjichristophorou 1995; Florida Fish and Wildlife Conservation Commission 2016).

Ultimately, the measure of success of a sea turtle nesting site is the number of hatchlings entering the sea and their sex ratio, although land-based threats may also have an effect on hatchlings after they enter the sea (e.g., Lorne and Salmon 2007). Therefore, in principle, the negative impact of anthropogenic threats could be measured in terms of their effect on these two biological variables. While sex ratio

(SR) is a fundamental variable (cannot be broken down), the number of individuals entering the sea (N) results from the combination of six variables: N=C*CS*F*IS*SS*BS, where C is the number of clutches laid at the nesting site, CS is the average clutch size (number of eggs per clutch), F is the average fertility (proportion of fertile eggs on the total CS), IS is the average incubation success (proportion of fertile eggs that hatch), SS is the average surfacing success (proportion of hatchlings that emerge at beach surface), and BS is the average beach survival (proportion of emerged hatchlings that enter the sea). As said, C is primarily affected by factors at sea, and changes in NS are expected to be detected before changes of C, therefore NS is a valuable variable to monitor too. CS and F are entirely due to factors not acting at the nesting site (on land). IS, SS, BS and SR are entirely due to factors acting at the nesting site (on land). Therefore, six primary biological variables (C, NS, IS, SS, BS and SR) should be considered for monitoring the conservation status of a nesting site. However, IS and SS can be estimated only if F is estimated too, which is challenging (Phillott and Godfrey 2020). The two alternative variables commonly measured in sea turtle nesting studies are hatching success (HS; proportion of hatched eggs to total eggs laid) and emergence success (ES; proportion of hatchlings that emerge on the beach surface to the total eggs laid) (Florida Fish and Wildlife Conservation Commission 2016; Ceriani et al. 2021). They incorporate F (HS=F*IS; ES=F*IS*SS) and therefore can be seen as a proxy of IS and SS if F is assumed to be constant. BS is very difficult to estimate (Brost et al. 2015) and is affected by several factors acting synergically. The main mortality factors are predation and, if the hatchling cannot reach the sea, dehydration (especially during the next daylight) (Witherington and Martin 2000; Salmon 2006; Lorne and Salmon 2007; Erb and Wyneken 2019). Disorientation by light pollution (Salmon 2006) and entrapment by anthropogenic obstacles (e.g., debris or ditches) (Triessnig et al. 2012; van de Merwe et al. 2012) can considerably increase the time spent on the beach and therefore can increase these mortality factors. Therefore, BS could be monitored through three main direct or indirect indicators: predation rate of hatchling on the beach (PH) (Erb and Wyneken 2019), orientation index (OI) (Dimitriadis et al. 2018; Hirama et al. 2021) and rate of entrapment (E) (Triessnig et al. 2012; van de Merwe et al. 2012). SR can be investigated through direct or indirect methods such as gonad examination (Kaska et al. 2006), blood sampling for hormone levels (Tezak et al. 2020), incubation temperature during the thermosensitive period of development (when temperature affects the embryo's sex) (Rees and Margaritoulis 2004; Kaska et al. 2006; Fuentes et al. 2017) and incubation duration (ID) (Mrosovsky et al. 1999; Zbinden et al. 2007; Margaritoulis et al. 2022).

The six biological variables above (through their proxies or indicators), could inform about the impact of specific anthropogenic threats if these threats are also monitored and the two sets of variables are analyzed together. To our knowledge, such a comprehensive monitoring scheme is not currently available in a form useful to conservationists and decision makers. To this aim, we provide here (Table 1) a summary of the 13 main anthropogenic threats affecting a sea turtle nesting site and the relationship among these threats (some with possible quantitative indicators) and the six turtle variables (with 12 possible quantitative indicators).

## Conclusions and recommendations

To assess and monitor the conservation status of a sea turtle nesting site, the assessment of human-related indicators is important and can be improved if all the main anthropogenic threats are considered and measured in a quantitative way as well as the level of engagement of local communities. However, ultimately only turtle-related indicators can inform about the real impact of anthropogenic threats on turtles. We recommend to (i) identify the nesting sites that currently benefit from the effect of remoteness and monitor the evolution of human aggregations in the area and their attitude towards sea turtles, because it will probably anticipate conservation issues and could prompt early implementation of conservation measures; (ii) define the conservation status in terms of trend of hatchling and sex ratio production instead of anthropogenic factors or clutch counts; (iii) collect the necessary data or use existing data to monitor the conservation status of nesting sites through quantitative indicators of anthropogenic threats and of a comprehensive set of biological variables used to estimate hatchling productivity and sex ratio. To this aim, we provided here a set of the most feasible indicators for sea turtle nesting site monitoring.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s11852-025-01117-x.

**Acknowledgements** We thank the following organizations and individuals for their direct or indirect contributions to this study. The many ARCHELON field leaders and volunteers for their devoted work in collecting data for many years. The Department of Environmental Protection, the Society for the Protection of Turtles, and Karsiyaka Turtle Watch, based in northern Cyprus. The Fundação Projeto Tamar team contributed to the implementation of sea turtle conservation actions in its monitoring area. All conservation actions in Brazil are part of the National Action Plan for the Conservation of Marine Turtles - PNA ICMBio/MMA, coordinated by the National Center for Marine Turtle Research and Conservation and East Marine Biodiversity - Centro Tamar/ICMBio. All data collected are under Sisbio License No. 42760 - Biodiversity Authorization and Information System of the Ministry of Environment (MMA) (Brazil). The coordinated network of Florida sea turtle permit holders that collect sea turtle nesting data under the authority of the Florida Fish and Wildlife Conservation Commission (FWC) for their dedication and effort on behalf of sea turtle conservation. The DEKAMER field leaders and volunteers for their hard work in collecting data for many years under the coordination of the Ministry of Environment, Urbanisation and Climate Change. M. Koperski (FWC) for sharing information and perspective on sea turtle conservation in Florida. R. Trindell (FWC) for early input on the matrix of variables. This study benefited from funding from the Bern Convention of the Council of Europe to the Marine Vertebrate Research Institute. The opinions and concepts expressed in this study are the responsibility of the authors and do not necessarily reflect the views of the Council of Europe.

**Authors contribution** Conceptualization: PC. Methodology: TA, EE, WF, YK, DM, AO, DS, PT. Formal analysis: PC. Investigation: TA, SAC, EE, WF, YK, TML, MAM, DM, AO, AS, DS, PT. Writing - Original Draft: PC. Writing - Review & Editing: TA, SAC, EE, WF, YK, TML, MAM, DM, AO, AS, DS, PT. Supervision: PC.

**Funding** No funding was received to assist with the preparation of this manuscript.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

**Ethical approval** This study did not involve human participants or the use of live animals, and therefore did not require ethical approval.

## References

Ackerman RA (1997) The nest environment and the embryonic development of sea turtles. In: Lutz PL, Musick JA (eds) The biology of sea turtles. CRC Marine Science Series. CRC Press, Inc., Boca Raton, Florid, pp 83–106

Başkale E, Katilmiş Y, Azmaz M, Sözbilen D, Polat F, Lambropoulos M, Fellhofer-Mihcioğlu C, Stachowitsch M, Kaska Y (2016) Monitoring and conservation of loggerhead turtle's nests on fethiye beaches, Turkey. Biharean Biologist 10:20–23

Başkale E, Sözbilen D, Katılmış Y, Azmaz M, Kaska Y (2018) An evaluation of sea turtle strandings in the Fethiye-Göcek specially protected area: an important foraging ground with an increasing mortality rate. Ocean Coast Manag 154:26–33. https://doi.org/10.1016/j.ocecoaman.2018.01.003

Bell CD, Solomon JL, Blumenthal JM, Austin TJ, Ebanks-Petrie G, Broderick AC, Godley BJ (2007) Monitoring and conservation of critically reduced marine turtle nesting populations: lessons from the Cayman Islands. Anim Conserv 10:39–47. https://doi.org/10.1111/j.1469-1795.2006.00068.x

Brost B, Witherington B, Meylan A, Leone E, Ehrhart L, Bagley D (2015) Sea turtle hatchling production from Florida (USA) beaches, 2002–2012, with recommendations for analyzing hatching success. Endang Species Res 27:53–68. https://doi.org/10.3354/esr00653

Campbell LM (2003) Contemporary culture, use, and conservation of sea turtles Lutz, P L,Musick, J A, Wyneken, J Editors, The Biology of Sea Turtles Volume II CRC Marine Biology Series, CRC Press, Inc, pp Boca Raton, London, New York, Washington D.C. 455:2307–2338

Casale P, Broderick AC, Camiñas JA, Cardona L, Carreras C, Demetropoulos A, Fuller WJ, Godley BJ, Hochscheid S, Kaska Y, Lazar B, Margaritoulis D, Panagopoulou A, Rees AF, Tomás J, Turkozan O (2018) Mediterranean sea turtles: current knowledge and priorities for conservation and research. Endang Species Res 36:229–267. https://doi.org/10.3354/esr00901

Ceriani SA, Casale P, Brost M, Leone EH, Witherington BE (2019) Conservation implications of sea turtle nesting trends: elusive recovery of a globally important loggerhead population. Ecosphere 10. https://doi.org/10.1002/ecs2.2936

Ceriani SA, Brost B, Meylan AB, Meylan PA, Casale P (2021) Bias in sea turtle productivity estimates: error and factors involved. Mar Biol 168. https://doi.org/10.1007/s00227-021-03843-w

Chan SKF, Cheng IJ, Zhou T, Wang HJ, Gu HX, Song XJ (2007) A comprehensive overview of the population and conservation status of sea turtles in China. Chelonian Conserv Biol 6:185–198

Chattopadhyay N, Chetia A, Machahary K, Dupak O (2018) Assessment of conservation measures for Olive ridley sea turtle (Lepidochelys Olivacea) along Rushikulya rookery, Ganjam disrict, odisha, India. Int J Mar Biol Res 3:1–9

Colman LP, Lara PH, Bennie J, Broderick AC, de Freitas JR, Marcondes A, Witt MJ, Godley BJ (2020) Assessing coastal artificial light and potential exposure of wildlife at a National scale: the case of marine turtles in Brazil. Biodivers Conserv 29:1135–1152. https://doi.org/10.1007/s10531-019-01928-z

da Silva VRF, Mitraud SF, Ferraz MLCP, Lima EHSM, Melo MTD, Santos AJB, da Silva ACCD, de Castilhos JC, Batista JAF, Lopez GG, Tognin F, Thomé JC, Baptistotte C, da Silva BMG, Becker JH, Wanderline J, de Vasconcellos Pegas F, Róstan G, Dei Marcovaldi GG, Dei Marcovaldi MÂG (2015) Adaptive threat management framework: integrating people and turtles. Environ Dev Sustain. https://doi.org/10.1007/s10668-015-9716-0

de Castilhos J, Giffoni B, Medeiros L, Santos A, Tognin F, da Silva A, Oliveira F, Fonseca E, Weber M, de Melo A, de Abreu J, Marcovaldi M, Tiwari M (2022) Long-term of Olive ridley sea turtles (*Lepidochelys olivacea*) nesting in Brazil reveals one of the largest rookeries in the Atlantic. Herpetol Conserv Biol 17:593–601

Demetropoulos A, Hadjichristophorou M (1995) Manual on marine turtle conservation in the mediterranean. UNEP(MAP)SPA/IUCN/CWS/Fishery Department MANRE, Cyprus

Dimitriadis C, Fournari– Konstantinidou I, Sourbès L, Koutsoubas D, Mazaris AD (2018) Reduction of sea turtle population recruitment caused by nightlight: evidence from the mediterranean region. Ocean Coast Manag 153:108–115. https://doi.org/10.1016/j.ocecoaman.2017.12.013

Dimopoulos D (2001) The National marine park of zakynthos: a refuge for the loggerhead turtle in the mediterranean. Mar Turt Newsl 93:5–9

Dugan JE, Hubbard DM (2006) Ecological responses to coastal armoring on exposed sandy beaches. Shore Beach 74:10–16

Dutton PH, Squires D (2011) A holistic strategy for Pacific sea turtle conservation. In: Squires D (ed) Conservation and sustainable management of sea turtles in the Pacific. Ocean University of Hawaii, Honolulu, Hawaii, USA, pp 37–59

Ehrhart L, Redfoot W, Bagley D, Mansfield K (2014) Long-term trends in loggerhead (*Caretta caretta*) nesting and reproductive success at an important Western Atlantic rookery. Chelonian Conserv Biol 13:173–181

Elginoz E, Sonmez B, Ilgaz M, Altinkaya H (2022) Local effort to the conservation of loggerhead sea turtles: results of 2021 monitoring study on Çıralı beach. Mediterranean Turt Bull 1:24–28

Erb V, Wyneken J (2019) Nest-to-surf mortality of loggerhead sea turtle (*Caretta caretta*) hatchlings on Florida's east coast. Front Mar Sci 6. https://doi.org/10.3389/fmars.2019.271

Ergene S, Ergene M, Ucar AH, Aymak C, Kaçar Y (2016) Identification of a new nesting beach in mersin, turkey: nesting activity of green and loggerhead sea turtles over 6 nesting seasons (2009–2014) at davultepe beach. Mar Turt Newsl 149:6–9

Ferraro PJ, Gjertsen H (2009) A global review of incentive payments for sea turtle conservation. Chelonian Conserv Biol 8:48–56

Fish MR, Cote IM, Horrocks JA, Mulligan B, Watkinson AR, Jones AP (2008) Construction setback regulations and sea-level rise: mitigating sea turtle nesting beach loss. Ocean Coastal Manage 51:330–341. https://doi.org/10.1016/j.ocecoaman.2007.09.002

Flores-Monter YM, Aceves-Quesada JF, García-Romero A, Peters Recagno EM (2015) Multi-criteria analysis of the potential impact of tourism on nesting sea turtles in chalacatepec, Jalisco. Nova Scientia 7:644–673. https://doi.org/10.21640/ns.v7i14.117

Florida Fish and Wildlife Conservation Commission (2016) Marine Turtle ConservationHandbook. https://myfwc.com/license/wildlife/marine-turtle-permit/

Foley AM, Peck SA, Harman GR, Richardson LW (2000) Loggerhead turtle (*Caretta caretta*) nesting habitat on low-relief Mangrove Islands in Southwest Florida and consequences to hatchling sex ratios. Herpetologica 56:433–445

Foley AM, Peck SA, Harman GR (2006) Effects of sand characteristics and inundation on the hatching success of loggerhead sea turtle (Caretta caretta) clutches on low-relief Mangrove Islands in Southwest Florida. Chelonian Conserv Biol 5:32–41

Fuentes MMPB, Monsinjon J, Lopez M, Lara P, Santos A, dei Marcovaldi MAG, Girondot M (2017) Sex ratio estimates for species with temperature-dependent sex determination differ according to the proxy used. Ecol Model 365:55–67. https://doi.org/10.1016/j.ecolmodel.2017.09.022

Fujisaki I, Lamont MM (2016) The effects of large beach debris on nesting sea turtles. J Exp Mar Biol Ecol 482:33–37. https://doi.org/10.1016/j.jembe.2016.04.005

Fujisaki I, Lamont M, Carthy R (2018) Temporal shift of sea turtle nest sites in an eroding barrier Island beach. Ocean Coast Manag 155:24–29. https://doi.org/10.1016/j.ocecoaman.2017.12.032

Fuller W, Yalinca G, Seffer J, Stanova V, Ozden Ö, Hessenberg C, Kara C (2010) Management Plan for Akdeniz SEPA. Technical Assistance for Management and Protection of Potential Natura 2000 Sites in the Northern Part of Cyprus 389:89

Fuller W, Seffer J, Ozden Ö, Sefferova V, Dogan O, Stritih J, Kara C (2011) Management Plan for Alagadi SEPA. Technical Assistance for Management and Protection of Potential Natura 2000 Sites in the Northern Part of Cyprus 389:89

Garcin M, Vende-Leclerc M, Read T, Oremus M, Bourgogne H (2022) Assessment method of the sea turtle-nesting habitat of small reef Islands. J Coastal Conserv 26:1–13

González JM, Anastácio R, Lizárraga-Cubedo HA, Pereira MJ (2020) *Caretta caretta* nesting activity on Akumal beaches. Mexico Sci Rep 10. https://doi.org/10.1038/s41598-020-60018-1

Halls JN, Randall AL (2018) Nesting patterns of loggerhead sea turtles (*Caretta caretta*): development of a multiple regression model tested in North carolina, USA. Can Hist Rev 7. https://doi.org/10.3390/ijgi7090348

Hirama S, Witherington B, Kneifl K, Sylvia A, Wideroff M, Carthy R (2021) Environmental factors predicting the orientation of sea turtle hatchlings on a naturally lighted beach: A baseline for light-management goals. J Exp Mar Biol Ecol 541. https://doi.org/10.1016/j.jembe.2021.151568

Irvine CW, Belalides T, Siori I (1998) Management policies for the conservation of the nesting habitat of *Caretta caretta* on the island of Crete, Greece. In: Epperly SP, Braun J (eds) Proceedings of the Seventeenth Annual Sea Turtle Symposium. NOAA Tech Memo. NMFS-SEFSC-415, pp 201–203

Jensen MP, Allen CD, Eguchi T, Bell IP, LaCasella EL, Hilton WA, Hof CAM, Dutton PH (2018) Environmental warming and feminization of one of the largest sea turtle populations in the world. Curr Biol 28:154–159e154. https://doi.org/10.1016/j.cub.2017.11.057

Karavas N, Georghiou K, Arianoutsou M, Dimopoulos D (2005) Vegetation and sand characteristics influencing nesting activity of *Caretta caretta* on Sekania beach. Biol Conserv 121:177–188. https://doi.org/10.1016/j.biocon.2004.04.017

Kaska Y (2000) Predation pattern of loggerhead and green turtle nests in the Eastern mediterranean and its possible effect on sex ratio. Isr J Zool 46:343–349

Kaska Y, Ilgaz C, Ozdemir A, Baskale E, Turkozan O, Baran I, Stachowitsch M (2006) Sex ratio estimations of loggerhead sea turtle hatchlings by histological examination and nest temperatures at fethiye beach. Turk Naturwissenschaften 93:338–343. https://doi.org/10.1007/s00114-006-0110-5

Kaska Y, Başkale E, Urhan R, Katılmış Y, Gidiş M, Sarı F, Sözbilen D, Canbolat AF, Yılmaz F, Barlas M, Özdemir N, Özkul M (2010) Natural and anthropogenic factors affecting the nest-site selection of loggerhead turtles, *Caretta caretta*, on dalaman-sarıgerme beach in south-west turkey: (Reptilia: Cheloniidae). Zool Middle East 50:47–58. https://doi.org/10.1080/09397140.2010.10638411

Kelly I, Leon JX, Gilby BL, Olds AD, Schlacher TA (2017) Marine turtles are not fussy nesters: A novel test of small-scale nest site selection using structure from motion beach terrain information. PeerJ 2017 https://doi.org/10.7717/peerj.2770

Limpus CJ, Miller JD, Pfaller JB (2020) Flooding-induced mortality of loggerhead sea turtle eggs. Wildl Res: - doi. https://doi.org/10.1071/WR20080

Liu TM (2017) Unexpected threat from conservation to endangered species: reflections from the front-line staff on sea turtle conservation. J Environ Planning Manage 1–17. https://doi.org/10.1080/09640568.2016.1273824

Lopez GG, Saliés EC, Lara PH, Tognin F, Marcovaldi MA, Serafini TZ (2015) Coastal development at sea turtles nesting ground: efforts to Establish a tool for supporting conservation and coastal management in Northeastern Brazil. Ocean Coast Manag 116:270–276. https://doi.org/10.1016/j.ocecoaman.2015.07.027

Lorne JK, Salmon M (2007) Effects of exposure to artificial lighting on orientation of hatchling sea turtles on the beach and in the ocean. Endang Species Res 3:23–30

Lutcavage ME, Plotkin P, Witherington BE, Lutz PL (1997) Human impacts on sea turtle survival. In: Lutz PL, Musick JA (eds) The biology of sea turtles. CRC Press, Inc., Boca Raton, Florida, pp 387–409

Lyons MP, von Holle B, Caffrey MA, Weishampel JF (2020) Quantifying the impacts of future sea level rise on nesting sea turtles in the southeastern united States. Ecol Appl Doi. https://doi.org/10.1002/eap.2100

Marcovaldi MA, Chaloupka M (2007) Conservation status of the loggerhead sea turtle in brazil: an encouraging outlook. Endang Species Res 3:132–143

Marcovaldi MA, dei Marcovaldi GG (1999) Marine turtles of brazil: the history and structure of Projeto TAMAR-IBAMA. Biol Conserv 91:35–41

Margaritoulis D (2005) Nesting activity and reproductive output of loggerhead sea turtles, *Caretta caretta*, over 19 seasons (1984–2002) at Laganas bay, zakynthos, greece: the largest rookery in the mediterranean. Chelonian Conserv Biol 4:916–929

Margaritoulis D, Kousias N, Nicolopoulou G, Teneketzis K (1992) Incidental catch of sea turtles in Greece: the case of Lakonikos Bay. In: Salmon M, Wyneken J (eds) Proceedings of the Eleventh Annual Workshop on Sea Turtle Biology and Conservation. NOAA Tech. Mem. NMFS-SEFSC-302, pp 168–170

Margaritoulis D, Koutsodendris A, Panagopoulou A (2007) Fisheries interactions with marine turtles. In: Papaconstantinou C, Zenetos A, Vassilopoulou V, Tserpes G (eds) State of Hellenic fisheries. Hellenic Centre for Marine Research Publ., Athens, Greece, pp 279–286

Margaritoulis D, Lourenço G, Riggall TE, Rees AF (2022) Thirty-eight years of loggerhead turtle nesting in Laganas bay, zakynthos, greece: a review. Chelonian Conserv Biol 21:143–157

Martins S, Patino–Martinez J, Abella E, de Santos Loureiro N, Clarke LJ, Marco A (2022) Potential impacts of sea level rise and beach flooding on reproduction of sea turtles. Clim Change Ecol 3:100053. https://doi.org/10.1016/j.ecochg.2022.100053

Mazaris AD, Matsinos YG, Margaritoulis D (2006) Nest site selection of loggerhead sea turtles: the case of the Island of zakynthos, W Greece. J Exp Mar Biol Ecol 336:157–162. https://doi.org/10.1016/j.jembe.2006.04.015

Mazaris AD, Matsinos G, Pantis JD (2009) Evaluating the impacts of coastal squeeze on sea turtle nesting. Ocean Coastal Manage 52:139–145. https://doi.org/10.1016/j.ocecoaman.2008.10.005

McGehee MA (1990) Effects of moisture on eggs and hatchlings of loggerhead sea turtles (*Caretta caretta*). Herpetologica: 251–258

McLachlan A, Defeo O, Jaramillo E, Short AD (2013) Sandy beach conservation and recreation: guidelines for optimising management strategies for multi-purpose use. Ocean Coastal Manage 71:256–268

Miller JD (1997) Reproduction in sea turtles. In: Lutz PL, Musick JA (eds) The biology of sea turtles. CRC Marine Science Series, CRC Press, Inc., Boca Raton, Florida, pp 51–81

Miller JDL, J.Godfrey C (2003) M. H. Nest Site Selection, Oviposition, Eggs, Development, Hatching, and Emergence of Loggerhead Turtles. In: Bolten AB, Witherington B (eds) Loggerhead Sea Turtles, pp 125–143

Mills M, Leon JX, Saunders MI, Bell J, Liu Y, O'Mara J, Lovelock CE, Mumby PJ, Phinn S, Possingham HP (2016) Reconciling development and conservation under coastal squeeze from rising sea level. Conserv Lett 9:361–368

Mrosovsky N, Baptistotte C, Godfrey MH (1999) Validation of incubation duration as an index of the sex ratio of hatchling sea turtles. Can J Zool 77:831–835

Nelson Sella KA, Fuentes MMPB (2019) Exposure of marine turtle nesting grounds to coastal modifications: implications for management. Ocean Coast Manag 169:182–190. https://doi.org/10.1016/j.ocecoaman.2018.12.011

Nelson Sella KA, Sicius L, Fuentes MMPB (2019) Using expert elicitation to determine the relative impact of coastal modifications on marine turtle nesting grounds. Coast Manage 47:492–506. https://doi.org/10.1080/08920753.2019.1642176

Noss RF (2011) Between the devil and the deep blue sea: florida's unenviable position with respect to sea level rise. Clim Change 107:1–16

Omeyer LCM, Stokes KL, Beton D, Çiçek BA, Davey S, Fuller WJ, Godley BJ, Sherley RB, Snape RTE, Broderick AC (2021) Investigating differences in population recovery rates of two sympatrically nesting sea turtle species. Anim Conserv. https://doi.org/10.1111/acv.12689

Oz M, Erdogan A, Kaska Y, Dusen S, Aslan A, Sert H, Yavuz M, Tunc MR (2004) Nest temperatures and sex-ratio estimates of loggerhead turtles at Patara beach on the Southwestern Coast of Turkey. Can J Zool 82:94–101. https://doi.org/10.1139/z03-200

Panagopoulou A, Dimopoulos D (2003) Five years of implementing management policies for the protection of sea turtles on Crete: an evaluation. In: Seminoff JA (ed) Proceedings of the Twenty-Second Annual Symposium on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-503, pp 108–109

Peters A, Verhoeven KJF, Strijbosch H (1994) Hatching and emergence in the Turkish mediterranean loggerhead turtle, *Caretta caretta*: natural causes for egg and hatching failure. Herpetologica 50:369–373

Phillott AD, Godfrey MH (2020) Assessing the evidence of 'infertile' sea turtle eggs. Endang Species Res 41:329–338. https://doi.org/10.3354/esr01032

Price JT, Drye B, Domangue RJ, Paladino FV (2018) Exploring the role of artificial lighting in loggerhead turtle (*Caretta caretta*) nest-site selection and hatchling disorientation. Herpetol Conserv Biol 13:415–422

R Development Core Team (2022) R: A Language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria

Rees AF (2005) ARCHELON, the sea turtle protection society of greece: 21 years studying and protecting sea turtles. Testudo 6:32–50

Rees AF, Margaritoulis D (2004) Beach temperatures, incubation durations and estimated hatchling sex ratio for loggerhead sea turtle nests in Southern kyparissia Bay. Greece Testudo 6:23–36

Rees AF, Alfaro-Shigueto J, Barata PCR, Bjorndal KA, Bolten AB, Bourjea J, Broderick AC, Campbell LM, Cardona L, Carreras C, Casale P, Ceriani SA, Dutton PH, Eguchi T, Formia A, Fuentes MMPB, Fuller WJ, Girondot M, Godfrey MH, Hamann M, Hart KM, Hays GC, Hochscheid S, Kaska Y, Jensen MP, Mangel JC, Mortimer JA, Naro-Maciel E, Ng C, Nichols WJ, Phillott AD, Reina RD, Revuelta O, Schofield G, Seminoff JA, Shanker K, Tomás J, van de Merwe JP, Van Houtan KS, Vander Zanden HB, Wallace BP, Wedemeyer-Strombel KR, Work TM, Godley BJ (2016) Are we working towards global research priorities for management and conservation of sea turtles? Endang Species Res 31:337–382. https://doi.org/10.3354/esr00801

Richards SA (2005) Testing ecological theory using the information-theoretic approach: examples and cautionary results. Ecology 86:2805–2814

Rizkalla CE, Savage A (2011) Impact of seawalls on loggerhead sea turtle (*Caretta caretta*) nesting and hatching success. J Coast Res 27:166–173. https://doi.org/10.2112/jcoastres-d-10-00081.1

Salmon M (2006) Protecting sea turtles from artificial night lighting at florida's oceanic beaches. Ecol Consequences Artif Night Lighting: 141–168

Senko J, Schneller AJ, Solis J, Ollervides F, Nichols WJ (2011) People helping turtles, turtles helping people: Understanding resident attitudes towards sea turtle conservation and opportunities for enhanced community participation in Bahia magdalena, Mexico. Ocean Coastal Manage 54:148–157

Serafini TZ, Lopez GG, da Rocha PLB (2009) Nest site selection and hatching success of hawksbill and loggerhead sea turtles (Testudines, Cheloniidae) at Arembepe Beach, northeastern Brazil. Phyllomedusa: Journal of Herpetology 8: 03–17

Seto KC, Güneralp B, Hutyra LR (2012) Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc Natl Acad Sci 109:16083–16088

Silva E, Marco A, da Graça J, Pérez H, Abella E, Patino-Martinez J, Martins S, Almeida C (2017) Light pollution affects nesting behavior of loggerhead turtles and predation risk of nests and hatchlings. J Photochem Photobiol B 173:240–249. https://doi.org/10.1016/j.jphotobiol.2017.06.006

Silva R, Martínez ML, van Tussenbroek BI, Guzmán-Rodríguez LO, Mendoza E, López-Portillo J (2020) A framework to manage coastal squeeze. Sustainability 12:10610

Siqueira-Silva IS, Arantes MO, Hackradt CW, Schiavetti A (2020) Environmental and anthropogenic factors affecting nesting site selection by sea turtles. Mar Environ Res 162. https://doi.org/10.1016/j.marenvres.2020.105090

Sloan NA, Wicaksono A, Tomascik T, Uktolseya H (1994) Pangumbahan sea turtle rookery, java, indonesia: toward protection in a complex regulatory regime. Coast Manage 22:251–264

Snape RTE, Beton D, Broderick AC, Çiçek BA, Fuller WJ, Özden Ö, Godley BJ (2013) Strand monitoring and anthropological surveys provide insight into marine turtle bycatch in small-scale fisheries of the Eastern mediterranean. Chelonian Conserv Biol 12:44–55. https://doi.org/10.2744/ccb-1008.1

Sönmez B, Elginöz E, Ilgaz M, Altınkaya H (2021) Nesting activity of loggerhead turtles (2013–2020) and 20 years abundance trend (2001–2020) on Çıralı beach, Turkey. Reg Stud Mar Sci 44:101758. https://doi.org/10.1016/j.rsma.2021.101758

Speakman JR, Hays GC, Lindblad E (1998) Thermal conductivity of sand and its effect on the temperature of loggerhead sea turtle (*Caretta caretta*) nests. J Mar Biol Assoc UK 78:1337–1352

Teneketzis K, Margaritoulis D (2003) The involvement of local communities in sea turtle conservation: the case of Evrotas Delta, Lakonikos Bay, Greece. In: Margaritoulis D, Demetropoulos A (eds) Proceedings of the First Mediterranean Conference on Marine Turtles. Barcelona Convention - Bern Convention - Bonn Convention (CMS), Nicosia, Cyprus, pp 226–230

Tezak B, Sifuentes-Romero I, Milton S, Wyneken J (2020) Identifying sex of neonate turtles with Temperature-dependent sex determination via small blood samples. Sci Rep 10. https://doi.org/10.1038/s41598-020-61984-2

Tognin F, Ferraro LJ, Marcovaldi M (2019) Between cultural changes and the formations of ecological individuals: the tartarugueiros of Tamar Project. Revista Ecologias Humanas: 90–98

Triessnig P, Roetzer A, Stachowitsch M (2012) Beach condition and marine debris: new hurdles for sea turtle hatchling survival. Chelonian Conserv Biol 11:68–77

Türkozan O, Kaska Y (2010) Turkey. In: Casale P, Margaritoulis D (eds) Sea turtles in the mediterranean: distribution, threats and conservation priorities. IUCN, Gland, Switzerland, pp 257–293

Tuttle J, Rostal D (2010) Effects of nest relocation on nest temperature and embryonic development of loggerhead sea turtles (*Caretta caretta*). Chelonian Conserv Biol 9:1–7

Van De Geer CH, Bourjea J, Broderick AC, Dalleau M, Fernandes RS, Harris LR, Inteca GE, Kiponda FK, Louro CM, Mortimer JA (2022) Marine turtles of the African East coast: current knowledge and priorities for conservation and research. Endang Species Res 47:297–331

van de Merwe JP, West EJ, Ibrahim K (2012) Effects of off-road vehicle tyre Ruts on the beach dispersal of green sea turtle Chelonia mydas hatchlings. Endang Species Res 18:27–34

Varela-Acevedo E, Eckert KL, Eckert SA, Cambers G, Horrocks JA (2009) Sea turtle nesting beach characterization manual. Examining the Effects of Changing Coastline Processes on Hawksbilll Sea Turtle (*Eretmochelys imbricata*) Nesfing Habitat: 46–97

Wallace BP, DiMatteo AD, Bolten AB, Chaloupka MY, Hutchinson BJ, Abreu-Grobois FA, Mortimer JA, Seminoff JA, Amorocho D, Bjorndal KA, Bourjea J, Bowen BW, Duenas RB, Casale P, Choudhury BC, Costa A, Dutton PH, Fallabrino A, Finkbeiner EM, Girard A, Girondot M, Hamann M, Hurley BJ, Lopez-Mendilaharsu M, Marcovaldi MA, Musick JA, Nel R, Pilcher NJ, Troeng S, Witherington B, Mast RB (2011) Global conservation priorities for marine turtles. PLoS ONE 6:e24510. https://doi.org/10.1371/journal.pone.0024510

Ware M, Fuentes MMPB (2020) Leave no trace ordinances for coastal species management: influences on sea turtle nesting success. Endang Species Res 41:197–207. https://doi.org/10.3354/esr01020

Witherington BE (1992) Behavioral responses of nesting sea turtles to artificial lighting. Herpetologica: 31–39

Witherington BE (2003) Social and economic aspects of sea turtle conservation. In: Lutz PL, Musick JA, Wyneken J (eds) The biology of sea turtles volume II. CRC Marine Biology Series. CRC Press, Inc., Boca Raton, London, New York, Washington D.C., pp 355–384

Witherington BE, Martin RE (2000) Understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches. Florida Fish and Wildlife Conservation Commission. FMRI Technical Report TR-2

Witherington B, Hirama S, Mosier A (2011) Sea turtle responses to barriers on their nesting beach. J Exp Mar Biol Ecol 401:1–6. https://doi.org/10.1016/j.jembe.2011.03.012

Yerli SD (1996) F. Marine turtles in Turkey: A survey on nesting site status DHKD (Dogal Hayati Koruma Dernegi), CMS Rep No, pp 96/94, Istanbul; 1996, 1133 pp

Zbinden JA, Davy C, Margaritoulis D, Arlettaz R (2007) Large Spatial variation and female bias in the estimated sex ratio of loggerhead sea turtle hatchlings of a mediterranean rookery. Endang Species Res 3:305–312. https://doi.org/10.3354/esr00058