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Nesting Ecology and Anthropogenic Threats to Sea Turtles (*Caretta caretta*) Along the Northern Coast of Libya

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ABSTRACT

The nesting range of sea turtles has noticeably expanded in recent years, leading them into areas heavily influenced by human activities like fishing, maritime traffic, and operations from oil companies. Given that sea turtles exhibit no parental care, the choice of nesting sites becomes critical for their reproductive success. In 2025, A study was conducted on the nesting behaviors of loggerhead sea turtles (*Caretta caretta*) across 25 kilometer stretch along the Zueitina and Amerir Gabes coastline in northern Libya. The observed avoidance of re-nesting near the shoreline suggests an adaptive behavioral response to environmental stressors, particularly rising sea levels, while alternative nesting habitats might be available, human activities like egg harvesting and the use of fishing nets substantially increase mortality rates, exacerbating the decline of turtle populations, particularly on Zueitina beaches, remained unnoticed due to the lack of specific monitoring. This study represents a preliminary assessment and highlights the urgent need for long-term monitoring and conservation strategies along the Libyan coast.

بيئة التعشيش والتحديات البشرية للسلاحف البحرية *Caretta caretta* على طول الساحل الشمالي الليبي

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توسع نطاق تعشيش السلاحف البحرية بشكل ملحوظ في السنوات الأخيرة، ما دفعها إلى مناطق تتأثر بشدة بالأنشطة البشرية كالصيد وحركة الملاحة البحرية وشركات النفط. ونظراً لعدم إظهار السلاحف البحرية أي رعاية أبوية، يصبح اختيار مواقع التعشيش أمر بالغ الأهمية لنجاح تكاثرها. في عام 2025، تم إجراء دراسة حول سلوكيات التعشيش لدى السلاحف البحرية ضخمة الرأس (*Caretta caretta*) على امتداد 25 كيلومتر على طول ساحل الزويتينة وأميرير قابس شمال ليبيا. ويشير تجنب إعادة التعشيش بالقرب من الشاطئ إلى استجابة سلوكية تكيفية للضغوط البيئية، ولا سيما ارتفاع منسوب مياه البحر، ورغم توفر موائل تعشيش بديلة، إلا أن الأنشطة البشرية كجمع البيض واستخدام شباك الصيد تزيد بشكل كبير من معدلات النفوق، ما يفاقم انخفاض أعداد السلاحف، لا سيما على شواطئ الزويتينة، وهو أمر لم يرصد بسبب غياب المراقبة الدقيقة. تمثل هذه الدراسة تقييماً أولياً وتسليط الضوء على الحاجة الملحة إلى استراتيجيات الرصد والحفظ طويلة الأجل على طول الساحل الليبي.

INTRODUCTION

The shores of Zueitina and Amerir Gabes provide an ideal ecological environment for sea turtles to nest, offering sandy terrain and natural features that promote

biodiversity. Sea turtles are among the most crucial environmental creatures, serving as a vital link in coastal and marine ecosystems, contributing to the equilibrium of food chains and maintaining the health of coastal habitats (Islam, 2024; Ahmed and Tamim, 2025; Sobhana, 2025), their numbers are experiencing a significant decline due

to the impact of human activity and environmental threats. This study aims to outline four main factors that directly affect the outcome of sea turtle reproduction on beaches, the choice of suitable nesting sites away from human settlements, disruption of nests (Siqueira-Silva *et al.*, 2020), predation of turtle eggs (Butler *et al.*, 2020; Stokes *et al.*, 2024), and plastic debris from netting, which leads to the death of young turtles and adults (Wilcox *et al.*, 2018; Dayananda *et al.* 2025; Firouzi, 2025). The ecological impact of each factor is also presented, as well as field methods and proposed conservation measures to mitigate their harmful effects.

Importance of Selecting Suitable Nesting Sites

The selection of a nesting site represents a critical stage in the life cycle of sea turtles, the success of egg laying and hatching of young depends largely on beach characteristics such as beach width, sand composition, slope, and exposure to human disturbance (Cunha, 2021; Maurer, 2021). Quiet beaches, away from artificial lighting and pedestrians, provide stable thermal conditions, reducing the risk of nest destruction and increasing chick survival rates. Conversely, human presence near nesting sites causes several problems: foot traffic and sand compaction can damage the surface layer and destroy nests; nighttime lighting disrupts the landing and hatching paths of mothers; and beach activities (vehicles, tourism, infrastructure) reduce the available nesting space and alter the temperature and humidity conditions within nests (Quintana *et al.*, 2019). Therefore, conservation strategies require identifying protected nesting areas away from human settlements, establishing rules for light management, restricting beach activities during nesting seasons, and creating buffer zones to protect sensitive beaches. The beaches of Zueitina and Amerir Gabes feature soft, warm, and slightly humid sands, accompanied by gentle slopes and calm, subtly illuminated shores perfect conditions for sea turtles to nest.

Effects of Human Intervention on Nests

Disturbance of nests, whether for the purpose of collecting eggs for consumption, uncontrolled scientific intervention, or for entertainment, significantly reduces hatching rates. Any opening or movement of an egg alters the temperature and humidity balance within the nest and may expose the eggs to infection or heat shock (Ceolotto *et al.*, 2025). In addition, tampering increases the likelihood of egg predation because human left evidence makes nests more visible to predators (Topping and Valenzuela, 2021). From a scientific perspective, permissible interventions require strict protocols such as relocating nests only within approved rescue programs and under expert supervision, and accurately documenting temperature, depth, and angle of eggs during relocation to reduce mortality. Legal awareness and enforcement through penalties for tampering and enhanced community monitoring are essential tools for protecting nesting sites.

Plastic Pollution, Net Lines, and Their Deadly Impact

Plastic pollution poses one of the most serious contemporary threats to sea turtles. Net lines, broken fishing lines, and small pieces of plastic can entangle and stick to the body or limbs, leading to serious injury, deepening wounds, loss of swimming ability, and impaired feeding (Duncan *et al.*, 2021; Nelms *et al.*, 2016). For eggs and hatchlings, plastic fragments create a physical barrier on the beach that prevents hatchlings from emerging or alters the structure of the nest habitat, which can reduce humidity and affect the exchange of vital gases within the nest (Smith *et al.*, 2025). Proposed solutions include systematic beach clean-ups, the introduction of fishing waste management systems such as collection points for used nets feeding, the promotion of the use of environmentally friendly and compostable fishing gear, and regulatory policies that require manufacturers and marine professionals to adhere to responsible practices. Reeducation and awareness programs for fishermen and coastal residents also reduce the dumping of fishing waste at sea and increase the recovery rates of damaged fishing gear.

Sea turtle species face varying levels of threat due to habitat degradation and human-related activities, making nesting success vital for their survival. The Libyan coastline especially areas like Zueitina and Amerir Gabes, serves as significant nesting grounds for *C. caretta*, though these sites are still insufficiently studied. This study focuses on observing nesting and re-nesting behaviors, evaluating the effects of human interference, and offering strategies to enhance sea turtle conservation in the region.

MATERIALS AND METHODS

Study Area

The study was conducted on Zueitina Beach, a village northwest of Ajdabiya, which is home to one of Libya's oil export ports. The study also took place on Amerir Gabes Beach, a village west of Ajdabiya in eastern Libya on the Mediterranean coast. These areas represent natural nesting areas for *C. caretta*. The surveyed area spans about 25 km during the nesting season, with monitoring carried out over a three-month period in 2025. Both beaches are defined by sandy dune ridges next to human settlements. Zueitina beach is exposed to heavy human activity, whereas Amerir Gabes is noted for high sand accumulation. The overabundant and unnatural buildup of sand at Amerir Gabes was found to impede sea turtle movement, as females encounter difficulties traversing dense or unstable sand to reach suitable nesting sites.

Data Collection

From May to July 2025, daytime and nighttime surveys were conducted to record nesting events. Adult females were encountered during nesting attempts. The next sites

were plotted using GPS, and clutch characteristics were documented.

Threat Monitoring

Direct observations, photographic records, and reports from local fishermen were used to document human interference, nest predation, and turtle mortality. Instances of egg collection, nest destruction, and entanglement in fishing gear were recorded systematically.

Data Analysis

The distribution of nests was analyzed in relation to their proximity to the shore to assess nesting site preferences. Re-nesting behaviour was assessed during the same season. Mortality and disturbance rates were calculated as percentages of total nesting attempts.

RESULTS AND DISCUSSION

Nesting Distribution and Temporal Patterns

During the 2025 nesting season, a total of 24 nesting events of *C. caretta* females were recorded along Zueitina and Amerir Gabes. Zueitina beach accounted for 17 nests (71% of total nests) occurring in May and June, while Amerir Gabes beach had 7 nests (29%) recorded in July. This indicates a temporal and spatial shift in nesting activity, with Zueitina serving as the primary nesting site early in the season, and Amerir Gabes later (Fig.1).



Figure (1): Turtle buries its eggs in the sand, carefully covering them to ensure their safety.

Nesting Site Selection

GPS data showed that nests were strategically placed away from the immediate shoreline, suggesting an adaptive response to high tides and rising sea levels (Fig.2). At Zueitina nests clustered between 30°50'–31°06'N latitude and 20°02'–20°10'E longitude, mainly in areas with minimal human disturbance. At Amerir Gabes nests were located between 30°35'–30°36'N latitude and

19°49'–19°51'E longitude, where sand accumulation created natural obstacles for nesting females.



Figure (2): Destruction of sea turtle nests poses a serious threat to survival.

Female Morphometrics

The Straight Carapace Width (SCW) of nesting females ranged from 45–76 cm, and Curved Carapace Length (CCL) ranged from 65–96 cm. Larger females (CCL > 90 cm) tended to select higher, undisturbed nesting zones, while smaller females (CCL < 80 cm) often nested in mid beach areas. This pattern may reflect a strategy to maximize hatching success under varying environmental and anthropogenic pressures.

Mortality Patterns

A total of 6 adult female mortalities were recorded during the same season (20% of the total adult turtles observed). Zueitina Beach accounted for 4 mortalities (May–June), primarily large females (SCW 60–77 cm, CCL 82–90 cm). Amerir Gabes beach recorded 2 mortalities (July), smaller females (SCW 54–60 cm, CCL 70–80 cm). Field observations indicated that human interference (egg collection, nest disturbance) and entanglement in fishing gear or plastic debris were the main causes of death. Notably, the higher mortality rate at Zueitina aligns with its increased anthropogenic activity. Sea turtles on the beach present a striking contrast, some having successfully reached the shore, while others lie dead, in varying stages of decomposition. These visuals highlight the dual realities of natural nesting alongside mortality, much of which stems from human induced threats like plastic pollution (top left), bycatch, and the destruction of coastal habitats. Such field observations serve as crucial environmental indicators, playing an essential role in

biodiversity research and coastal management efforts aimed at safeguarding endangered species (Fig.3).

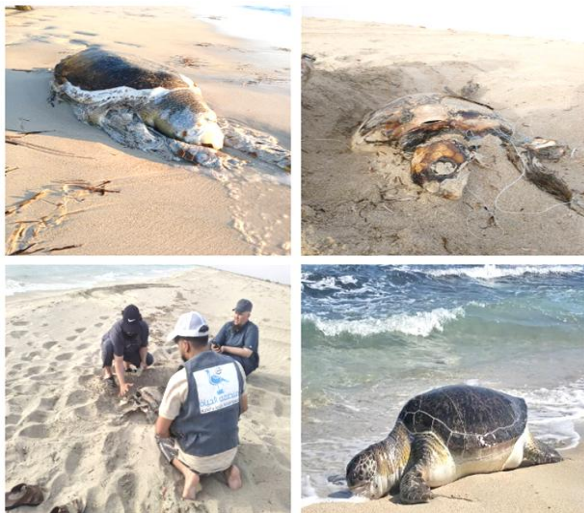


Figure (3): Sea turtle mortality documented along the shores of Zueitina and Amerir Gabes.

Comparative Analysis

Nest success and mortality were inversely related to human activity levels: Zueitina had more nesting events but also higher mortality, while Amerir Gabes had fewer nests with lower mortality but faced natural obstacles due to sand accumulation. Temporal patterns suggest that nesting at the Amerir Gabes may act as a refuge later in the season when Zueitina experiences higher human pressure(Fig.4).

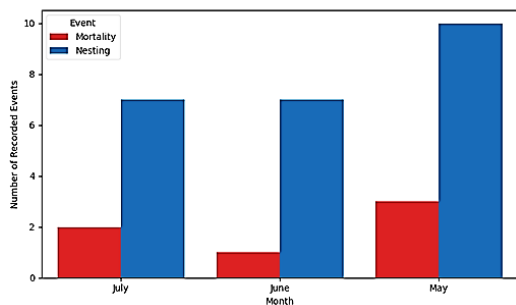


Figure (4): Stacked Representation of Sea Turtle Nesting and Mortality at Zueitina and Amerir Gabes.

DISCUSSION

The present results provide preliminary insights into the nesting ecology and anthropogenic impacts on *Caretta caretta* along the Libyan coast. However, further long-term and large-scale studies are required to validate and generalize these findings. The study highlights how nesting timing, site selection, and mortality rates are influenced by a combination of human activities and coastal geomorphological characteristics.

The findings are consistent with broader regional and global patterns, indicating that sea turtles tend to prefer

wide, dark, and minimally disturbed beaches for nesting. Moreover, human-related factors such as proximity to urban areas, artificial lighting, beach traffic, and fishing practices pose significant threats to both nesting success and adult turtle survival. This observation is consistent with previous studies (Christiaanse *et al.*, 2024; Hays *et al.*, 2025), which demonstrated that increased human activity negatively affects nesting habitats and increases mortality risks in sea turtle populations.

Using GPS-based clustering to identify nesting sites away from the immediate swash zone strengthens the hypothesis that females select elevations offering protection against tidal flooding and storm surges. This behavior becomes even more significant considering rising sea levels and the anticipated increase in storm frequency, emphasizing the critical need to conserve upper-beach and dune habitats nest (Stemle,2024).

The increased number of nests at Zueitina coincided with higher adult turtle mortality, highlighting a key conservation dilemma: beaches that draw nesting females may also pose heightened dangers when located near areas of intense human activity. Observations in the field have pointed to gear entanglement and plastic debris as significant threats, aligning with established patterns of injury and mortality within the Mediterranean, where coastal fisheries overlap with turtle habitats and abandoned fishing gear is prevalent (Franchini *et al.*,2021; Himpson *et al.*, 2023).

Nest disturbances documented in the area align with prior research indicating that interference not only disrupts hatching success by altering temperature and humidity dynamics but also increases predation risk by leaving scent or visual markers. Even minor, unsupervised handling prompted by curiosity or attempts at rescue can inadvertently cause harm, emphasizing the importance of standardized intervention protocols and the active involvement of local communities in enforcing protective measures (Martins *et al.*,2022; Guimaraes *et al.*,2023; Folkerts Caldwell *et al.*, 2023).

CONCLUSIONS

Zueitina and Amerir Gabes currently operate as complementary nesting habitats for *C. caretta* turtles, with Zueitina supporting early-season nesting despite higher human activity, while Amerir Gabes offers later-season nesting opportunities where physical barriers limit access. Female turtles exhibit adaptive behaviours, such as placing nests farther from the shoreline and utilizing microhabitats based on size, which likely enhance offspring survival amidst changing environmental conditions. However, significant human-induced disturbances such as lighting, recreational beach activities, and debris from fishing result in high adult mortality and pose severe threats to nesting success. Immediate implementation of targeted management interventions can produce substantial improvements. Mitigating gear and plastic pollution: Establish dedicated

collection points for fishing gear, incentivize recovery of lost nets, and enforce extended producer responsibility policies for fishing equipment to reduce entanglement risks. Organizing periodic community-led cleanup efforts aligned with the nesting season will ensure safer hatchling emergence corridors.

Enhancing nest protection: In areas with elevated risks of tampering or predation, employing measures such as protective nest cages, informative signage, and regular ranger patrols backed by clear legal penalties can significantly increase hatching success. Seasonal regulations on artificial lighting and access at Zueitina should be strictly enforced, alongside infrastructure for gear waste management and cleanup initiatives at both sites. Additionally, introducing soft-engineering techniques to mitigate excessive sand barriers at Amerir Gabes can further support nesting opportunities.

Strengthening legal safeguards, encouraging sustained community support, and adhering to scientifically grounded protocols will minimize interference with nests while curbing predation risks. Expanding and standardizing monitoring programs throughout the nesting seasons will provide valuable data to evaluate intervention effectiveness and guide adaptive management strategies.

By combining habitat conservation, fisheries waste reduction, and fostering community participation, these Libyan beaches have the potential to sustain and even increase loggerhead turtle nesting success. Such efforts will not only secure the recovery of this threatened species but also enhance the ecological health of Mediterranean coastal ecosystems.

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